UNITED STATES
PATENT AND TRADEMARK OFFICE

P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

ACKNOWLEDGEMENT OF LOSS OF ENTITLEMENT TO ENTITY STATUS DISCOUNT

APPLICATION #	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET #	REQUEST ID
16/692,972	11/22/2019	Neal Solomon	5311.001US5	232186

The entity status change request below filed through Patent Center on 06/18/2024 has been accepted.

Certifications

APPLICANT CHANGING TO REGULAR UNDISCOUNTED FEE STATUS

Signature

I certify, in accordance with 37 CFR 1.4(d)(4), that I am one of the signatories making the entity status change.

Signature	Name	Registration #
/Michael Scheer/	Michael Scheer	34425

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
16/692,972	11/22/2019	Neal Solomon	5311.001US5

CONFIRMATION NO. 7825

144524
The Law Office of Michael J. Scheer
5531 Murietta Avenue
Sherman Oaks, CA 91401

POA ACCEPTANCE LETTER

OC000000069696418

Date Mailed: 03/15/2024

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 02/08/2024.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/sltorres/

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
16/692,972	11/22/2019	Neal Solomon	5311.001US5

CONFIRMATION NO. 7825

21186
SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

POWER OF ATTORNEY NOTICE

OC000000069696369

Date Mailed: 03/15/2024

NOTICE REGARDING CHANGE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 02/08/2024.

- The Power of Attorney to you in this application has been revoked by the applicant. Future correspondence will be mailed to the new address of record(37 CFR 1.33).

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/sltorres/

UNITED STATES
PATENT AND TRADEMARK OFFICE

P.O. Box 1450
Alexandria, VA 22313 - 1450
www.uspto.gov

ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
16/692,972	**02/08/2024 04:15:32 PM Z ET**	**5311.001US5**

Title of Invention

DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	10877266
CONFIRMATION #	7825	FILED BY	Michael Scheer
PATENT CENTER #	64263004	FILING DATE	11/22/2019
CUSTOMER #	21186	FIRST NAMED INVENTOR	Neal Solomon
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	-

Documents

TOTAL DOCUMENTS: 2

DOCUMENT	PAGES	DESCRIPTION	SIZE (KB)
1020-1004 US10877266 Transmittal letter for Power of Attorney.pdf	1	Transmittal Letter	88 KB
1020-1004 Executed US10877266 Power of Attorney.pdf	2	Power of Attorney	165 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
1020-1004 US10877266 Transmittal letter for Power of Attorney.pdf	FBA20BEBFA3BB4B9F5375671D6E065B920B148EBB46217C78C6AAF26E4AC129622BC378ABDF295E9BA2D28552F656FC2144ED4E5557287F0F3F5470D218D4274

1020-1004 Executed US10877266 Power of Attorney.pdf	EBB40B0046C3F5508488FDDDD8E0120801688FDA49A904D3E1F908C21C867901C87DE9387E410BB854445E0583E5A3B296B1CC9760F765BBE55D03FEF14AD831

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant : Neal SOLOMON	Patent No.: 10,877,266
Application No.: 16/692,972	Issue Date: December 29, 2020
Filing Date: November 22, 2019	Confirmation No.: 7825
For: DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER	Attorney Docket No.: 1020-1004

TRANSMITTAL OF POWER OF ATTORNEY

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313 - 1450

Sir:

Please find attached a Revocation of Power of Attorney With a New Power of Attorney and Change of Correspondence Address (PTO/AIA/81A).

All previous Powers of Attorney have been revoked. It is respectfully requested that the undersigned be recognized as the attorney of record and all future correspondence be directed to the undersigned.

Date: February 8, 2023,

Respectfully submitted,

/ Michael J. Scheer/
Michael J. Scheer, Reg. No. 34,425
The Law Office of Michael J. Scheer PC
Customer No. 144524
818- 616-3363

PTO/AIA/81A (02-15)
Approved for use through 03/31/2021. OMB 0651-0035
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995 no persons are required to respond to a collection of information unless it displays a valid OMB control number

PATENT - POWER OF ATTORNEY OR REVOCATION OF POWER OF ATTORNEY WITH A NEW POWER OF ATTORNEY AND CHANGE OF CORRESPONDENCE ADDRESS

Patent Number	US 10,877,266
Issue Date	December 29, 2020
First Named Inventor	Neal Solomon
Title	DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER
Attorney Docket No.	1020-1004

I hereby revoke all previous powers of attorney given in the above-identified patent.

☐ A Power of Attorney is submitted herewith.

OR

☒ I hereby appoint Practitioner(s) associated with the Customer Number identified in the box at right as my/our attorney(s) or agent(s) with respect to the patent identified above, and to transact all business in the United States Patent and Trademark Office connected therewith: 144524

OR

☐ I hereby appoint Practitioner(s) named below as my/our attorney(s) or agent(s) with respect to the patent identified above, and to transact all business in the United States Patent and Trademark Office connected therewith:

Practitioner(s) Name	Registration Number

Please recognize or change the correspondence address for the above-identified patent to:

☒ The address associated with the above-identified Customer Number.

OR

☐ The address associated with the Customer Number identified in the box at right:

OR

☐ Firm or Individual Name					
Address					
City		State		Zip	
Country					
Telephone		Email			

I am the:

☒ Applicant.

OR

☐ Patent owner.

Statement under 37 CFR 3.73(c) (Form PTO/AIA/96) submitted herewith or filed on _____.

SIGNATURE of Applicant or Patent Owner

Signature	/ Neal E. Solomon /	Date	2/8/24
Name	Neal Solomon	Telephone	
Title and Company	Managing Member OPTIMUM IMAGING TECHNOLOGIES LLC		

NOTE: Signatures of all the applicants or patent owners of the entire interest or their representative(s) are required. If more than one signature is required, submit multiple forms, check the box below, and identify the total number of forms submitted in the blank below.

☐ A total of _____ forms are submitted.

This collection of information is required by 37 CFR 1.31, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public, which is to update (and by the USPTO to process) the file of a patent or reexamination proceeding. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Privacy Act Statement

The **Privacy Act of 1974 (P.L. 93-579)** requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (*i.e.*, GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/692,972	12/29/2020	10877266	5311.001US5	7825

21186 7590 12/09/2020

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

ISSUE NOTIFICATION

The projected patent number and issue date are specified above.

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment is 0 day(s). Any patent to issue from the above-identified application will include an indication of the adjustment on the front page.

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) WEB site (http://pair.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Application Assistance Unit (AAU) of the Office of Data Management (ODM) at (571)-272-4200.

APPLICANT(s) (Please see PAIR WEB site http://pair.uspto.gov for additional applicants):

Neal Solomon, Oakland, CA;
Optimum Imaging Technologies LLC, Austin, TX;

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage and facilitate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.

United States Patent and Trademark Office

Office of the Chief Financial Officer

Document Code:WFEE

User :C46167

Sale Accounting Date:11/18/2020

Sale Item Reference Number	Effective Date
16692972	11/17/2020

Document Number	Fee Code	Fee Code Description	Amount Paid	Payment Method
I2020AH722213017	2501	UTILITY APPL ISSUE FEE	$500.00	Deposit Account

United States Patent and Trademark Office

Office of the Chief Financial Officer

Document Code:WFEE

User :C46167

Sale Adjustment Accounting Date:11/18/2020

Effective Date	Sale Accounting Date	Sale Item Reference Number
04/24/2020	11/18/2020	16692972

Document Number	Fee Code	Fee Code Description	Amount Paid	Payment Method
I2020AH714582957	2501	UTILITY APPL ISSUE FEE	$500.00	DA

United States Patent and Trademark Office

Office of the Chief Financial Officer

Document Code:WFEE

User :C46167

Refund Accounting Date:11/18/2020

Effective Date	Sale Item Reference Number	Refund Total
04/24/2020	16692972	$500.00

Document Number	Fee Code	Fee Code Description	Amount Paid	Payment Method	Account Number
I2020AH714582957	2501	UTILITY APPL ISSUE FEE	$500.00	DA	190743

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s):	Neal Solomon	Examiner:	MARLY S.B. CAMARGO
Serial No.:	16/692,972	Group Art Unit:	2697
Filed:	November 22, 2019	Docket No.:	5311.001US5
Customer No.:	21186	Confirmation No.:	7825
Title:	DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER		

COMMUNICATION RE: FEE ADDRESS

Mail Stop Issue Fee
Commissioner for Patents
P.O.Box 1450
Alexandria, VA 22313-1450

In response to the Notice of Allowance and Issue Fee Due, please record the Fee Address under the provisions of 37 CFR 1.363 as the following:

Customer Number 21186

Please direct any inquiries to the undersigned attorney at (612) 373-6912.

Respectfully submitted,

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. Box 2938
Minneapolis, MN 55402
(612) 373-6912

Date Nov. 17, 2020

By /Timothy E. Bianchi/
Timothy E. Bianchi
Reg. No. 39,610

TEB:CMG:kap

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s):	Neal Solomon	Examiner: MARLY S.B. CAMARGO	
Serial No.:	16/692,972	Group Art Unit: 2697	
Filed:	November 22, 2019	Docket No.: 5311.001US5	
Customer No.:	21186	Confirmation No.: 7825	
Title:	DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER		

REQUEST TO APPLY PREVIOUSLY PAID ISSUE FEE

Mail Stop Issue Fee
Commissioner for Patents
P.O.Box 1450
Alexandria, VA 22313-1450

An issue fee for the above-identified application was previously paid on April 24, 2020. A petition under 37 CFR 1.313(c)(2) to withdraw the above-identified application from issue after payment of the issue fee was subsequently filed on May 15, 2020. Applicant received a decision, dated, granting the petition to withdraw.

Applicant respectfully requests that the above-identified previously-paid issue fee be applied toward the fee required by the new Notice of Allowance dated September 30, 2020.

This request is being submitted together with the new Issue Fee Transmittal Form PTOL-85, as well as a copy of the above-identified decision granting the petition to withdraw. Please charge any additional required fees or credit overpayment to Deposit Account No. 19-0743. Please direct any inquiries to the undersigned attorney at (612) 373-6912.

Respectfully submitted,

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. Box 2938
Minneapolis, MN 55402
(612) 373-6912

Date Nov. 17, 2020

By /Timothy E. Bianchi/
Timothy E. Bianchi
Reg. No. 39,610

TEB:CMG:kap

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), by mail or fax, or via EFS-Web.

By mail, send to: Mail Stop ISSUE FEE
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

By fax, send to: (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

21186 7590 09/30/2020
SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being transmitted to the USPTO via EFS-Web or by facsimile to (571) 273-2885, on the date below.

Kimberlie Pates	(Typed or printed name)
/Kimberlie Pates/	(Signature)
October 26, 2020	(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/692,972	11/22/2019	Neal Solomon	5311.001US5	7825

TITLE OF INVENTION: DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$500	$0.00	$500.00	$0	12/30/2020

EXAMINER	ART UNIT	CLASS-SUBCLASS
CAMARGO, MARLY S.B.	2697	348-241000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☒ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-09 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 Schwegman Lundberg
2 & Woessner, P.A.
3

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: Optimum Imaging Technologies LLC

(B) RESIDENCE: (CITY and STATE OR COUNTRY): Austin, Texas

Please check the appropriate assignee category or categories (will not be printed on the patent) : ☐ Individual ☒ Corporation or other private group entity ☐ Government

4a. Fees submitted: ☒ Issue Fee ☐ Publication Fee (if required) ☐ Advance Order - # of Copies _____

4b. Method of Payment: *(Please first reapply any previously paid fee shown above)*

☒ Electronic Payment via EFS-Web ☐ Enclosed check ☐ Non-electronic payment by credit card (Attach form PTO-2038)

☒ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment to Deposit Account No. 190743

5. **Change in Entity Status** (from status indicated above)

☐ Applicant certifying micro entity status. See 37 CFR 1.29

☐ Applicant asserting small entity status. See 37 CFR 1.27

☐ Applicant changing to regular undiscounted fee status.

NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.
NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.
NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature /Timothy E. Bianchi/ Date Nov. 17, 2020

Typed or printed name Timothy E. Bianchi Registration No. 39,610

PTOL-85 Part B (08-18) Approved for use through 01/31/2020 OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Samsung Exhibit 1002, Page 15 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s): Neal Solomon
Title: DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

Docket No.:	5311.001US5	Serial No.:	16/692,972
Filed:	November 22, 2019	Due Date:	December 30, 2020
Examiner:	MARLY S.B. CAMARGO	Group Art Unit:	2697
Customer No.:	21186	Confirmation No.:	7825

Notice of Allowance Date: September 30, 2020

Mail Stop Issue Fee
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

We are transmitting herewith the following:

X Issue Fee Transmittal (Form PTOL-85).
X Request to Apply Previously Paid Issue Fee (1 pg.)
X Communication Re: Fee Address (1 page).

Please charge any additional required fees or credit overpayment to Deposit Account No. 19-0743.

SCHWEGMAN LUNDBERG & WOESSNER, P.A. By /Timothy E. Bianchi/
Customer No.: 21186 Timothy E. Bianchi
TEB:CMG:kap Reg. No. 39,610

CERTIFICATE UNDER 37 CFR 1.8: The undersigned hereby certifies that this correspondence is being filed using the USPTO's electronic filing system EFS-Web, and is addressed to: Mail Stop Issue Fee, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on this 26th day of October, 2020.

Kimberlie Pates /Kimberlie Pates/
Name Signature

Electronic Acknowledgement Receipt

EFS ID:	41147063
Application Number:	16692972
International Application Number:	
Confirmation Number:	7825
Title of Invention:	DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER
First Named Inventor/Applicant Name:	Neal Solomon
Customer Number:	21186
Filer:	James D. Hallenbeck/Kimberlie Pates
Filer Authorized By:	James D. Hallenbeck
Attorney Docket Number:	5311.001US5
Receipt Date:	17-NOV-2020
Filing Date:	22-NOV-2019
Time Stamp:	15:36:48
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		5311001US5_IFEE.pdf	287537 ad865aa3c23cae5055861350479efff4d20ca46d	yes	4

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Miscellaneous Incoming Letter	4	4
	Miscellaneous Incoming Letter	3	3
	Issue Fee Payment (PTO-85B)	2	2
	Transmittal Letter	1	1
Warnings:			
Information:			
	Total Files Size (in bytes):	287537	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.
National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.
New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Best Available Copy

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), by mail or fax, or via EFS-Web.

OPAP
NOV 17 2020

By mail, send to: Mail Stop ISSUE FEE
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

By fax, send to: (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

21186 7590 09/30/2020
SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being transmitted to the USPTO via EFS-Web or by facsimile to (571) 273-2885, on the date below.

Kimberlie Pates	(Typed or printed name)
/Kimberlie Pates/	(Signature)
October 26, 2020	(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/692,972	11/22/2019	Neal Solomon	5311.001US5	7825

TITLE OF INVENTION: DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$500	$0.00	$500.00	$0	12/30/2020

EXAMINER	ART UNIT	CLASS-SUBCLASS
CAMARGO, MARLY S.B.	2697	348-241000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☒ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-09 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 Schwegman Lundberg
2 & Woessner, P.A
3

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: Optimum Imaging Technologies LLC

(B) RESIDENCE: (CITY and STATE OR COUNTRY): Austin, Texas

Please check the appropriate assignee category or categories (will not be printed on the patent) : ☐ Individual ☒ Corporation or other private group entity ☐ Government

4a. Fees submitted: ☒ Issue Fee ☐ Publication Fee (if required) ☐ Advance Order - # of Copies _____

4b. Method of Payment: *(Please first reapply any previously paid fee shown above)*

☒ Electronic Payment via EFS-Web ☐ Enclosed check ☐ Non-electronic payment by credit card (Attach form PTO-2038)

☒ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment to Deposit Account No. 190743

5. **Change in Entity Status** (from status indicated above)

☐ Applicant certifying micro entity status. See 37 CFR 1.29

☐ Applicant asserting small entity status. See 37 CFR 1.27

☐ Applicant changing to regular undiscounted fee status.

NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.
NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.
NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature /Timothy E. Bianchi/ Date Nov. 17, 2020

Typed or printed name Timothy E. Bianchi Registration No. 39,610

PTOL-85 Part B (08-18) Approved for use through 01/31/2020 OMB 0651-0033 U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/692,972	11/22/2019	Neal Solomon	5311.001US5	7825

7590 10/30/2020

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

EXAMINER	
CAMARGO, MARLY S.B.	

ART UNIT	PAPER NUMBER
2697	

NOTIFICATION DATE	DELIVERY MODE
10/30/2020	ELECTRONIC

NOTICE OF NON-COMPLIANT INFORMATION DISCLOSURE STATEMENT

An Information Disclosure Statement (IDS) filed 10/23/2020 in the above-identified application fails to meet the requirements of 37 CFR 1.97(d) for the reason(s) specified below. Accordingly, the IDS will be placed in the file, but the information referred to therein has not been considered.

The IDS is not compliant with 37 CFR 1.97(d) because:

☒ The IDS lacks a statement as specified in 37 CFR 1.97(e).

☐ The IDS lacks the fee set forth in 37 CFR 1.17(p).

☐ The IDS was filed after the issue fee was paid. Applicant may wish to consider filing a petition to withdraw the application from issue under 37 CFR 1.313(c) to have the IDS considered. See MPEP 1308.

/TC/
571-272-4200 or 1-888-786-0101
FOR Application Assistance Unit
Office of Data Management

FORM PTOM327-B (Rev. 02/08)

Samsung Exhibit 1002, Page 20 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/692,972	11/22/2019	Neal Solomon	5311.001US5	7825

21186 7590 10/27/2020

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

EXAMINER	
CAMARGO, MARLY S.B.	

ART UNIT	PAPER NUMBER
2697	

NOTIFICATION DATE	DELIVERY MODE
10/27/2020	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

SLW@blackhillsip.com
uspto@slwip.com

Corrected ***Notice of Allowability***	**Application No.** 16/692,972	**Applicant(s)** Solomon, Neal	
	Examiner MARLY S CAMARGO	**Art Unit** 2697	**AIA (FITF) Status** No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☑ This communication is responsive to attorney's secretary call about missing IDS of 5/15/2020.
   ☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2. ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

3. ☑ The allowed claim(s) is/are 2-31 . As a result of the allowed claim(s), you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see **http://www.uspto.gov/patents/init_events/pph/index.jsp** or send an inquiry to **PPHfeedback@uspto.gov.**

4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

   Certified copies:

   a) ☐ All b) ☐ Some *c) ☐ None of the:

   1. ☐ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____ .

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date _____ .

   Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).

6. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☐ Notice of References Cited (PTO-892)
2. ☑ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date _____.
3. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material _____.
4. ☑ Interview Summary (PTO-413), Paper No./Mail Date. _____.
5. ☐ Examiner's Amendment/Comment
6. ☐ Examiner's Statement of Reasons for Allowance
7. ☐ Other _____.

/MARLY S CAMARGO/
Primary Examiner , Art Unit 2697

Samsung Exhibit 1002, Page 22 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Applicant-Initiated Interview Summary	**Application No.** 16/692,972	**Applicant(s)** Solomon, Neal	
	Examiner MARLY S CAMARGO	**Art Unit** 2697	**AIA (FITF) Status** No

All participants (applicant, applicants representative, PTO personnel):

(1) MARLY S.B.. CAMARGO. (3) _____.

(2) Mr. Bianchi secretary. (4) _____.

Date of Interview: 21 October 2020.

Type: ☑ Telephonic ☐ Video Conference
☐ Personal [copy given to: ☐ applicant ☐ applicant's representative]

Exhibit shown or demonstration conducted: ☐ Yes ☑ No.
If Yes, brief description: _____.

Issues Discussed ☐101 ☐112 ☐102 ☐103 ☑Others
(For each of the checked box(es) above, please describe below the issue and detailed description of the discussion)

Claim(s) discussed: n/a.

Identification of prior art discussed: n/a.

Substance of Interview
(For each issue discussed, provide a detailed description and indicate if agreement was reached. Some topics may include: identification or clarification of a reference or a portion thereof, claim interpretation, proposed amendments, arguments of any applied references etc...)

Mr. Bianchi (Applicant's representative) secretary called about that the ids filed on May 15, 2020 with the Examiner's signature was missing and that they did not receive it. The Examiner checked it up and the IDS was signed and annotated. They want to pay the fee but were waiting to get the copy of the annotated IDS. The Examiner informed that she will do a corrected Notice of Allowance and attach the IDS to it..

Applicant recordation instructions: The formal written reply to the last Office action must include the substance of the interview. (See MPEP section 713.04). If a reply to the last Office action has already been filed, applicant is given a non-extendable period of the longer of one month or thirty days from this interview date, or the mailing date of this interview summary form, whichever is later, to file a statement of the substance of the interview.

Examiner recordation instructions: Examiners must summarize the substance of any interview of record. A complete and proper recordation of the substance of an interview should include the items listed in MPEP 713.04 for complete and proper recordation including the identification of the general thrust of each argument or issue discussed, a general indication of any other pertinent matters discussed regarding patentability and the general results or outcome of the interview, to include an indication as to whether or not agreement was reached on the issues raised.

☐ Attachment

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Summary of Record of Interview Requirements

Manual of Patent Examining Procedure (MPEP), Section 713.04, Substance of Interview Must be Made of Record
A complete written statement as to the substance of any face-to-face, video conference, or telephone interview with regard to an application must be made of record in the application whether or not an agreement with the examiner was reached at the interview.

Title 37 Code of Federal Regulations (CFR) 1.133 Interviews
Paragraph (b)

In every instance where reconsideration is requested in view of an interview with an examiner, a complete written statement of the reasons presented at the interview as warranting favorable action must be filed by the applicant. An interview does not remove the necessity for reply to Office action as specified in §§ 1.111, 1.135. (35 U.S.C. 132)

37 CFR §1.2 Business to be transacted in writing.
All business with the Patent or Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office. No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt.

The action of the Patent and Trademark Office cannot be based exclusively on the written record in the Office if that record is itself incomplete through the failure to record the substance of interviews.

It is the responsibility of the applicant or the attorney or agent to make the substance of an interview of record in the application file, unless the examiner indicates he or she will do so. It is the examiners responsibility to see that such a record is made and to correct material inaccuracies which bear directly on the question of patentability.

Examiners must complete an Interview Summary Form for each interview held where a matter of substance has been discussed during the interview by checking the appropriate boxes and filling in the blanks. Discussions regarding only procedural matters, directed solely to restriction requirements for which interview recordation is otherwise provided for in Section 812.01 of the Manual of Patent Examining Procedure, or pointing out typographical errors or unreadable script in Office actions or the like, are excluded from the interview recordation procedures below. Where the substance of an interview is completely recorded in an Examiners Amendment, no separate Interview Summary Record is required.

The Interview Summary Form shall be given an appropriate Paper No., placed in the right hand portion of the file, and listed on the "Contents" section of the file wrapper. In a personal interview, a duplicate of the Form is given to the applicant (or attorney or agent) at the conclusion of the interview. In the case of a telephone or video-conference interview, the copy is mailed to the applicants correspondence address either with or prior to the next official communication. If additional correspondence from the examiner is not likely before an allowance or if other circumstances dictate, the Form should be mailed promptly after the interview rather than with the next official communication.

The Form provides for recordation of the following information:
- Application Number (Series Code and Serial Number)
- Name of applicant
- Name of examiner
- Date of interview
- Type of interview (telephonic, video-conference, or personal)
- Name of participant(s) (applicant, attorney or agent, examiner, other PTO personnel, etc.)
- An indication whether or not an exhibit was shown or a demonstration conducted
- An identification of the specific prior art discussed
- An indication whether an agreement was reached and if so, a description of the general nature of the agreement (may be by attachment of a copy of amendments or claims agreed as being allowable). Note: Agreement as to allowability is tentative and does not restrict further action by the examiner to the contrary.
- The signature of the examiner who conducted the interview (if Form is not an attachment to a signed Office action)

It is desirable that the examiner orally remind the applicant of his or her obligation to record the substance of the interview of each case. It should be noted, however, that the Interview Summary Form will not normally be considered a complete and proper recordation of the interview unless it includes, or is supplemented by the applicant or the examiner to include, all of the applicable items required below concerning the substance of the interview.

A complete and proper recordation of the substance of any interview should include at least the following applicable items:
1) A brief description of the nature of any exhibit shown or any demonstration conducted,-
2) an identification of the claims discussed,
3) an identification of the specific prior art discussed,
4) an identification of the principal proposed amendments of a substantive nature discussed, unless these are already described on the Interview Summary Form completed by the Examiner,
5) a brief identification of the general thrust of the principal arguments presented to the examiner,
(The identification of arguments need not be lengthy or elaborate. A verbatim or highly detailed description of the arguments is not required. The identification of the arguments is sufficient if the general nature or thrust of the principal arguments made to the examiner can be understood in the context of the application file. Of course, the applicant may desire to emphasize and fully describe those arguments which he or she feels were or might be persuasive to the examiner.)
6) a general indication of any other pertinent matters discussed, and
7) if appropriate, the general results or outcome of the interview unless already described in the Interview Summary Form completed by the examiner.

Examiners are expected to carefully review the applicants record of the substance of an interview. If the record is not complete and accurate, the examiner will give the applicant an extendable one month time period to correct the record.

Examiner to Check for Accuracy

If the claims are allowable for other reasons of record, the examiner should send a letter setting forth the examiners version of the statement attributed to him or her. If the record is complete and accurate, the examiner should place the indication, Interview Record OK on the paper recording the substance of the interview along with the date and the examiners initials.

Doc code: IDS
Doc description: Information Disclosure Statement (IDS) Filed

PTO/SB/08a (01-10)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16692972
	Filing Date	2019-11-22
	First Named Inventor	Neal Solomon
	Art Unit	~~2699~~ 2697
	Examiner Name	M. Camargo
	Attorney Docket Number	5311.001US5

U.S.PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	10674046		2020-06-02	Solomon, Neal	
	2	8194136		2012-06-05	Askey, Philip, et al.	
	3	8194136		2012-06-05	Askey, Philip, et al.	

If you wish to add additional U.S. Patent citation information please click the Add button.

U.S.PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	20020012054	A1	2002-01-31	Osamoto, Akira	
	2	20030039402	A1	2003-02-27	Robins, David R, et al.	
	3	20040150726	A1	2004-08-05	Gallagher, Andrew C	

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16692972
	Filing Date	2019-11-22
	First Named Inventor	Neal Solomon
	Art Unit	~~2699~~ 2697
	Examiner Name	M. Camargo
	Attorney Docket Number	5311.001US5

	4	20050030394	A1	2005-02-10	Mendis, Sunetra K, et al.	
	5	20050261849	A1	2005-11-24	Kochi, Nobuo, et al.	
	6	20060120599	A1	2006-06-08	Steinberg, Eran, et al.	
	7	20070103744	A1	2007-05-10	Chiba, Takuya	
	8	20070252074	A1	2007-11-01	Ng, Yi-ren, et al.	
	9	20080291447	A1	2008-11-27	Vakrat, Dudi, et al.	
	10	20100106841	A1	2010-04-29	Barnert, Andrew	
	11	20120106841	A1	2012-05-03	Tzur, Yochay, et al.	

If you wish to add additional U.S. Published Application citation information please click the Add button.

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2] i	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T[5]
	1							☐

If you wish to add additional Foreign Patent Document citation information please click the Add button

EFS Web 2.1.17 ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16692972
	Filing Date	2019-11-22
	First Named Inventor	Neal Solomon
	Art Unit	~~2699~~ 2697
	Examiner Name	M. Camargo
	Attorney Docket Number	5311.001US5

NON-PATENT LITERATURE DOCUMENTS			
Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	1	"Application Serial No. 13 691,805, Notice of Allowance mailed 01-29-20", 13 pages.	☐
	2	"Application Serial No. 16 692,939, Non Final Office Action mailed 02-04-20", 22 pages.	☐
	3	"Application Serial No. 16 694,838, Non Final Office Action mailed 02-13-20", 21 pages.	☐
	4	"Application Serial No. 16 694,850, Non Final Office Action mailed 03-04-20", 25 pages.	☐
	5	"Application Serial No. 13 691,805, Corrected Notice of Allowability mailed 03-18-20", 2 pages.	☐
	6	"Application Serial No. 16 692,939, Examiner Interview Summary mailed 05-06-20", 4 pages.	☐
	7	"Application Serial No. 16 692,939, Response to Non Final Office Action mailed 02-04-20 filed 05-04-20", 12 pages.	☐
	8	"PCTUS2007015544 Published International Application 10-23-2008", (10 23 2008), 3 pages.	☐
	9	"PCTUS2007015544 Notification Recording Change 11-21-2008", (11 21 2008), 1 page.	☐

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16692972
	Filing Date	2019-11-22
	First Named Inventor	Neal Solomon
	Art Unit	~~2690~~ 2697
	Examiner Name	M. Camargo
	Attorney Docket Number	5311.001US5

	10	"PCTUS2007015544 Written Opinion ISA 01-11-2009", (1 11 2009), 7 pages.	☐
	11	"PCTUS2007015544 IPRP 01-13-2009", (1 13 2009), 8 pages.	☐
	12	"Application Serial No. 16 694,838, Examiner Interview Summary mailed 05-13-20", 4 pages.	☐
	13	"Application Serial No. 16 694,850, Examiner Interview Summary mailed 05-13-20", 4 pages.	☐
	14	"PCTUS2007015544 Documents 1-17-2008", (1 17 2008), 147 pages.	☐

If you wish to add additional non-patent literature document citation information please click the Add button

EXAMINER SIGNATURE

Examiner Signature	/MARLY S CAMARGO/	Date Considered	06/07/2020

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16692972
	Filing Date	2019-11-22
	First Named Inventor	Neal Solomon
	Art Unit	~~2699~~ 2697
	Examiner Name	M. Camargo
	Attorney Docket Number	5311.001US5

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

OR

☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(2).

☐ See attached certification statement.

☐ The fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ A certification statement is not submitted herewith.

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Timothy E. Bianchi/	Date (YYYY-MM-DD)	2020-05-15
Name/Print	Timothy E. Bianchi	Registration Number	39,610

This collection of information is required by 37 CFR 1.97 and 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1 hour to complete, including gathering, preparing and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these record s.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 1 of 1	Attorney Docket No: 5311.001US5	

US PATENT DOCUMENTS

	USP Document Number	Publication Date	Name of Patentee or Applicant of cited Document
	US-6,301,440	10/09/2001	Bolle, Rudolf M, et al.

FOREIGN PATENT DOCUMENTS

Examiner Initial *	Foreign Document Number	Publication Date	Name of Patentee or Applicant of cited Document	T 1

OTHER DOCUMENTS – NON PATENT LITERATURE DOCUMENTS

Examiner Initial *	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T 1
	"Application Serial No. 13/691,805, Notice of Allowance mailed 09-16-20", 14 pgs	
	"Application Serial No. 16/692,939, Non Final Office Action mailed 10-02-20", 24 pgs	
	"Application Serial No. 16/694,838, Response filed 09-29-20 to Final Office Action mailed 07-29-20", 11 pgs.	
	"Application Serial No. 16/694,850, Notice of Allowance mailed 10-15-20", 15 pgs	

EXAMINER **DATE CONSIDERED**

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

Electronic Acknowledgement Receipt	
EFS ID:	40929688
Application Number:	16692972
International Application Number:	
Confirmation Number:	7825
Title of Invention:	DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER
First Named Inventor/Applicant Name:	Neal Solomon
Customer Number:	21186
Filer:	Robert Mark Hirning/Jamie Johnson
Filer Authorized By:	Robert Mark Hirning
Attorney Docket Number:	5311.001US5
Receipt Date:	23-OCT-2020
Filing Date:	22-NOV-2019
Time Stamp:	13:19:07
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		16692972_SIDS_10-23-2020.pdf	198145 f29c07433974e5a2146c69e6e1bad83acd8c62bb	yes	4

	Multipart Description/PDF files in .zip description				
	Document Description		**Start**	**End**	
	Miscellaneous Incoming Letter		1	1	
	Transmittal Letter		2	3	
	Information Disclosure Statement (IDS) Form (SB08)		4	4	
Warnings:					
Information:					
2	Non Patent Literature	0001_2_npl_5311001us3_noar_09162020_f.pdf	824933 8690c368f5df76342cad6cc1575fc46a96c56b55	no	14
Warnings:					
Information:					
3	Non Patent Literature	0002_2_npl_5311001us4_oarn_10022020_f.pdf	1211109 e237d8abacf8f14c4bebde2720dbd6139bfba069	no	24
Warnings:					
Information:					
4	Non Patent Literature	0003_2_npl_5311001us6_aarf_20200929_f.pdf	503802 55e9b9008485466f308aca238937bfcf9f82a963	no	11
Warnings:					
Information:					
5	Non Patent Literature	0004_2_npl_5311001us7_noar_10152020_f.pdf	959639 9e757313da350f56e208b92c46796693fac4dff5	no	15
Warnings:					
Information:					
		Total Files Size (in bytes):	3697628		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s): Neal Solomon
Title: DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

Docket No.:	5311.001US5	Serial No.:	16/692,972
Filed:	November 22, 2019	Due Date:	N/A
Examiner:	MARLY S.B. CAMARGO	Group Art Unit:	2697
Customer No.:	21186	Confirmation No.:	7825

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

We are transmitting herewith the following attached items (as indicated with an "X"):

X Supplemental Information Disclosure Statement under 37 C.F.R. § 1.97(i) (2 pgs.), Form 1449 (1 pg.)
Copies of Cited References (4).

If not provided for in a separate paper filed herewith, please consider this a PETITION FOR EXTENSION OF TIME for sufficient number of months to enter these papers and please charge any additional fees or credit overpayment to Deposit Account No. 19-0743. If applicable, any papers or fees supplied herewith are considered to be timely filed pursuant to 37 C.F.R. § 1.7(a), the response period falling on a Federal Holiday, Saturday or Sunday being extended to the next succeeding business day.

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
Customer No.: 21186

By: /Timothy E. Bianchi/
Timothy E. Bianchi
Reg. No. 39,610

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s):	Neal Solomon	Examiner:	MARLY S.B. CAMARGO
Serial No.:	16/692,972	Group Art Unit:	2697
Filed:	November 22, 2019	Docket:	5311.001US5
Customer No.:	21186	Confirmation No.:	7825
Title:	DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER		

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT UNDER 37 CFR 1.97(i)

MS Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

In compliance with the duty imposed by 37 C.F.R. § 1.56, and in accordance with 37 C.F.R. §§ 1.97 *et. seq.*, the enclosed materials are brought to the attention of the Examiner for consideration in connection with the above-identified patent application. U.S. 6,301,440 was cited by Exr. Camargo in related application Ser. No. 16/692,939 in an Office Action of Oct. 2, 2020. Kindly place this submission in the file in accordance with USPTO procedure. MPEP 609.

Pursuant to 37 C.F.R. § 1.97(b), it is believed that no fee or statement is required with the Information Disclosure Statement to be entered into the record. However, the Commissioner is hereby authorized to charge the required fees to Deposit Account No. 19-0743 if deemed necessary.

Pursuant to 37 C.F.R. § 1.98(a)(2), copies of cited U.S. Patents and Published Applications, and Non-Published Applications identifiable by USPTO Serial Number, are no longer required to be provided to the Office. Applicant acknowledges the requirement to submit copies of foreign patent documents and non-patent literature in accordance with 37 C.F.R § 1.98(a)(2).

The Examiner is invited to contact the undersigned at the telephone number indicated if there are any questions regarding this communication.

Respectfully submitted,

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. Box 2938
Minneapolis, MN 55402
(612) 373-6912

Date 10/23/2020 By /Timothy E. Bianchi/
Timothy E. Bianchi
TEB:jj Reg. No. 39,610

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

NOTICE OF ALLOWANCE AND FEE(S) DUE

21186 7590 09/30/2020
SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

EXAMINER	
CAMARGO, MARLY S.B.	
ART UNIT	PAPER NUMBER
2697	

DATE MAILED: 09/30/2020

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/692,972	11/22/2019	Neal Solomon	5311.001US5	7825

TITLE OF INVENTION: DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$500	$0.00	$500.00	$0	12/30/2020

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE DOES NOT REFLECT A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE IN THIS APPLICATION. IF AN ISSUE FEE HAS PREVIOUSLY BEEN PAID IN THIS APPLICATION (AS SHOWN ABOVE), THE RETURN OF PART B OF THIS FORM WILL BE CONSIDERED A REQUEST TO REAPPLY THE PREVIOUSLY PAID ISSUE FEE TOWARD THE ISSUE FEE NOW DUE.

HOW TO REPLY TO THIS NOTICE:

I. Review the ENTITY STATUS shown above. If the ENTITY STATUS is shown as SMALL or MICRO, verify whether entitlement to that entity status still applies.

If the ENTITY STATUS is the same as shown above, pay the TOTAL FEE(S) DUE shown above.

If the ENTITY STATUS is changed from that shown above, on PART B - FEE(S) TRANSMITTAL, complete section number 5 titled "Change in Entity Status (from status indicated above)".

For purposes of this notice, small entity fees are 1/2 the amount of undiscounted fees, and micro entity fees are 1/2 the amount of small entity fees.

II. PART B - FEE(S) TRANSMITTAL, or its equivalent, must be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted. If an equivalent of Part B is filed, a request to reapply a previously paid issue fee must be clearly made, and delays in processing may occur due to the difficulty in recognizing the paper as an equivalent of Part B.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Maintenance fees are due in utility patents issuing on applications filed on or after Dec. 12, 1980. It is patentee's responsibility to ensure timely payment of maintenance fees when due. More information is available at www.uspto.gov/PatentMaintenanceFees.

PTOL-85 (Rev. 02/11)

Samsung Exhibit 1002, Page 38 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), by mail or fax, or via EFS-Web.

By mail, send to: Mail Stop ISSUE FEE
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

By fax, send to: (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

21186 7590 09/30/2020
SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being transmitted to the USPTO via EFS-Web or by facsimile to (571) 273-2885, on the date below.

(Typed or printed name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/692,972	11/22/2019	Neal Solomon	5311.001US5	7825

TITLE OF INVENTION: DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$500	$0.00	$500.00	$0	12/30/2020

EXAMINER	ART UNIT	CLASS-SUBCLASS
CAMARGO, MARLY S.B.	2697	348-241000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

❑ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

❑ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-09 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1_____
2_____
3_____

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE (B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) : ❑ Individual ❑ Corporation or other private group entity ❑ Government

4a. Fees submitted: ❑Issue Fee ❑Publication Fee (if required) ❑Advance Order - # of Copies _____

4b. Method of Payment: *(Please first reapply any previously paid fee shown above)*

❑ Electronic Payment via EFS-Web ❑ Enclosed check ❑ Non-electronic payment by credit card (Attach form PTO-2038)

❑ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment to Deposit Account No. _____

5. **Change in Entity Status** (from status indicated above)

❑ Applicant certifying micro entity status. See 37 CFR 1.29

❑ Applicant asserting small entity status. See 37 CFR 1.27

❑ Applicant changing to regular undiscounted fee status.

NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.
NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.
NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature _____ Date _____

Typed or printed name _____ Registration No. _____

Samsung Exhibit 1002, Page 39 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/692,972	11/22/2019	Neal Solomon	5311.001US5	7825

21186 7590 09/30/2020

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402

EXAMINER	
CAMARGO, MARLY S.B.	
ART UNIT	**PAPER NUMBER**
2697	

DATE MAILED: 09/30/2020

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(Applications filed on or after May 29, 2000)

The Office has discontinued providing a Patent Term Adjustment (PTA) calculation with the Notice of Allowance.

Section 1(h)(2) of the AIA Technical Corrections Act amended 35 U.S.C. 154(b)(3)(B)(i) to eliminate the requirement that the Office provide a patent term adjustment determination with the notice of allowance. See Revisions to Patent Term Adjustment, 78 Fed. Reg. 19416, 19417 (Apr. 1, 2013). Therefore, the Office is no longer providing an initial patent term adjustment determination with the notice of allowance. The Office will continue to provide a patent term adjustment determination with the Issue Notification Letter that is mailed to applicant approximately three weeks prior to the issue date of the patent, and will include the patent term adjustment on the patent. Any request for reconsideration of the patent term adjustment determination (or reinstatement of patent term adjustment) should follow the process outlined in 37 CFR 1.705.

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at 1-(888)-786-0101 or (571)-272-4200.

PTOL-85 (Rev. 02/11)

Samsung Exhibit 1002, Page 40 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

OMB Clearance and PRA Burden Statement for PTOL-85 Part B

The Paperwork Reduction Act (PRA) of 1995 requires Federal agencies to obtain Office of Management and Budget approval before requesting most types of information from the public. When OMB approves an agency request to collect information from the public, OMB (i) provides a valid OMB Control Number and expiration date for the agency to display on the instrument that will be used to collect the information and (ii) requires the agency to inform the public about the OMB Control Number's legal significance in accordance with 5 CFR 1320.5(b).

The information collected by PTOL-85 Part B is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 30 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450. Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Notice of Allowability	Application No. 16/692,972	Applicant(s) Solomon, Neal	
	Examiner MARLY S CAMARGO	Art Unit 2697	AIA (FITF) Status No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☑ This communication is responsive to RCE field on 09/04/2020.
   ☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2. ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

3. ☑ The allowed claim(s) is/are 2-31 . As a result of the allowed claim(s), you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see **http://www.uspto.gov/patents/init_events/pph/index.jsp** or send an inquiry to **PPHfeedback@uspto.gov.**

4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

   Certified copies:

   a) ☐ All b) ☐ Some *c) ☐ None of the:

   1. ☐ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____ .

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date _____ .

   Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).

6. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☐ Notice of References Cited (PTO-892)
2. ☑ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date _____.
3. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material _____.
4. ☐ Interview Summary (PTO-413), Paper No./Mail Date. _____.
5. ☐ Examiner's Amendment/Comment
6. ☑ Examiner's Statement of Reasons for Allowance
7. ☐ Other _____.

/MARLY S CAMARGO/
Primary Examiner , Art Unit 2697

Samsung Exhibit 1002, Page 42 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Notice of Pre-AIA or AIA Status

The present application is being examined under the pre-AIA first to invent provisions.

Change in Art Unit Designation for Your Application

1. The Art Unit designation of your application in the USPTO has changed from 2699 to 2697. The examiner assigned to this application remains the same. To aid in correlating any papers for this application, all further correspondence regarding this application should be directed to Art Unit 2697.

Detailed Action

Response to Amendment

2. In response Applicant RCE filed on September 04, 2020, the Examiner acknowledges the following:

- Claims 2 – 31 remain the same.
- Claim 1 was previously canceled by Applicant
- Currently claims 1 – 31 are pending. Claim 1 was previously canceled; therefore, claims 2 – 31 are being considered for examination.

Information Disclosure Statement

3. The information disclosure statement (IDS) document submitted on 09/04/2020 is acknowledged by the Examiner.

Continued Examination Under 37 CFR 1.114

4. A request for continued examination under 37 CFR 1.114, including the fee set forth in 37 CFR 1.17(e), was filed in this application after final rejection. Since this application is eligible for continued examination under 37 CFR 1.114, and the fee set forth in 37 CFR 1.17(e) has been timely paid, the finality of the previous Office action has been withdrawn pursuant to 37 CFR 1.114. Applicant's submission filed on 09/04/2020 has been entered.

Allowable Subject Matter

5. Claims 2 – 31 (renumbered as 1 – 30) are allowed.

6. The following is an examiner's statement of reasons for allowance: The closest art of record teaches: 1) a digital imaging system with optical lens mechanism, a digital sensor, a CPU, system software, a communication circuit and a memory sub-system. The system further includes an external computer with a digital processor and a database management system and storage sub-system, wherein the CPU sends an image to the external computer, which accesses the database management system and applies a specific algorithm to modify the optical and digital aberrations in the digital image file and wherein the digital signal processor DSP of camera is upgraded by download software algorithms (Solomon - US 2012/0229655 A1). The prior art of record also discloses an image processing system for receiving an input image taken by a converging lens group having an optical zoom mechanism and for correcting distortion of the image, the image processing system comprising: zoom position acquiring means for acquiring a zoom

position indicating a lens position condition of the optical zoom mechanism on taking an input image; zooming-direction encoding means for compressing correction parameters for distortion correction, which correspond to each of a lens position condition by utilizing zoom petitioning points at which lens position conditions in the optical zoom mechanism are serially partitioned between a wide-end and a tele-end into plural levels including both the ends, wherein the image processing system corrects distortions of the image based on the correction parameters and wherein the correction parameters are updated (Nose – US 2008/0175514 A1). The prior art of record also teaches system and method of operation for reducing image degradation due to image capture problems, a method utilizes image data corresponding to a captured image and image capture metadata that refers specifically to information that is associated with capture of the image. A database of correction parameters is provided in order to reduce degradation present in the captured image, whereby each correction parameter is associated with particular image capture metadata. The method involves using the image capture metadata to determine whether the database contains one or more correction parameters associated with that image capture metadata, and then producing correction parameters from the database of correction parameters when the database contains correction parameters associated with the image capture metadata (Gallagher – US 7,327,390 B2). Another prior art teaches a system and method for correcting distortions that occur in image capture systems (Lewis – US 2002/0041383 A1). A further prior art teaches an aberration correcting method for an image pickup apparatus comprising: a lens apparatus comprising: an image taking optical system for guiding a beam from an object to a camera apparatus; and a memory unit that stores, as correcting data, a correcting amount with respect to an image height

for correcting aberration caused by the image taking optical system, the lens apparatus being attached to the camera apparatus detachably (Natsume – US 9,077,842 B2). Osamato – US 2002/0012054 A1 – cited in a previous IDS) teaches a method of interpolation for a complementary-color-filtered array image, comprising the steps of: (a) provide a complementary-color-filtered array of pixel values with yellow pixel values Ye on a first subarray, cyan pixel values Cy on a second subarray, magenta pixel values Mg on a third subarray, and green pixel values G on a fourth subarray; (b) interpolating the subarray of yellow pixel values to form a yellow array; (c) interpolating the subarray of cyan pixel values to form a cyan array; (d) interpolating the subarray of magenta pixel values to form a magenta array; (e) interpolating the subarray of green pixel values to form a green array; (f) adjusting the color values for each pixel by (i) subtracting a quantity (Ye+Cy-2*G-Mg)/4 from Ye to generate the pixel's adjusted yellow value where Ye is the pixel's yellow value from step (b), Cy is the pixel's cyan value from step (c), Mg is the pixel's magenta value from step (d), and G is the pixel's green value from step (e); (ii) subtracting the quantity (Ye+Cy-2*G-Mg)/4 from Cy to generate the pixel's adjusted cyan value; (iii) adding the quantity (Ye+Cy-2*G-Mg)/4 to Mg to generate the pixel's adjusted magenta value; and (iv) adding the quantity (Ye+Cy-2*G-Mg)/8 to G to generate the pixel's adjusted green value, wherein the system allows for upgrading the software to conform to new standards or improve image pipeline quality.

Even though, Solomon, Nose, Gallagher, Lewis, Natsume and Osamato teach some of the features of the current invention, all either alone or in combination fail to teach or to fairly suggest the combination of limitations as in the independent claims 2 and 23 as it follows below.

Regarding Claim 2:

The combination of Solomon, Nose, Gallagher, Lewis, Natsume and Osamato fails to explicitly disclose *a method for processing one or more images* with a camera comprising *digitally processing at least one captured image the processing using in-camera hardware and software, configured to perform a plurality of image correction algorithms, process image correction data stored in a database system, receive updated software and image correction data, and upgrade the digital camera with the updated software and image correction data; storing in memory one or more corrected images resulting from digitally processing the at least one captured image; and wirelessly transmitting at least one of the one or more corrected images, wherein the in-camera software and database system are upgradable to provide improved algorithms and correction data for correction of images.*

Therefore, as discussed above, claim 2 is allowable over the prior art of record.

Regarding Claims 3 – 22 and 29 – 31:

Claims 3 – 22 and 29 – 31 depend directly or indirectly to claim 2 and they require the same limitations as claim 2 which are allowable over the prior art of record. Therefore, claims 3 – 22 and 29 – 31 are allowable for the same reasons as claim 2.

Regarding Claim 23:

The combination of Solomon, Nose, Gallagher, Lewis, Natsume and Osamato fails to explicitly disclose *a method of displaying one or more images captured*

by a digital camera on an external monitor, comprising: digitally processing at least one captured image to produce one or more corrected image, the processing using in-camera hardware and software that is configured to: perform a plurality of image correction algorithms, process image correction data stored in a database system, store updated software or image correction data or both, and upgrade the digital camera with the updated software or image correction data or both; and wirelessly transmitting at least one of the one or more corrected images in a format that the external monitor can receive, wherein the in-camera software and database system are upgradable to provide improved algorithms and correction data for correction of images.

Therefore, as discussed above, claim 23 is allowable over the prior art of record.

Regarding Claims 24 –28:

Claims 24 – 28 depend directly or indirectly to claim 23 and they require the same limitations as claim 23 which are allowable over the prior art of record. Therefore, claims 24 – 28 are allowable for the same reasons as claim 23.

Any comments considered necessary by applicant must be submitted no later than the payment of the issue fee and, to avoid processing delays, should preferably accompany the issue fee. Such submissions should be clearly labeled "Comments on Statement of Reasons for Allowance."

Contact

7. Any inquiry concerning this communication or earlier communications from the examiner should be directed to MARLY CAMARGO whose telephone number is (571)270-3729. The examiner can normally be reached on 6:00AM - 10PM, M-F, EST.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Lin Ye can be reached on (571)272-7372. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/MARLY S CAMARGO/
Primary Examiner , Art Unit 2697

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

CPC						
Symbol					Type	Version
G02B	/	27	/	0025	F	2013-01-01
H04N	/	5	/	238	I	2013-01-01
H04N	/	5	/	2254	I	2013-01-01
H04N	/	5	/	23212	I	2013-01-01
H04N	/	5	/	23296	I	2013-01-01
H04N	/	5	/	3572	I	2013-01-01
H04N	/	5	/	23203	I	2013-01-01
H04N	/	5	/	2353	I	2013-01-01
H04N	/	5	/	243	I	2013-01-01
H04N	/	5	/	35563	I	2013-01-01
H04N	/	5	/	2171	I	2013-01-01
H04N	/	5	/	2258	I	2013-01-01
G06T	/	7	/	194	I	2017-01-01
H04N	/	5	/	232125	I	2018-08-01
H04N	/	5	/	35721	I	2018-08-01
H04N	/	5	/	217	I	2013-01-01
H04N	/	5	/	2253	I	2013-01-01

CPC Combination Sets							
Symbol					Type	Set	Ranking	Version
	/		/					

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	30	
/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	27 September 2020	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	2	1

U.S. Patent and Trademark Office — Part of Paper No.: 20200927

Samsung Exhibit 1002, Page 50 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	**Art Unit**
	MARLY S CAMARGO	2697

INTERNATIONAL CLASSIFICATION				
CLAIMED				
H04N	/	5	/	217
H04N	/	5	/	225
H04N	/	5	/	238
H04N	/	5	/	357
H04N	/	5	/	76
H04N	/	5	/	374
H04N	/	9	/	04
G06K	/	9	/	36
G06K	/	9	/	40
G01J	/	1	/	04
G01J	/	3	/	02
G01J	/	1	/	20
H04N	/	1	/	00
	/		/	

NON-CLAIMED				
	/		/	

US ORIGINAL CLASSIFICATION	
CLASS	**SUBCLASS**

CROSS REFERENCES(S)						
CLASS	**SUBCLASS (ONE SUBCLASS PER BLOCK)**					
348	222.1	241	231.99	335	333.08	208.11
382	275	167	254	255	263	264
359	16	637	666	665	676	354

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	30	
/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	27 September 2020	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	2	1

U.S. Patent and Trademark Office — Part of Paper No.: 20200927

Samsung Exhibit 1002, Page 51 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	**Art Unit**
	MARLY S CAMARGO	2697

☑ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIMS

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
	1	9	10	17	19	30	28								
1	2	10	11	19	20	22	29								
2	3	11	12	20	21	23	30								
3	4	12	13	21	22	24	31								
4	5	13	14	25	23										
5	6	14	15	26	24										
6	7	16	16	27	25										
7	8	18	17	28	26										
8	9	15	18	29	27										

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	30	
/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	27 September 2020	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	2	1

U.S. Patent and Trademark Office — Part of Paper No.: 20200927

Samsung Exhibit 1002, Page 52 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

CPC - Searched*		
Symbol	**Date**	**Examiner**
(H04N5/357 | H04N5/217 | H04N5/2253 | H04N5/2254 | H04N5/228 | H04N5/238 | H04N5/76 | H04N5/225 | H04N5/374 | G06K9/36 | G06K9/40 | G01J1/20).CPC.	01/13/2020	M. Camargo
(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	01/16/2020	M. Camargo
(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	06/06/2020	M. Camargo
(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	09/26/2020	M. Camargo

CPC Combination Sets - Searched*		
Symbol	**Date**	**Examiner**

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Samsung Exhibit 1002, Page 53 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

US Classification - Searched*			
Class	**Subclass**	**Date**	**Examiner**
348	241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349	01/13,16/2020	M. Camargo
382	167,254,255,264,263,266,275	01/13,16/2020	M. Camargo
359	16,637,666,665,207.2,354,676	01/13,16/2020	M. Camargo
348	241,231.99,222.1,240.99,335,333.08,340,342,240.1,208.11,207.99,345,346-350,355,240.3,349	06/06/2020	M. Camargo
382	167,254,255,264,263,266,275	06/06/2020	M. Camargo
359	16,637,666,665,207.2,354,676	06/06/2020	M. Camargo
348	241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349	09/26/2020	M. Camargo
382	167,254,255,264,263,266,275	09/26/2020	M. Camargo
359	16,637,666,665,207.2,354,676	09/26/2020	M. Camargo

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	**Date**	**Examiner**

/MARLY S CAMARGO/
Primary Examiner , Art Unit 2697

Samsung Exhibit 1002, Page 54 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

(H04N5/357 | H04N5/217 | H04N5/2253 | H04N5/2254 | H04N5/228 | H04N5/238 | H04N5/76 | H04N5/225 | H04N5/374 | G06K9/36 | G06K9/40 | G01J1/20).CPC. and the results text limited- see attached search history printout.	01/13/2020	M. Camargo
(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and the results text limited - see attached search history printout.	01/18/2020	M. Camargo
EAST as BRS	14/13/2020- 01/19/ 2020	M. Camargo
inventor	01/13/2020	M. Camargo
assignee	01/13/2020	M. Camargo
searched 13/691805, 12/932520 and 12/932865 for possible double patent	01/13/2020	M. Camargo
(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and the results text limited - see attached search history printout.	06/06/2020- 06/07/ 2020	M. Camargo
EAST - updated	06/06/2020	M. Camargo
inventor - updated	06/06/2020	M. Camargo
assignee - updated	06/06/2020	M. Camargo
Google & Google Patents	06/06/2020- 06/07/ 2020	M. Camargo
(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and the results text limited - see attached search history printout.	09/26/2020	M. Camargo
EAST - updated	09/26/2020	M. Camargo
inventor - updated	09/26/2020	M. Camargo
assignee - updated	09/26/2020	M. Camargo
Google and Google Patents	09/20/2020- 09/26/ 2020	M. Camargo

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Samsung Exhibit 1002, Page 55 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

Interference Search			
US Class/CPC Symbol	**US Subclass/CPC Group**	**Date**	**Examiner**
EAST		01/18,19/2020	M. Camargo
inventor		01/18/2020	M. Camargo
assignee		01/18/2020	M. Camargo
348	241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349	01/18/2020	M. Camargo
382	167,254,255,264,263,266,275	01/18/2020	M. Camargo
359	16,637,666,665,207.2,354,676	01/18/2020	M. Camargo
CPC	(H04N5/357 | H04N5/217 | H04N5/2253 | H04N5/2254 | H04N5/228 | H04N5/238 | H04N5/76 | H04N5/225 | H04N5/374 | G06K9/36 | G06K9/40 | G01J1/20).CPC.	01/18/2020	M. Camargo
CPC	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	01/18/2020	M. Camargo
claim (US PAT/US PG Pub)	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	01/18/2020	M. Camargo
claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (" in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with data$base))).clm.	01/18/2020	M. Camargo

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Samsung Exhibit 1002, Page 56 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

claim	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image $1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software))).clm.	01/18/2020	M. Camargo
claim	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	01/18/2020	M. Camargo
claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat $3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and (user with (adjust$4 with variable$1)))).clm.	01/18/2020	M. Camargo
claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with algorithm $1)) and (correct$4 with algorithm$1) and ((" in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat $3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))).clm.	01/19/2020	M. Camargo

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Samsung Exhibit 1002, Page 57 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera " or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))).clm.	01/19/2020	M. Camargo
claim	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image $1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD))).clm.	01/19/2020	M. Camargo
EAST		06/07/2020	M. Camargo
inventor		06/07/2020	M. Camargo
assignee		06/07/2020	M. Camargo
348	241,231.99,222.1,240.99,335,333.08,340,342,240. 1,208.11,207.99,345,346-350,355,240.3,349	06/07/2020	M. Camargo
382	167,254,255,264,263,266,275	06/07/2020	M. Camargo
359	16,637,666,665,207.2,354,676	06/07/2020	M. Camargo
CPC	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/ 2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/ 04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	06/07/2020	M. Camargo

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	**Art Unit**
	MARLY S CAMARGO	2697

claim (US PAT/ US PG Pub)	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	06/07/2020	M. Camargo
claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with algorithm $1)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat $3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))).clm.	06/07/2020	M. Camargo
claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera " or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	06/07/2020	M. Camargo
claim	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image $1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD))).clm.	06/07/2020	M. Camargo

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and ((" in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat $3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))).clm.	06/07/2020	M. Camargo
claim	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image $1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))).clm.	06/07/2020	M. Camargo
EAST		09/26/2020	M. Camargo
inventor		09/26/2020	M. Camargo
assignee		09/26/2020	M. Camargo
348	241,231.99,222.1,335,240.99,240.1,240.3,333.08,3 40,342,208.11,345,346-350,355,349	09/26/2020	M. Camargo
382	167,254,255,264,263,266,275	09/26/2020	M. Camargo
359	16,637,666,665,207.2,354,676	09/26/2020	M. Camargo
CPC	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/ 2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/ 04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	09/26/2020	M. Camargo
Claim (US PAT / US PG Pub)	((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and ((" in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat $3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))))).clm.	09/26/2020	M. Camargo

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Samsung Exhibit 1002, Page 60 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/692,972	Solomon, Neal
	Examiner	Art Unit
	MARLY S CAMARGO	2697

claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image $1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1))))).clm.	09/26/2020	M. Camargo
claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image $1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))))).clm.	09/26/2020	M. Camargo
claim	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image $1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))))).clm.	09/26/2020	M. Camargo
claim	((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera " or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))).clm.	09/26/2020	M. Camargo
claim	((((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))).clm.	09/26/2020	

/MARLY S CAMARGO/ Primary Examiner , Art Unit 2697	

Samsung Exhibit 1002, Page 61 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

BIB DATA SHEET

CONFIRMATION NO. 7825

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
16/692,972	11/22/2019 **RULE**	348	2697	5311.001US5

APPLICANTS
Optimum Imaging Technologies LLC, Austin, TX;

INVENTORS
Neal Solomon, Oakland, CA;

** **CONTINUING DATA** **********
This application is a CON of 13/691,805 12/02/2012
which is a CON of 12/586,221 09/18/2009 PAT 8451339
which is a CON of 11/825,521 07/06/2007 PAT 7612805
which claims benefit of 60/807,065 07/11/2006

** **FOREIGN APPLICATIONS** **********

** **IF REQUIRED, FOREIGN FILING LICENSE GRANTED** ** ** SMALL ENTITY **
12/16/2019

		STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
Foreign Priority claimed ☐ Yes ☑ No 35 USC 119(a-d) conditions met ☐ Yes ☑ No Verified and Acknowledged /MARLY S.B. CAMARGO/ Examiner's Signature	☐ Met after Allowance Initials	CA	19	30	2

ADDRESS

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402
UNITED STATES

TITLE

DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

FILING FEE RECEIVED		
1285	FEES: Authority has been given in Paper No._____ to charge/credit DEPOSIT ACCOUNT No._____ for following:	☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other _____ ☐ Credit

BIB (Rev. 05/07).

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 1 of 5	Attorney Docket No: 5311.001US5	

US PATENT DOCUMENTS

	USP Document Number	Publication Date	Name of Patentee or Applicant of cited Document
	US-6,888,571	05/03/2005	Koshizuka, Yasuo, et al.
	US-8,395,677	03/12/2013	Kikuchi, Atsuo, et al.
	US-9,843,710	12/12/2017	Hamano, Hideyuki, et al.
	US-10,282,822	05/07/2019	Shmunk, Dmitry Valerievich, et al.
	US-20050078173A1	04/14/2005	Steinberg, Eran, et al.
	US-20070189757A1	08/16/2007	Steinberg, Eran, et al.
	US-20090167925A1	07/02/2009	Murata, Tsukasa
	US-20100321537A1	12/23/2010	Zamfir, Marta, et al.
	US-20140333971A1	11/13/2014	Macciola, Anthony, et al.
	US-20160028921A1	01/28/2016	Thrasher, Christopher W., et al.
	US-20170339334A1	11/23/2017	Bayser, Maira Gatti, et al.
	US-20170339340A1	11/23/2017	Bayser, Maira Gatti, et al.
	US-20200267286A1	08/20/2020	Solomon, Neal
	US-20200267287A1	08/20/2020	Solomon, Neal
	US-20200267289A1	08/20/2020	Solomon, Neal
	US-20200267290A1	08/20/2020	Solomon, Neal

FOREIGN PATENT DOCUMENTS

Examiner Initial *	Foreign Document Number	Publication Date	Name of Patentee or Applicant of cited Document	T 1

EXAMINER /MARLY S CAMARGO/ DATE CONSIDERED 09/27/2020

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 2 of 5	Attorney Docket No: 5311.001US5	

OTHER DOCUMENTS – NON PATENT LITERATURE DOCUMENTS		
Examiner Initial *	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T 1
	"Application Serial No. 16/692,939, Final Office Action mailed 06-18-20", 24 pages.	
	"Application Serial No. 16/692,939, Response filed 08-28-20 to Final Office Action mailed 06-18-20", 9 pgs.	
	"Application Serial No. 16/694,838, Final Office Action mailed 07-29-20", 28 pgs.	
	"Application Serial No. 16/694,850, Corrected Notice of Allowability mailed 08-27-20", 17 pgs.	
	"Canon Powershot SD300 and SD200 Camera User Guide, Petitioner Canon, Inc., Ex. 1040 - VOL. 1", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 89 pgs.	
	"Canon Powershot SD300 and SD200 Camera User Guide, Petitioner Canon, Inc., Ex. 1040 - VOL. 2", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 90 pgs.	
	"Carasso, US 5,4114,782, Petitioner Canon, Inc., Ex. 1025", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 12 pgs.	
	"Certified Translation of "Guan, et al., 'Digital Image Correcting Method for Digital Camera', Ricoh Technical Report No. 31, 103-110, (2005)", Petitioner Canon, Inc., Ex. 1018", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 9 pgs.	
	"Certified Translation of JP2000-184247A, Petitioner Canon, Inc., Ex. 1023", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 13 pgs.	
	"Certified Translation of JP2002-190979, Petitioner Canon, Inc., Ex. 1015", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 12 pgs.	
	"Certified Translation of JP2002-199410, Petitioner Canon, Inc., Ex. 1039", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 18 pgs.	
	"Certified Translation of JP2004-328506A, Petitioner Canon, Inc., Ex. 1011", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 21 pgs.	
	"Certified Translation of JP2004-343358, Petitioner Canon, Inc., Ex. 1009", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 31 pgs.	
	"Certified Translation of JP2006-72660, Petitioner Canon, Inc., Ex. 1027", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 14 pgs.	

EXAMINER /MARLY S CAMARGO/ DATE CONSIDERED 09/27/2020

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 3 of 5	Attorney Docket No: 5311.001US5	

	"Certified Translation of JPH11-313250, Petitioner Canon, Inc., Ex. 1013", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 6 pgs.	
	"Claim Construction Memorandum Opinion and Order, Document 88 in 2:19-CV-00246-JRG (E.D. Tex. June 11, 2019), Petitioner Canon, Inc., Ex. 1004", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 60 pgs.	
	"Complaint for Patent Infringement in 2:19-CV-00246-JRG (E.D. Tex. July 8, 2019), Petitioner Canon, Inc., Ex. 1003", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 26 pgs.	
	"Declaration Leonard Laub, Petitioner Canon, Inc., Ex. 1002", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 94 pgs.	
	"Declaration of Kiyoto Nagai, Petitioner Canon, Inc., Ex. 1019", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 11 pgs.	
	"Declaration of Leonard Laub, Petitioner Canon, Inc., Ex. 1002", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 117 pgs.	
	"Dobbins, III, US 4,903,204, Petitioner Canon, Inc., Ex. 1026", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 28 pgs.	
	"Enomoto, US 7,245,319 B1, Petitioner Canon, Inc., Ex. 1012", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 10 pgs.	
	"File History for US 8,451,339, Petitioner Canon, Inc., Ex. 1038", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 234 pgs.	
	"Havens, US20070080280A1, Petitioner Canon, Inc., Ex. 1029", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 32 pgs.	
	"Inoue, US20070171288A1, Petitioner Canon, Inc., Ex. 1030", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 85 pgs.	
	"JP Patent Office Machine Translation of JP05-323444A, Petitioner Canon, Inc., Ex. 1033", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 21 pgs.	
	"JP Patent Office Machine Translation of JP2000-224611A, Petitioner Canon, Inc., Ex. 1034", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 12 pgs.	
	"Kawanishi, US20050089241A1, Petitioner Canon, Inc., Ex. 1010", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 31 pgs.	

EXAMINER /MARLY S CAMARGO/ DATE CONSIDERED 09/27/2020

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 4 of 5	Attorney Docket No: 5311.001US5	

	"Kodak EasyShare V570 User Guide, Petitioner Canon, Inc., Ex. 1041", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 75 pgs.	
	"Library of Congress Catalog entry for "Russ, John C., The Image Processing Handbook, 4th Ed., CRC Press (2002)", Petitioner Canon, Inc., Ex. 1036", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 1 pg.	
	"Master, US 7,609,297 B2, Petitioner Canon, Inc., Ex. 1028", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 55 pgs.	
	"Ng, US 7,936,392 B2, Petitioner Canon, Inc., Ex. 1031", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 51 pgs.	
	"Niikawa, US20020135688A1, Petitioner Canon, Inc., Ex. 1006", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 47 pgs.	
	"Olympus Digital Camera E-1 Reference Manual, Petitioner Canon, Inc., Ex. 1043", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 182 pgs.	
	"Petition for Inter Partes Review", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 68 pgs.	
	"Petition for Inter Partes Review", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 74 pgs.	
	"Petitioner's Motion to Seal Confidential Litigation Filing, Ex. 1005", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 13 pgs.	
	"Petitioner's Power of Attorney", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 4 pgs.	
	"Petitioner's Power of Attorney", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 4 pgs.	
	"Ricoh Technical Report No. 31, RICOH, (April 20, 2006), Petitioner Canon, Inc., Ex. 1020", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, [Online] Retrieved from the Internet: <URL: https://web.archive.org/web/20060420051054/http:/www.ricoh.co.jp/about/business_overview/report/31/>, (07-20-2020), 4 pgs.	
	"Solomon, US 8,451,339 B2, Petitioner Canon, Inc., Ex. 1001", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 41 pgs.	
	"Solomon, US Patent No. 7,612,805, Petitioner Canon, Inc., Ex. 1001", IPR2020-01321, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 41 pgs.	
	"Steinberg, US 7,590,305 B2, Petitioner Canon, Inc., Ex. 1022", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 23 pgs.	

EXAMINER /MARLY S CAMARGO/ DATE CONSIDERED 09/27/2020

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 5 of 5	Attorney Docket No: 5311.001US5	

	"Steinberg, US 7,738,015 B2, Petitioner Canon, Inc., Ex. 1021", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 23 pgs.	
	"Taylor Francis Group, LLC Customer Service Publication Confirmation, Petitioner Canon, Inc., Ex. 1044", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 2 pgs.	
	"The Nikon Guide to Digital Photography with the CoolPix 7900 5900 Digital Camera, Petitioner Canon, Inc., Ex. 1042", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 165 pgs.	
	"USPTO File History for US 7,612,805, Petitioner Canon, Inc., Ex. 1037", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 288 pgs.	
	"Watanabe, US20050280877A1, Petitioner Canon, Inc., Ex. 1007", IPR2020-01321, US Patent No. 7,612,805; PR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 20 pgs.	
	"Wheeler, US20030095197A1, Petitioner Canon, Inc., Ex. 1032", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 32 pgs.	
	"Yamanaka, US20040150732A1, Petitioner Canon, Inc., Ex. 1017", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 31 pgs.	
	"Yokota, US 5,905,530, Petitioner Canon, Inc., Ex. 1014", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 71 pgs.	
	GONZALEZ, RAFAEL C, et al., "Digital Image Processing, 2nd Ed., Prentice Hall (2002), Petitioner Canon, Inc., Ex. 1024 -- VOL. 1", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 442 pgs.	
	GONZALEZ, RAFAEL C, et al., "Digital Image Processing, 2nd Ed., Prentice Hall (2002), Petitioner Canon, Inc., Ex. 1024 -- VOL. 2", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 373 pgs.	
	RUSS, JOHN C, "The Image Processing Handbook, 4th Ed., CRC Press (2002), Petitioner Canon, Inc., Ex. 1008 - VOL. 1", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 294 pgs.	
	RUSS, JOHN C, "The Image Processing Handbook, 4th Ed., CRC Press (2002), Petitioner Canon, Inc., Ex. 1008 - VOL. 2", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 268 pgs.	
	RUSS, JOHN C, "The Image Processing Handbook, 4th Ed., CRC Press (2002), Petitioner Canon, Inc., Ex. 1008 -- VOL. 3", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 183 pgs.	

EXAMINER /MARLY S CAMARGO/ DATE CONSIDERED 09/27/2020

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S.C/

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
S1	0	16/692972	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 14:46
S2	0	13/691805	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 14:47
S3	2	12/586221	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 14:47
S4	4	11/825521	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/01/13 14:47

			IBM_TDB			
S5	104	((("SOLOMON") near3 ("Neal"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2020/01/13 14:48
S6	0	((("OPTIMUM") near3 ("IMAGING") near3 ("TECHNOLOGIES") near3 ("LLC"))).AS,AANM.	USPAT	OR	ON	2020/01/13 14:48
S7	17	(neal with solomon).in. and (correct$4 with aberration$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 14:49
S8	522	(marly with camargo).xa,xp.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 14:49
S9	18	(marly with camargo).xa,xp. and (correct$4 with aberration$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 14:50
S10	54	("6483941" | "7346210" | "7656444" | "7667738" | "8189075").PN. OR ("8305458").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/13 14:53

S11	12	("20020079370" | "20040096118" | "20040165090" | "20060232681" | "20080031610" | "20080212168" | "3971065" | "5359185" | "8305458" | "8339462" | "8437539" | "8988590").PN. OR ("9253393").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/13 14:55
S12	88	("20020012054" | "20020114532" | "20030002735" | "20030108245" | "20040120598" | "20040218813" | "20060093234" | "20080137947" | "20080170124" | "20080181495" | "20080219585" | "20120070083" | "4605956" | "4642678" | "4663655" | "5220620" | "5398124" | "5778106" | "5982953" | "6356672" | "6621595" | "6621937" | "6625329" | "6650795" | "6671401" | "6724702" | "6754279" | "6791609" | "6829016" | "6914628" | "6915024" | "7057659" | "7330209" | "7460728" | "7587099" | "7657123" | "7751619" | "7920146" | "8090199" | "8098294" | "8115820" | "8144984" | "8155441").PN. OR ("8437539").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/13 14:58
S13	12	(aberration$1 with digital with database)	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/13 15:08
S14	34,600	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 15:18
S15	23,944	382/167,254,255,264,263,266,275.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 15:18
S16	5,422	359/16,637,666,665,207.2,354,676.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWE	OR	ON	2020/01/13 15:18

			NT; IBM_TDB			
S17	132,232	(H04N5/357 | H04N5/217 | H04N5/2253 | H04N5/2254 | H04N5/228 | H04N5/238 | H04N5/76 | H04N5/225 | H04N5/374 | G06K9/36 | G06K9/40 | G01J1/20).CPC.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 15:19
S18	386	("1269422" | "20030098952" | "20040008853" | "20040218283" | "20040227063" | "20040228003" | "20050002113" | "20050014306" | "20050100270" | "20050212952" | "20050218231" | "20060072915" | "20060076540" | "20060086596" | "20070063048" | "20070080280" | "20070116858" | "20080144185" | "20080144186" | "20080245872" | "20090072037" | "2062468" | "2300251" | "3161718" | "3305294" | "3583790" | "3761157" | "3778170" | "4134393" | "4191594" | "4210121" | "4249516" | "4261655" | "4286839" | "4289379" | "4312709" | "4407567" | "4487659" | "4514048" | "4783153" | "4783155" | "4784479" | "4802746" | "5091801" | "5150234" | "5305356" | "5389222" | "5396144" | "5684637" | "5892625" | "5917657" | "5973852" | "6081388" | "6109852" | "6188526" | "6212015" | "6368954" | "6369954" | "6376971" | "6399954" | "6437925" | "6449081" | "6475639" | "6529620" | "6538823" | "6542309" | "6545815" | "6545816" | "6586859" | "6628040" | "6702483" | "6715876" | "6734903" | "6747806" | "6762210" | "6806621" | "6806988" | "6809462" | "6812624" | "6882086" | "6891317" | "6934090" | "6936809" | "7169822" | "7224106" | "7301708" | "7416125" | "RE39874").PN. OR ("8027095").URPN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 16:20
S19	0	(digital with camera$1 or video$1) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and (updat$3 or upgrad$3) and (in$camera with (hardware or software)) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 17:02

S20	0	(digital with camera$1 or video$1) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and (updat$3 or upgrad$3) and ("in-camera" with (hardware or software)) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 17:03
S21	0	(digital with camera$1 or video$1) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and (updat$3 or upgrad$3) and ("in-camera" with (hardware or software))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 17:04
S22	3,196	(digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 17:04
S23	66	(digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 17:06
S24	64	(digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO;	OR	ON	2020/01/13 17:08

		with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software))	DERWENT; IBM_TDB			
S25	49	("20030038957" | "20040150732" | "20040227978" | "20050162532" | "20060061664" | "20060062562" | "20060232681" | "20070103744" | "4466018" | "5713053" | "6788822" | "6807299" | "6822762" | "6862373" | "7088388" | "7158686" | "7973850" | "8089555" | "8194136").PN. OR ("8654240").URPN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 17:24
S26	8	("20070236574" | "20080174678").PN. OR ("8395668").URPN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/13 17:25
S28	10	(aberration$1 with digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/15 10:49
S30	42	((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/15 16:12
S31	3	("20080174678").PN. OR ("8395682").URPN.	US-PGPUB;	OR	ON	2020/01/15 16:22

			USPAT; USOCR			
S32	6	("20070236574" | "20080174678").PN. OR ("8395668").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/15 16:26
S33	0	(11/278268).APP.	USPAT; USOCR	OR	ON	2020/01/15 16:28
S34	109	("6642956" | "20020145671" | "5580728" | "5748491" | "5751861" | "6154574" | "6927922" | "20030169944" | "5867410" | "20030057353" | "5535291" | "6240219" | "20050117114" | "7365326" | "4532548" | "5748371" | "6567570" | "5003618" | "6567570" | "20020118457" | "5307175" | "6545714" | "7065256" | "5696850" | "5023641" | "6525302" | "4691366" | "6069738" | "6094467" | "6333990").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:08
S35	22	("20050117114" | "5003618" | "5696850" | "6567570" | "6642956" | "7365326").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:18
S36	37,324	348/241,231.99,222.1,240.99,335,333.08,340,342,240.1, 208.11,207.99,345,346-350,355,240.3,349.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:34
S37	21,831	382/275,252,321,167,253,264,263,266.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWE	OR	ON	2020/01/16 10:35

			NT; IBM_TDB			
S38	5,422	359/16,637,665,666,207.2,354,676.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:36
S39	151,021	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:41
S40	22	S36 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:42
S41	16	S37 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:46
S42	0	S38 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with	US-PGPUB; USPAT; USOCR;	OR	ON	2020/01/16 10:48

		(correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	FPRS; EPO; JPO; DERWENT; IBM_TDB			
S43	62	S39 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:48
S44	0	S36 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:55
S45	0	S37 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:56
S46	0	S38 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:56

S47	0	S39 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:57
S48	64	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:57
S49	0	S36 and S48	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:58
S50	0	S37 and S48	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:58
S51	0	S38 and S48	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO;	OR	ON	2020/01/16 10:59

			DERWENT; IBM_TDB			
S52	0	S39 and S48	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:59
S53	66	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 10:59
S54	0	S36 and S53	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:00
S55	0	S37 and S53	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:00
S56	0	S38 and S53	US-PGPUB; USPAT;	OR	ON	2020/01/16 11:00

			USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			
S57	0	S39 and S53	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:00
S58	42	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:01
S59	12	S36 and S58	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:02
S60	0	S37 and S58	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/01/16 11:03

			IBM_TDB			
S61	1	382/$.ccls. and S58	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:03
S62	7	359/$.ccls. and S58	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:04
S63	56	("20020110320" | "20020126591" | "20020162973" | "4750022" | "4779135" | "4845352" | "5051770" | "5198653" | "5204770" | "5291008" | "5430807" | "5559629" | "5574536" | "5710430" | "5719620" | "5737084" | "5757425" | "5876327" | "5973844" | "6005916" | "6008945" | "6020988" | "6078390" | "6084991" | "6088097" | "6124974" | "6128068" | "6178346" | "6195213" | "6248988" | "6249360" | "6268918" | "6285811" | "6344893" | "6448556" | "6711283" | "7053942" | "7379758" | "H001060").PN. OR ("7863552").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/16 11:05
S64	202	("3013467" | "4509826" | "4802748" | "4927254" | "5065008" | "5067805" | "5081349" | "5248876" | "5452090" | "5532874" | "5557452" | "5563702" | "5586058" | "5587832" | "5594235" | "5612818" | "5737084").PN. OR ("6248988").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/16 11:09
S65	12	S36 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:12

S66	8	S39 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:34
S67	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:36
S68	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:37
S69	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:37
S70	14	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1).clm.)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO;	OR	ON	2020/01/16 11:38

			DERWENT; IBM_TDB			
S71	2	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:42
S72	271	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:47
S73	271	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:49
S74	271	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:51
S75	0	S36 and(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and	US-PGPUB; USPAT;	OR	ON	2020/01/16 11:53

		(wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)))	USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			
S76	0	S36 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:54
S77	5	348/$.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:55
S78	7	382/$.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 11:57
S79	0	359/$.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/01/16 11:59

			IBM_TDB			
S80	13	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 12:00
S81	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 12:03
S82	59	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and (user with (adjust$4 with variable$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 12:06
S83	76	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 12:07
S84	308	("20010009973" | "20020036750" | "20020064341" | "20020072658" | "20020109819" | "20020124843" | "20030007124" | "20030009156" | "20030071969" |	US-PGPUB;	OR	ON	2020/01/16 12:12

		"20030081170" | "20030187503" | "20030210378" | "20040085648" | "20040114242" | "20040129949" | "20040130783" | "20040136570" | "20040151466" | "20040254438" | "20040257958" | "20050015120" | "20050122475" | "20050159662" | "20050244476" | "20050246783" | "20050280777" | "20050286019" | "20060033992" | "20060114411" | "20060114585" | "20060152525" | "20060159395" | "20060186325" | "20070010748" | "20070027442" | "20070121120" | "20070139613" | "20070200927" | "20070236661" | "20080091250" | "20080117289" | "20080117384" | "20080124787" | "20080137031" | "20080212738" | "20080213904" | "20080218685" | "20080277601" | "20080309879" | "20090024191" | "20090030299" | "20090036955" | "20090073428" | "20090082829" | "20090153796" | "20090182291" | "20090219486" | "20090231545" | "20090268162" | "20100004537" | "20100033676" | "20100069775" | "20100149073" | "20100201944" | "20100214635" | "20100220914" | "20100283969" | "20110007277" | "20110018903" | "20110063571" | "20110109877" | "20110118556" | "20110178815" | "20110218456" | "20110242306" | "20110267663" | "20110276312" | "20110299027" | "20120019703" | "20120069413" | "20120083718" | "20120113092" | "20120127062" | "20120127426" | "20120133890" | "20120147038" | "20120147163" | "20120172854" | "20120188637" | "20120194781" | "20120206485" | "20120212399" | "20120226267").PN. OR ("20120236257" | "20120249956" | "20120274897" | "20120293773" | "20120307203" | "20120330387" | "20130004485" | "20130016292" | "20130023966" | "20130070338" | "20130072916" | "20130082922" | "20130100401" | "20130125027" | "20130144137" | "20130169930" | "20130177883" | "20130184554" | "20130245505" | "20130250207" | "20130250430" | "20130250431" | "20130253330" | "20130257312" | "20130285885" | "20130286053" | "20130296710" | "20130308094" | "20130314793" | "20130321265" | "20130322810" | "20140003762" | "20140009741" | "20140016093" | "20140039309" | "20140043320" | "20140046291" | "20140055746" | "20140058483" | "20140063005" | "20140068513" | "20140071539" | "20140098010" | "20140129259" | "20140152531" | "20140160283" | "20140168783" | "20140177023" | "20140178861" | "20140186348" | "20140194702" | "20140194740" | "20140198017" | "20140218468" | "20140240842" | "20140275935" | "20140285429" | "20140285769" | "20140306866" | "20140306874" | "20140313484" | "20140340390" | "20140354514" | "20140368793" | "20140372944" | "20140375790" | "20150016777" | "20150018781" | "20150035744" | "20150038869" | "20150088546" | "20150103306" | "20150124073" | "20150146301" | "20150150444" |	USPAT; USOCR			

		"20150178923" | "20150178939" | "20150182118" | "20150185503" | "20150205126" | "20150222883" | "20150222884" | "20150234188" | "20150238362" | "20150241614" | "20150248169" | "20150248170" | "20150248788" | "20150248793" | "20150257735" | "20150262424" | "20150265146" | "20150268415").PN. OR ("20150277121" | "20150281630" | "20150289762" | "20150302652" | "20150313949" | "20150326570" | "20150346490" | "20150346495" | "20150351690" | "20150356781" | "20150356782" | "20160008169" | "20160011375" | "20160011419" | "20160026253" | "20160033771" | "20160066780" | "20160067087" | "20160077338" | "20160089023" | "20160104453" | "20160106591" | "20160116979" | "20160159276" | "20160216515" | "20160256086" | "20160270648" | "20160270656" | "20160287153" | "20160324403" | "20160324416" | "20160379593" | "20170000324" | "20170000325" | "20170000326" | "20170000330" | "20170000331" | "20170000332" | "20170000333" | "20170000334" | "20170000335" | "20170000337" | "20170000340" | "20170000341" | "20170000342" | "20170000343" | "20170000345" | "20170000454" | "20170000683" | "20170001032" | "20170007111" | "20170007115" | "20170007116" | "20170007122" | "20170007123" | "20170007182" | "20170007450" | "20170007799" | "20170007843" | "20170010469" | "20170010470" | "20170017083" | "20170078652" | "20170112666" | "20170127932" | "20170135896" | "20170205618" | "20170299869" | "20180011324" | "20180136471" | "20180136486" | "20180279870" | "3724938" | "4065208" | "4573982" | "4669836" | "4826308" | "4848898" | "5166778" | "5223971" | "5491492" | "5537162" | "5776068" | "5997141" | "6003991" | "6045515" | "6151167" | "6235014" | "6251101" | "6386706" | "6447119" | "6490319" | "6579235" | "6736510" | "6850221" | "6975898" | "7036931" | "7425067" | "7883505" | "8128606" | "8279544").PN. OR ("8348429" | "8721572" | "8820931" | "8824779" | "8909327" | "8950867" | "8956396" | "9125724" | "9215293" | "9295388" | "9310559" | "9348143" | "9417452" | "9462262" | "9462945" | "9489044" | "9671566" | "9720238" | "9791700" | "9874749" | "D758367").PN. OR ("10345590").URPN.				
S85	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and (user with (adjust$4 with variable$1))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/01/16 12:16

			IBM_TDB			
S86	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1)).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 12:17
S87	156	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 14:45
S88	104	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with software) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/16 14:47
S89	10	"7590305".pn. | "7738015".pn. | "5905530".pn. | "7936392".pn.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/17 09:03
S90	127	("0725567" | "20020159030" | "20030117511" | "20030156077" | "20050080602" | "4383170" | "4661986" | "4694185" | "5076687" | "5282045" | "5610390" | "5748371" | "5757423" | "6023523" | "6028606" | "6097394" | "6201899" | "6320979" |	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/17 09:13

		"6483535" | "6577342" | "6842297" | "7034866").PN. OR ("7936392").URPN.				
S91	35	(US-20030210343-$ | US-20050219391-$ | US-20080174678-$ | US-20110096176-$ | US-0062546-$ | US-0064649-$ | US-6023977-$ | US-6055330-$ | US-6508764-$ | US-6850272-$ | US-7245319-$ | US-7321685-$ | US-7406182-$ | US-7551205-$ | US-7612805-$ | US-7619663-$ | US-7636111-$ | US-7701484-$ | US-7764874-$ | US-8106976-$ | US-8451339-$ | US-5905530-$ | US-7590305-$ | US-7738015-$ | US-7936392-$ | US-20020163586-$ | US-20050099507-$ | US-20060285761-$ | US-20070002158-$ | US-20070236574-$ | US-20080151069-$ | US-20100073508-$ | US-20040150732-$).DID.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/17 09:42
S92	4	(TO-030212-$ | TO-042709-$ | TO-082312-$ | TO-121208-$ | AI-20060285761-$ | HI-1313250-$ | HI-1313250119-$ | JP-2004343358-$ | JP-20001842476-$ | JP-20021909797-$ | JP-20021994107-$ | JP-2004328506-$ | JP-20060726803-$ | ZR-706560-$).DID.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/17 09:43
S93	4	(11/825521 | 12/586221 | 13/691805).APP.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/17 09:51
S94	64	(US-20030210343-$ | US-20050219391-$ | US-20080174678-$ | US-20110096176-$ | US-0062546-$ | US-0064649-$ | US-6023977-$ | US-6055330-$ | US-6508764-$ | US-6850272-$ | US-7245319-$ | US-7321685-$ | US-7406182-$ | US-7551205-$ | US-7612805-$ | US-7619663-$ | US-7636111-$ | US-7701484-$ | US-7764874-$ | US-8106976-$ | US-8451339-$ | US-5905530-$ | US-7590305-$ | US-7738015-$ | US-7936392-$ | US-20020163586-$ | US-20050099507-$ | US-20060285761-$ | US-20070002158-$ | US-20070236574-$ | US-20080151069-$ | US-20100073508-$ | US-20040150732-$).DID.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/17 09:52
S95	65	(US-0062546-$ | US-0064649-$ | US-10237485-$ | US-6023977-$ | US-6055330-$ | US-6508764-$ | US-6850272-$ | US-7245319-$ | US-7321685-$ | US-	US-PGPUB; USPAT;	OR	ON	2020/01/18 20:15

		7406182-$ | US-7551205-$ | US-7612805-$ | US-7619663-$ | US-7636111-$ | US-7701484-$ | US-7764874-$ | US-8106976-$ | US-8451339-$ | US-9077842-$ | US-9998652-$ | US-7936392-$ | US-20020163586-$ | US-20040071318-$ | US-20050219391-$ | US-20070002158-$ | US-20070236574-$ | US-20070247672-$ | US-20080174678-$ | US-20100033604-$ | US-20110096176-$ | US-20010008418-$ | US-20030095197-$ | US-20040150732-$ | US-20040207733-$).DID.	USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			
S96	4	(11/825521 | 12/586221 | 13/691805 | 16/692972).APP.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:15
S97	12	(TO-011520-$ | TO-030212-$ | TO-042709-$ | TO-082312-$ | TO-111519-$ | TO-121208-$ | HI-1313250-$ | HI-1313250119-$ | JP-2004343358-$ | JP-20021994107-$ | JP-2000184247-$ | JP-20001842476-$ | JP-2002190979-$ | JP-20021909797-$ | JP-2002199410-$ | JP-2004328506-$ | JP-2006072660-$ | JP-20060726603-$ | SD-200300-$ | WD-2005093653-$ | ZR-300200-$ | ZR-706560-$).DID.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:16
S98	156	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:17
S99	0	S95 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWE	OR	ON	2020/01/18 20:19

		or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	NT; IBM_TDB			
S100	0	S96 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:20
S101	0	S97 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:20
S102	0	S95 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:21
S103	0	S96 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:21
S104	0	S97 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with	US-PGPUB; USPAT; USOCR;	OR	ON	2020/01/18 20:21

		(correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	FPRS; EPO; JPO; DERWENT; IBM_TDB			
S105	3	S95 and (aberration$1 with digital with database)	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/18 20:22
S106	3	S96 and (aberration$1 with digital with database)	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/18 20:22
S107	0	S97 and (aberration$1 with digital with database)	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/18 20:22
S108	42	((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:23
S109	4	S95 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:23
S110	4	S96 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/01/18 20:24

			IBM_TDB			
S111	0	S97 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:24
S112	76	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:25
S113	0	S95 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:25
S114	0	S96 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:26
S115	0	S97 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and	US-PGPUB; USPAT; USOCR; FPRS;	OR	ON	2020/01/18 20:26

		provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1)))	EPO; JPO; DERWENT; IBM_TDB			
S116	0	348/$.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:27
S117	0	382/$.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:27
S118	0	359/$.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:28
S119	0	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:31

		with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))				
S120	8	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:33
S121	42	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:35
S122	0	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:35
S123	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:36
S124	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with	US-PGPUB; USPAT; USOCR; FPRS;	OR	ON	2020/01/18 20:36

		(correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with data$base))).clm.	EPO; JPO; DERWENT; IBM_TDB			
S125	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:37
S126	13	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:41
S127	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:43
S128	0	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/01/18 20:44

			IBM_TDB			
S129	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and (user with (adjust$4 with variable$1)))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:46
S130	0	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and ((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data)))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:47
S131	151,075	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:48
S132	0	S131 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and user and (adjust$4 with variable$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/18 20:49

S145	104	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or scren or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 10:32
S146	4	09/957013	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 10:48
S147	31	("20030076420" | "20040135889" | "5461440" | "5671297" | "6115104" | "6219446" | "6323934" | "6657658" | "6935521" | "6937370" | "7065255" | "7151564").PN. OR ("7327390").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/19 10:49
S148	11	("20020041383" | "20070024714" | "20110069180" | "6437823" | "6940664" | "7224392" | "7327390" | "7623274" | "8203602" | "8675988" | "9224205").PN. OR ("10210602").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/19 10:51
S149	31	("20030076420" | "20040135889" | "5461440" | "5671297" | "6115104" | "6219446" | "6323934" | "6657658" | "6935521" | "6937370" | "7065255" | "7151564").PN. OR ("7327390").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/19 11:23
S150	19	S145 and ("20030076420" | "20040135889" | "5461440" | "5671297" | "6115104" | "6219446" | "6323934" | "6657658" | "6935521" | "6937370" | "7065255" | "7151564").PN. OR ("7327390").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/19 11:27
S151	0	S145 and ("20020041383" | "20070024714" | "20110069180" | "6437823" | "6940664" | "7224392" | "7327390" | "7623274" | "8203602" | "8675988" | "9224205").PN. OR ("10210602").URPN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:27

S152	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with algorithm$1)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or scren or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:30
S153	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with algorithm$1)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or scren or LCD))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:30
S154	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or scren or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:32
S155	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or scren or LCD))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:33
S156	64	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO;	OR	ON	2020/01/19 11:37

		(program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD)))	DERWENT; IBM_TDB			
S157	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:40
S158	0	348/$.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:41
S159	0	382/$.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:42
S160	0	359/$.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:42
S161	0	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 |	US-PGPUB; USPAT;	OR	ON	2020/01/19 11:43

		H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD)))	USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			
S162	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/19 11:43
S163	7	("20080174678" | "20090263012").PN. OR ("8570381").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/01/19 14:18
S167	0	16/692939	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/01/27 10:44
S168	0	16/692972	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:03
S169	0	13/691805	US-PGPUB; USPAT;	OR	ON	2020/06/06 15:03

			USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			
S170	104	((("SOLOMON") near3 ("Neal"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2020/06/06 15:04
S171	0	((("OPTIMUM") near3 ("IMAGING") near3 ("TECHNOLOGIES") near3 ("LLC"))).AS,AANM.	USPAT	OR	ON	2020/06/06 15:05
S172	17	(neal with solomon).in. and (correct$4 with aberration$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:05
S173	12	(aberration$1 with digital with database)	US-PGPUB; USPAT; USOCR	OR	ON	2020/06/06 15:20
S174	34,599	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:21
S175	24,041	382/167,254,255,264,263,266,275.ccls.	US-PGPUB; USPAT; USOCR; FPRS;	OR	ON	2020/06/06 15:21

			EPO; JPO; DERWENT; IBM_TDB			
S176	5,428	359/16,637,666,665,207.2,354,676.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:22
S177	161,463	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:23
S178	37,329	348/241,231.99,222.1,240.99,335,333.08,340,342,240.1, 208.11,207.99,345,346-350,355,240.3,349.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:23
S179	31	("20020012054" | "20030039402" | "20040150726" | "20050030394" | "20050261849" | "20060120599" | "20070103744" | "20070252074" | "20080291447" | "20100106841" | "20120106841" | "8194136").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:24

S180	22	(US-10674046-$ | US-16692972-$ | US-20030039402-$ | US-20040150726-$ | US-20050030394-$ | US-20050261849-$ | US-20060120599-$ | US-20070103744-$ | US-20070252074-$ | US-20080291447-$ | US-20100106841-$ | US-20120106841-$ | US-8194136-$).DID.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:28
S181	0	(IO-232008-$ | II-212008-$ | AI-20030039402-$ | AI-20040150726-$ | AI-20050030394-$ | AI-20050261849-$ | AI-20060120599-$ | AI-20070103744-$ | AI-20070252074-$ | AI-20080291447-$ | AI-20100106841-$ | AI-20120106841-$ | VA-223131450-$).DID.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/06 15:29
S182	65	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 10:20
S183	20	(marly with camargo).xa,xp. and (correct$4 with aberration$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 10:32
S184	5	("20060228097" | "8395677" | "9077842" | "9392176" | "9998652").PN. OR ("10237485").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2020/06/07 10:38
S185	19	("20040150732" | "20040218813" | "20050179788" | "20080007630" | "20080240709" | "20080291447" | "20090009633" | "20090052769" | "20090167925" |	US-PGPUB;	OR	ON	2020/06/07 10:45

		"20090202171" | "20090262231" | "20120300112" | "5227832" | "6646760" | "6747757" | "7321685" | "7425988").PN. OR ("9077842").URPN.	USPAT; USOCR			
S186	67	(digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 10:53
S187	43	((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 10:54
S188	0	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 10:59
S189	21	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:00
S190	19	382/167,254,255,264,263,266,275.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and	US-PGPUB; USPAT; USOCR;	OR	ON	2020/06/07 11:01

		(result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	FPRS; EPO; JPO; DERWENT; IBM_TDB			
S191	0	359/16,637,666,665,207.2,354,676.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:02
S192	64	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:03
S193	0	382/167,254,255,264,263,266,275.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:06
S194	0	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:07

		database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))				
S195	182	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:07
S196	0	359/16,637,666,665,207.2,354,676.ccls. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:08
S197	0	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC. and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:09
S198	200	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:10

S199	0	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:11
S200	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with algorithm$1)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:12
S201	0	("20020012054" | "20030039402" | "20040150726" | "20050030394" | "20050261849" | "20060120599" | "20070103744" | "20070252074" | "20080291447" | "20100106841" | "20120106841" | "8194136").PN. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:13
S202	0	(US-10674046-$ | US-16692972-$ | US-20030039402-$ | US-20040150726-$ | US-20050030394-$ | US-20050261849-$ | US-20060120599-$ | US-20070103744-$ | US-20070252074-$ | US-20080291447-$ | US-20100106841-$ | US-20120106841-$ | US-8194136-$).DID. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:14
S203	22	348/241,231.99,222.1,240.99,335,333.08,340,342,240.1,208.11,207.99,345,346-350,355,240.3,349.ccls. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO;	OR	ON	2020/06/07 11:15

		and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	JPO; DERWENT; IBM_TDB			
S204	0	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:19
S205	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with algorithm$1)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:20
S206	2	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:21
S207	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:27

S208	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:28
S209	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/07 11:30
S222	13	("20030002735" | "20040120598" | "20040252906" | "20080170124" | "20160314565" | "7688337").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/23 13:19
S223	0	("20030002735" | "20040120598" | "20040252906" | "20080170124" | "20160314565" | "7688337").PN. and ((((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/23 13:20
S224	1	S222 and (correct$4 with aberration$1)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO;	OR	ON	2020/06/23 13:21

			DERWENT; IBM_TDB			
S225	0	("20030002735" | "20040120598" | "20040252906" | "20080170124" | "20160314565" | "7688337").PN. and ((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/06/23 13:22
S226	1	16/692972	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 13:42
S227	109	((("SOLOMON") near3 ("Neal"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2020/09/26 13:43
S228	0	((("OPTIMUM") near3 ("IMAGING") near3 ("TECHNOLOGIES") near3 ("LLC"))).AS,AANM.	USPAT	OR	ON	2020/09/26 14:54
S229	51	(US-10282822-$ | US-6888571-$ | US-8395677-$ | US-9843710-$ | US-4903204-$ | US-5905530-$ | US-7245319-$ | US-7590305-$ | US-7609297-$ | US-7612805-$ | US-7738015-$ | US-7936392-$ | US-8451339-$ | US-20050078173-$ | US-20070189757-$ | US-20090167925-$ | US-20100321537-$ | US-20140333971-$ | US-20160028921-$ | US-20170339334-$ | US-20170339340-$ | US-20200267286-$ | US-20200267287-$ | US-20200267289-$ | US-20200267290-$ | US-20020135688-$ | US-20030095197-$ | US-20070171288-$).DID.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 15:14

S231	34,560	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:03
S232	24,046	382/167,254,255,264,263,266,275.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:05
S233	5,427	359/16,637,666,665,207.2,354,676.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:05
S234	166,908	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:08
S235	0	S231 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO;	OR	ON	2020/09/26 21:09

		or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	DERWENT; IBM_TDB			
S236	0	S232 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:10
S237	0	S233 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:10
S238	1	S234 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:11
S239	69	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:17
S240	0	S231 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with	US-PGPUB; USPAT;	OR	ON	2020/09/26 21:21

		(correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			
S241	0	S232 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:25
S242	0	S233 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:26
S243	2	S234 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:26
S244	31	("20020012054" | "20030039402" | "20040150726" | "20050030394" | "20050261849" | "20060120599" | "20070103744" | "20070252074" | "20080291447" | "20100106841" | "20120106841" | "8194136").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/09/26 21:27

			IBM_TDB			
S245	0	S244 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:28
S246	1	(US-10282822-$ | US-6888571-$ | US-8395677-$ | US-9843710-$ | US-4903204-$ | US-5905530-$ | US-7245319-$ | US-7590305-$ | US-7609297-$ | US-7612805-$ | US-7738015-$ | US-7936392-$ | US-8451339-$ | US-20050078173-$ | US-20070189757-$ | US-20090167925-$ | US-20100321537-$ | US-20140333971-$ | US-20160028921-$ | US-20170339334-$ | US-20170339340-$ | US-20200267286-$ | US-20200267287-$ | US-20200267289-$ | US-20200267290-$ | US-20020135688-$ | US-20030095197-$ | US-20070171288-$).DID. and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:29
S247	21	S231 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:29
S248	19	S232 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/09/26 21:31

			IBM_TDB			
S249	0	S233 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:39
S250	62	S234 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:39
S251	0	S231 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:45
S252	0	S232 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:46
S253	0	S233 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with	US-PGPUB; USPAT; USOCR; FPRS;	OR	ON	2020/09/26 21:46

		database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	EPO; JPO; DERWENT; IBM_TDB			
S254	2	S234 and ((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:47
S255	341	((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:48
S256	0	S231 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:49
S257	0	S232 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:50

S258	0	S233 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:50
S259	17	S234 and (((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:51
S260	48	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:53
S261	12	S231 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:53
S262	0	S232 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO;	OR	ON	2020/09/26 21:55

			DERWENT; IBM_TDB			
S263	0	S233 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 21:55
S264	13	S234 and (((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 22:01
S265	3	((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 22:04
S266	3	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 22:10
S267	0	((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or	US-PGPUB; USPAT;	OR	ON	2020/09/26 22:11

		internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))))).clm.	USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			
S268	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 22:13
S269	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 22:14
S270	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 22:15
S271	0	(((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2020/09/26 22:16

		database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))).clm.	IBM_TDB			
S272	1	((((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))).clm.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2020/09/26 22:18

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
S133	96	((("SOLOMON") near3 ("Neal"))).INV.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:38
S134	0	(((("OPTIMUM") near3 ("IMAGING") near3 ("TECHNOLOGIES") near3 ("LLC"))).AS,AANM.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:38
S135	21,404	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:39
S136	15,418	382/167,254,255,264,263,266,275.ccls.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:39
S137	3,017	359/16,637,666,665,207.2,354,676.ccls.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:39
S138	42,175	(H04N5/357 | H04N5/217 | H04N5/2253 | H04N5/2254 | H04N5/228 | H04N5/238 | H04N5/76 | H04N5/225 | H04N5/374 | G06K9/36 | G06K9/40 | G01J1/20).CPC.	US-PGPUB;	OR	ON	2020/01/18 20:39

			USPAT			
S139	0	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:40
S140	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with data$base))).clm.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:41
S141	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software))).clm.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:43
S142	0	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:44
S143	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database) and (correction data) and (user with (adjust$4 with variable$1)))).clm.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:46
S144	47,849	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	US-PGPUB; USPAT	OR	ON	2020/01/18 20:48
S164	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with algorithm$1)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or	US-PGPUB; USPAT	OR	ON	2020/01/19 11:30

		transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or scren or LCD))).clm.				
S165	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or scren or LCD))).clm.	US-PGPUB; USPAT	OR	ON	2020/01/19 11:33
S166	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD))).clm.	US-PGPUB; USPAT	OR	ON	2020/01/19 11:41
S210	96	((("SOLOMON") near3 ("Neal"))).INV.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:17
S211	0	(((("OPTIMUM") near3 ("IMAGING") near3 ("TECHNOLOGIES") near3 ("LLC"))).AS,AANM.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:17
S212	23,249	348/241,231.99,222.1,240.99,335,333.08,340,342,240.1,208.11,207.99,345,346-350,355,240.3,349.ccls.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:18
S213	15,422	382/167,254,255,264,263,266,275.ccls.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:18
S214	3,017	359/16,637,666,665,207.2,354,676.ccls.	US-PGPUB;	OR	ON	2020/06/07 11:18

			USPAT			
S215	50,039	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:18
S216	0	(((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1)).clm.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:19
S217	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with algorithm$1)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD))).clm.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:20
S218	2	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))	US-PGPUB; USPAT	OR	ON	2020/06/07 11:26
S219	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)) and ((updat$3 or upgrad$3) with (program$1 or software)) and format$4 and ((external or outside or exterior) with (monitor or screen or LCD))).clm.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:27
S220	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or	US-PGPUB; USPAT	OR	ON	2020/06/07 11:29

		updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))).clm.				
S221	0	((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1))).clm.	US-PGPUB; USPAT	OR	ON	2020/06/07 11:31
S273	101	((("SOLOMON") near3 ("Neal"))).INV.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:07
S274	4	((("OPTIMUM") near3 ("IMAGING") near3 ("TECHNOLOGIES") near3 ("LLC"))).AS,AANM.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:07
S275	21,413	348/241,231.99,222.1,335,240.99,240.1,240.3,333.08,340,342,208.11,345,346-350,355,349.ccls.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:08
S276	15,425	382/167,254,255,264,263,266,275.ccls.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:08
S277	3,017	359/16,637,666,665,207.2,354,676.ccls.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:09
S278	52,273	(H04N5/217 | H04N5/2253 | H04N5/238 | H04N5/2254 | H04N5/76 | H04N5/225 | H04N5/228 | H04N5/357 | H04N5/374 | H04N5/3572 | H04N9/04517 | H04N1/00872 | H04N3/23 | H04N5/208 | G06K9/36 | G06K9/40 | G01J1/20 | G01J1/0411 | G01J3/0208).CPC.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:09
S279	0	((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))).clm.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:12

S280	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)) and ((stor$3 imag$3) with database) and (captur$3 with image$1) and (plurality with (correct$4 with algorithm$1)))).clm.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:13
S281	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))).clm.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:14
S282	0	(((digital with camera$1 or video$1) and (digital$4 with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and (improv$4 with (algorithm$1 or procedure$1)))).clm.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:16
S283	0	((((digital with camera$1 or video$1) and (digital$4 with process$4) and (captur$3 with imag$3) and plural$4 and (receiv$4 with (updat$4 with software)) and (correct$4 with algorithm$1) and (("in-camera" or internal) with process$4) and (wireless$3 with (transmit$4 or transmission)) and (result$3 with (correct$4 image$1)) and provid$3 and provid$4 and ((improv$4 or upgrad$4 or updat$3) with ((algorithm$1 or procedure$1 or method$1)) with correct$4) and ((stor$3 imag$3) with database))and ((external$3 or outside or exterior) with (monitor or screen or LCD)))).clm.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:17
S284	1	((((digital or optical) with aberration$1) and (digital with database) and vignet$5 and (integrat$3 with circuit$3) and (lens with mechanism) and identif$5 and (imag$3 with file$1) and video and (modif$4 or chang$3 or alter$4) and (stor$4 with (original with video$1 or image$1)) and (algorithm$1 or procedure$1))).clm.	US-PGPUB; USPAT	OR	ON	2020/09/26 22:18

9/27/2020 3:02:39 PM
C:\Users\mcamargo\Documents\EAST\Workspaces\16692972.wsp

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 1 of 5	Attorney Docket No: 5311.001US5	

US PATENT DOCUMENTS

	USP Document Number	Publication Date	Name of Patentee or Applicant of cited Document
	US-6,888,571	05/03/2005	Koshizuka, Yasuo, et al.
	US-8,395,677	03/12/2013	Kikuchi, Atsuo, et al.
	US-9,843,710	12/12/2017	Hamano, Hideyuki, et al.
	US-10,282,822	05/07/2019	Shmunk, Dmitry Valerievich, et al.
	US-20050078173A1	04/14/2005	Steinberg, Eran, et al.
	US-20070189757A1	08/16/2007	Steinberg, Eran, et al.
	US-20090167925A1	07/02/2009	Murata, Tsukasa
	US-20100321537A1	12/23/2010	Zamfir, Marta, et al.
	US-20140333971A1	11/13/2014	Macciola, Anthony, et al.
	US-20160028921A1	01/28/2016	Thrasher, Christopher W., et al.
	US-20170339334A1	11/23/2017	Bayser, Maira Gatti, et al.
	US-20170339340A1	11/23/2017	Bayser, Maira Gatti, et al.
	US-20200267286A1	08/20/2020	Solomon, Neal
	US-20200267287A1	08/20/2020	Solomon, Neal
	US-20200267289A1	08/20/2020	Solomon, Neal
	US-20200267290A1	08/20/2020	Solomon, Neal

FOREIGN PATENT DOCUMENTS

Examiner Initial *	Foreign Document Number	Publication Date	Name of Patentee or Applicant of cited Document	T 1

EXAMINER DATE CONSIDERED

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 2 of 5	Attorney Docket No: 5311.001US5	

OTHER DOCUMENTS – NON PATENT LITERATURE DOCUMENTS

Examiner Initial *	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T 1
	"Application Serial No. 16/692,939, Final Office Action mailed 06-18-20", 24 pages.	
	"Application Serial No. 16/692,939, Response filed 08-28-20 to Final Office Action mailed 06-18-20", 9 pgs.	
	"Application Serial No. 16/694,838, Final Office Action mailed 07-29-20", 28 pgs.	
	"Application Serial No. 16/694,850, Corrected Notice of Allowability mailed 08-27-20", 17 pgs.	
	"Canon Powershot SD300 and SD200 Camera User Guide, Petitioner Canon, Inc., Ex. 1040 - VOL. 1", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 89 pgs.	
	"Canon Powershot SD300 and SD200 Camera User Guide, Petitioner Canon, Inc., Ex. 1040 - VOL. 2", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 90 pgs.	
	"Carasso, US 5,4114,782, Petitioner Canon, Inc., Ex. 1025", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 12 pgs.	
	"Certified Translation of "Guan, et al., 'Digital Image Correcting Method for Digital Camera', Ricoh Technical Report No. 31, 103-110, (2005)", Petitioner Canon, Inc., Ex. 1018", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 9 pgs.	
	"Certified Translation of JP2000-184247A, Petitioner Canon, Inc., Ex. 1023", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 13 pgs.	
	"Certified Translation of JP2002-190979, Petitioner Canon, Inc., Ex. 1015", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 12 pgs.	
	"Certified Translation of JP2002-199410, Petitioner Canon, Inc., Ex. 1039", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 18 pgs.	
	"Certified Translation of JP2004-328506A, Petitioner Canon, Inc., Ex. 1011", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 21 pgs.	
	"Certified Translation of JP2004-343358, Petitioner Canon, Inc., Ex. 1009", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 31 pgs.	
	"Certified Translation of JP2006-72660, Petitioner Canon, Inc., Ex. 1027", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 14 pgs.	

EXAMINER **DATE CONSIDERED**

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 3 of 5	Attorney Docket No: 5311.001US5	

	"Certified Translation of JPH11-313250, Petitioner Canon, Inc., Ex. 1013", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 6 pgs.	
	"Claim Construction Memorandum Opinion and Order, Document 88 in 2:19-CV-00246-JRG (E.D. Tex. June 11, 2019), Petitioner Canon, Inc., Ex. 1004", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 60 pgs.	
	"Complaint for Patent Infringement in 2:19-CV-00246-JRG (E.D. Tex. July 8, 2019), Petitioner Canon, Inc., Ex. 1003", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 26 pgs.	
	"Declaration Leonard Laub, Petitioner Canon, Inc., Ex. 1002", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 94 pgs.	
	"Declaration of Kiyoto Nagai, Petitioner Canon, Inc., Ex. 1019", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 11 pgs.	
	"Declaration of Leonard Laub, Petitioner Canon, Inc., Ex. 1002", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 117 pgs.	
	"Dobbins, III, US 4,903,204, Petitioner Canon, Inc., Ex. 1026", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 28 pgs.	
	"Enomoto, US 7,245,319 B1, Petitioner Canon, Inc., Ex. 1012", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 10 pgs.	
	"File History for US 8,451,339, Petitioner Canon, Inc., Ex. 1038", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 234 pgs.	
	"Havens, US20070080280A1, Petitioner Canon, Inc., Ex. 1029", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 32 pgs.	
	"Inoue, US20070171288A1, Petitioner Canon, Inc., Ex. 1030", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 85 pgs.	
	"JP Patent Office Machine Translation of JP05-323444A, Petitioner Canon, Inc., Ex. 1033", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 21 pgs.	
	"JP Patent Office Machine Translation of JP2000-224611A, Petitioner Canon, Inc., Ex. 1034", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 12 pgs.	
	"Kawanishi, US20050089241A1, Petitioner Canon, Inc., Ex. 1010", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 31 pgs.	

EXAMINER **DATE CONSIDERED**

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 4 of 5	Attorney Docket No: 5311.001US5	

	"Kodak EasyShare V570 User Guide, Petitioner Canon, Inc., Ex. 1041", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 75 pgs.	
	"Library of Congress Catalog entry for "Russ, John C., The Image Processing Handbook, 4th Ed., CRC Press (2002)", Petitioner Canon, Inc., Ex. 1036", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 1 pg.	
	"Master, US 7,609,297 B2, Petitioner Canon, Inc., Ex. 1028", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 55 pgs.	
	"Ng, US 7,936,392 B2, Petitioner Canon, Inc., Ex. 1031", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 51 pgs.	
	"Niikawa, US20020135688A1, Petitioner Canon, Inc., Ex. 1006", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 47 pgs.	
	"Olympus Digital Camera E-1 Reference Manual, Petitioner Canon, Inc., Ex. 1043", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 182 pgs.	
	"Petition for Inter Partes Review", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 68 pgs.	
	"Petition for Inter Partes Review", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 74 pgs.	
	"Petitioner's Motion to Seal Confidential Litigation Filing, Ex. 1005", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 13 pgs.	
	"Petitioner's Power of Attorney", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 4 pgs.	
	"Petitioner's Power of Attorney", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 4 pgs.	
	"Ricoh Technical Report No. 31, RICOH, (April 20, 2006), Petitioner Canon, Inc., Ex. 1020", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, [Online] Retrieved from the Internet: <URL: https://web.archive.org/web/20060420051054/http:/www.ricoh.co.jp/about/business_overview/report/31/>, (07-20-2020), 4 pgs.	
	"Solomon, US 8,451,339 B2, Petitioner Canon, Inc., Ex. 1001", IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 41 pgs.	
	"Solomon, US Patent No. 7,612,805, Petitioner Canon, Inc., Ex. 1001", IPR2020-01321, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 41 pgs.	
	"Steinberg, US 7,590,305 B2, Petitioner Canon, Inc., Ex. 1022", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 23 pgs.	

EXAMINER **DATE CONSIDERED**

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

Modified form PTO/SB/08A(04-07) OMB 651-0031
US Patent & Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for form 1449A/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** (Use as many sheets as necessary)	*Complete if Known*	
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
Sheet 5 of 5	Attorney Docket No: 5311.001US5	

	"Steinberg, US 7,738,015 B2, Petitioner Canon, Inc., Ex. 1021", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 23 pgs.	
	"Taylor Francis Group, LLC Customer Service Publication Confirmation, Petitioner Canon, Inc., Ex. 1044", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 2 pgs.	
	"The Nikon Guide to Digital Photography with the CoolPix 7900 5900 Digital Camera, Petitioner Canon, Inc., Ex. 1042", IPR2020-01321, US Patent No. 7,612,805, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 165 pgs.	
	"USPTO File History for US 7,612,805, Petitioner Canon, Inc., Ex. 1037", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 288 pgs.	
	"Watanabe, US20050280877A1, Petitioner Canon, Inc., Ex. 1007", IPR2020-01321, US Patent No. 7,612,805; PR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 20 pgs.	
	"Wheeler, US20030095197A1, Petitioner Canon, Inc., Ex. 1032", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 32 pgs.	
	"Yamanaka, US20040150732A1, Petitioner Canon, Inc., Ex. 1017", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 31 pgs.	
	"Yokota, US 5,905,530, Petitioner Canon, Inc., Ex. 1014", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 71 pgs.	
	GONZALEZ, RAFAEL C, et al., "Digital Image Processing, 2nd Ed., Prentice Hall (2002), Petitioner Canon, Inc., Ex. 1024 -- VOL. 1", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 442 pgs.	
	GONZALEZ, RAFAEL C, et al., "Digital Image Processing, 2nd Ed., Prentice Hall (2002), Petitioner Canon, Inc., Ex. 1024 -- VOL. 2", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 373 pgs.	
	RUSS, JOHN C, "The Image Processing Handbook, 4th Ed., CRC Press (2002), Petitioner Canon, Inc., Ex. 1008 - VOL. 1", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 294 pgs.	
	RUSS, JOHN C, "The Image Processing Handbook, 4th Ed., CRC Press (2002), Petitioner Canon, Inc., Ex. 1008 - VOL. 2", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 268 pgs.	
	RUSS, JOHN C, "The Image Processing Handbook, 4th Ed., CRC Press (2002), Petitioner Canon, Inc., Ex. 1008 -- VOL. 3", IPR2020-01321, US Patent No. 7,612,805; IPR2020-01322, US Patent No. 8,451,339, Canon, Inc. v. Optimum Imaging Technology, LLC, (07-20-2020), 183 pgs.	

EXAMINER **DATE CONSIDERED**

* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant is to place a check mark here if English language Translation is attached

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s):	Neal Solomon	Examiner:	MARLY S.B. CAMARGO
Serial No.:	16/692,972	Group Art Unit:	2697
Filed:	November 22, 2019	Docket:	5311.001US5
Customer No.:	21186	Confirmation No.:	7825
Title:	DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER		

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT

MS Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

In compliance with the duty imposed by 37 C.F.R. § 1.56, and in accordance with 37 C.F.R. §§ 1.97 *et. seq.*, the enclosed materials are brought to the attention of the Examiner for consideration in connection with the above-identified patent application. Applicant respectfully requests that this Information Disclosure Statement be entered and the documents listed on the attached PTO 1449 Form be considered by the Examiner and made of record. Pursuant to the provisions of MPEP 609, Applicant requests that a copy of the PTO 1449 Form, initialed as being considered by the Examiner, be returned to the Applicant with the next official communication.

Pursuant to 37 C.F.R. § 1.97(b), it is believed that no fee or statement is required with the Information Disclosure Statement. However, if an Office Action on the merits has been mailed after filing of the application or after the filing of the most recent RCE, the Commissioner is hereby authorized to charge the required fees to Deposit Account No. 19-0743 in order to have this Information Disclosure Statement considered.

Pursuant to 37 C.F.R. § 1.98(a)(2), copies of cited U.S. Patents and Published Applications, and Non-Published Applications identifiable by USPTO Serial Number, are no longer required to be provided to the Office. Applicant acknowledges the requirement to submit copies of foreign patent documents and non-patent literature in accordance with 37 C.F.R § 1.98(a)(2).

The Examiner is invited to contact the undersigned at the telephone number indicated if there are any questions regarding this communication.

Respectfully submitted,

SCHWEGMAN LUNDBERG & WOESSNER, P.A.
P.O. Box 2938
Minneapolis, MN 55402
(612) 373-6912

Date Sep. 4, 2020 By /Timothy E. Bianchi/
Timothy E. Bianchi
Reg. No. 39,610

TEB:jj

REQUEST FOR CONTINUED EXAMINATION (RCE) TRANSMITTAL		
	Application Number	16/692,972
	Filing Date	November 22, 2019
	First Named Inventor	Neal Solomon
	Confirmation Number	7825
	Group Art Unit	2697
	Examiner Name	MARLY S.B. CAMARGO
	Attorney Docket Number	5311.001US5
	Customer No.	21186

This is a Request for Continued Examination (RCE) under 37 C.F.R § 1.114 of the above-identified application entitled
DIGITAL CAMERA WITH WIRELESS IMAGE TRANSFER

1. Submission required under 37 C.F.R. § 1.114:

   X Information Disclosure Statement (2 pgs.), Form 1449 (5 pgs.), and copies of cited documents (56).

2. Fees

   X Authorization to charge deposit account 19-0743 in the amount of $950.00 to pay the subsequent RCE filing fee required under 37 C.F.R. § 1.17(e)(2).

The Commissioner is hereby authorized to charge any additional fees or credit overpayment to Deposit Account No. 19-0743.

SCHWEGMAN LUNDBERG & WOESSNER, P.A.

By: /Timothy E. Bianchi/
Timothy E. Bianchi
Reg. No. 39,610

US005414782A

United States Patent [19]

Carasso

[11] Patent Number: 5,414,782

[45] Date of Patent: May 9, 1995

[54] **PROCEDURE FOR DIGITAL IMAGE RESTORATION**

[75] Inventor: **Alfred S. Carasso**, North Potomac, Md.

[73] Assignee: **The United States of Amercia as represented by the Secretary of Commerce**, Washington, D.C.

[21] Appl. No.: **991,105**

[22] Filed: **Dec. 16, 1992**

[51] **Int. Cl.**[6] **G06K 9/40**

[52] **U.S. Cl.** **382/270**; 364/413.19; 382/128

[58] **Field of Search** 382/6, 54, 42; 364/413.13, 413.17, 413.19, 822

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,315,318	2/1982	Kato et al.	382/6
4,329,588	5/1982	Barrett et al.	364/416
4,331,877	5/1982	Barrett et al.	364/414
4,633,504	12/1986	Wihl	382/54
4,758,304	7/1988	McNeil et al.	156/626
4,877,479	10/1989	McNeil et al.	156/626
4,903,205	2/1990	Hishinuma	382/6
4,907,156	3/1990	Doi et al.	382/6
4,947,323	8/1990	Smith	364/413.13
5,047,968	9/1991	Carrington et al.	382/54

OTHER PUBLICATIONS

N. S. Kopeika, "Spectral Characteristics of Image Quality for Imaging Horizontally Through the Atmosphere," Applied Optics, vol. 16 (1977), pp. 2422–2426.

R. Weber, "The Ground-Based Electro-Optical Detection of Deep-Space Satellites," Applications of Electronic Imaging Systems, SPIE, vol. 143 (1978), pp. 59–69.

N. S. Kopeika, "Imaging Through the Atmosphere for Airborne Reconnaissance," Optical Engineering, vol. 26 (1987), pp. 1146–1154.

J. D. Gonglewski et al., "Laboratory and Field Results in Low Light Postdetection Turbulence Compensation Using Self Referenced Speckle Holography," Digital Image Synthesis and Inverse Optics, SPIE, vol. 1351 (1990), pp. 798–806.

H. T. Yura, "Imaging in Clear Ocean Water," Applied Optics, vol. 12 (1973), pp. 1061–1066.

C. B. Johnson, "A Method for Characterizing Electro-Optical Device Modulation Transfer Functions," Photographic Science and Engineering, vol. 14 (1970), pp. 413–415.

C. B. Johnson, "Classification of Electron-Optical Device Modulation Transfer Functions," Advances in Electronics and Electron Physics, vol. 33B (1972), pp. 579–584.

C. B. Johnson et al., "High Resolution Microchannel Plate Image Tube Development," Electron Image Tubes and Image Intensifiers II, SPIE, vol. 1449 (1991), pp. 2–12.

F. C. Wagner et al., "A Characterization of the Scatter Point-Spread-Function in Terms of Air Gaps," IEEE Transactions on Medical Imaging, vol. 7 (1988), pp. 337–344.

(List continued on next page.)

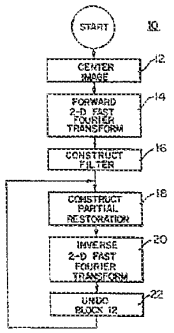
Primary Examiner—Joseph Mancuso

Attorney, Agent, or Firm—Panitch Schwarze Jacobs & Nadel

[57] **ABSTRACT**

The image restoration system and method of the present invention is applied to point spread functions p(x,y) which may be described in the Fourier domain as $\hat{p}(\xi,\eta)=\exp\{-\sum_{i=1}^{J}\lambda_i(\xi^2+\eta^2)^{\beta_i}\}$, $\lambda_i \geq 0$, $0<\beta_i \leq 1$, to improve noise performance and permit identification of fine detail. The novel method formulates the image restoration problem as a problem in the partial differential equations describing diffusion phenomena using a new type of a priori constraint. The restored image is obtained by minimizing a quadratic functional incorporating this new constraint. The solution of the minimization problem may be obtained directly by means of fast Fourier transform algorithms. The restoration method may be performed as a sequence of partial restorations as $t \downarrow 0$ wherein the partial restorations become sharper and noisier as $t \downarrow 0$, or as a single full restoration. The sequence of partial restorations may reveal features of the image before such features become obscured by noise and may permit adjustment of the parameters characterizing the blurring functions and constraints.

12 Claims, 3 Drawing Sheets



PE

OTHER PUBLICATIONS

S. Webb et al., "Constrained Deconvolution of SPECT Liver Tomograms by Direct Digital Image Restoration," Medical Physics, vol. 12 (1985), pp. 53–58.

U. Raff et al., "Improvement of Lesion Detection in Scintigraphic Images by SVD Techniques for Resolution Recovery," IEEE Transactions on Medical Imaging, vol. MI–5 (1986), pp. 35–44.

B. C. Penney et al., "Constrained Least–Squares Restoration of Nuclear Medicine Images: Selecting the Coarseness Function," Medical Physics, vol. 14 (1987), pp. 849–858.

B. C. Penney et al., "Relative Importance of the Error Sources in Wiener Restoration of Scintigrams," IEEE Transactions on Medical Imaging, vol. 9 (1990), pp. 60–70.

K. S. Pentlow et al., "Quantitative Imaging of I–124 Using Positron Emission Tomography with Applications to Radioimmunodiagnosis and Radioimmunotherapy," Medical Physics, vol. 18 (1991), pp. 357–366.

S. M. Mohapatra et al., "Transfer Function Measurement and Analysis for a Magnetic Resonance Imager," Medical Physics, vol. 18 (1991), pp. 1141–1144.

S. Rudin et al., "Improving Fluoroscopic Image Quality with Continously Variable Zoom Magnification," Medical Physics, vol. 18 (1991), pp. 972–977.

E. L. Nickoloff et al., "A Simplified Approach for Modulation Transfer Function Determinations in Computed Tomography," Medical Physics, vol. 12 (1985), pp. 437–442.

F. F. Yin et al., "Measurement of the Presampling Modulation Transfer Function of Film Digitizers Using a Curve Fitting Technique," Medical Physics, vol. 17 (1990), pp. 962–966.

P. J. Papin et al., "A Prototype Amorphous Selenium Imaging Plate System for Digital Radiography," Medical Physics, vol. 14 (1987), pp. 322–329.

S. Sanada et al., "Comparison of Imaging Properties of a Computed Radiography System and Screen–Film Systems," Medical Physics, vol. 18 (1991), pp. 414–420.

H. Fujita et al., "A Simple Method for Determining the Modulation Transfer Function in Digital Radiography," IEEE Transactions on Medical Imaging, vol. 11 (1992), pp. 34–39.

M. Takahashi et al., "Digital TV Tomography: Description and Physical Assessment," Medical Physics, vol. 17 (1990), pp. 681–685.

Y. Higashida et al., "Dual–Film Cassette Technique for Studying the Effect of Radiographic Image Quality on Diagnostic Accuracy," Medical Physics, vol. 11 (1984), pp. 646–652.

H. Kuhn et al., "Imaging Characteristics of Different Mammographic Screens," Medical Physics, vol. 19 (1992), pp. 449–457.

N. V. Rao, "Development of High Resolution Camera Tube for 2000 Line TV System," Electron Image Tubes and Image Intensifiers, SPIE, vol. 1243 (1990), pp. 81–86.

R. Barden et al., "High Resolution MS–Type Saticon Pick–Up Tube with Optimized Electron Optical Properties," Electron Image Tubes and Image Intensifiers II, SPIE, vol. 1449 (1991), pp. 136–147.

K. A. Costello et al., "Imaging GaAs Vacuum Photodiode with 40% Quantum Efficiency at 530 nm," Electron Image Tubes and Image Intensifiers, SPIE, vol. 1243 (1990), pp. 99–106.

A. S. Carasso et al., "Digital Removal of Random Media Image Degradations By Solving the Diffusion Equation Backwards in Time," SIAM Journal on Numerical Analysis, vol. 15 (1978), pp. 344–367.

PE

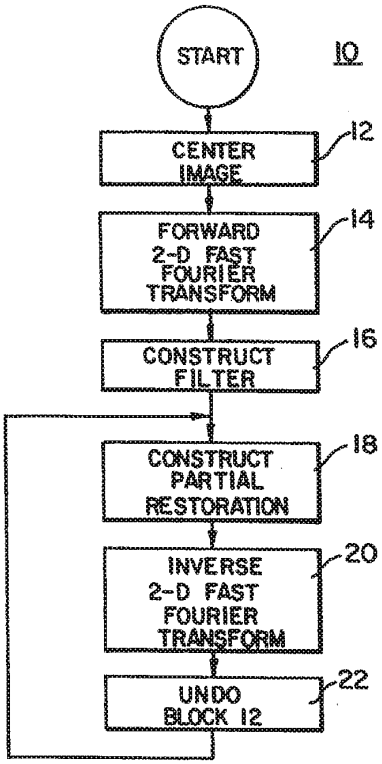

START
10
CENTER IMAGE
12
FORWARD 2-D FAST FOURIER TRANSFORM
14
CONSTRUCT FILTER
16
CONSTRUCT PARTIAL RESTORATION
18
INVERSE 2-D FAST FOURIER TRANSFORM
20
UNDO BLOCK 12
22

FIG. 1

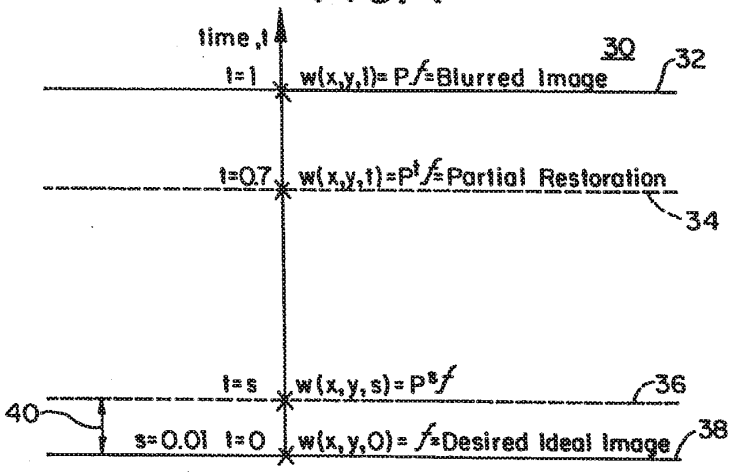

time, t
t=1
w(x,y,1)= P f =Blurred Image
30
32
t=0.7
w(x,y,t)=P^t f =Partial Restoration
34
t=s
w(x,y,s)=P^s f
36
40
s=0.01 t=0
w(x,y,0)= f =Desired Ideal Image
38

FIG. 2

PE

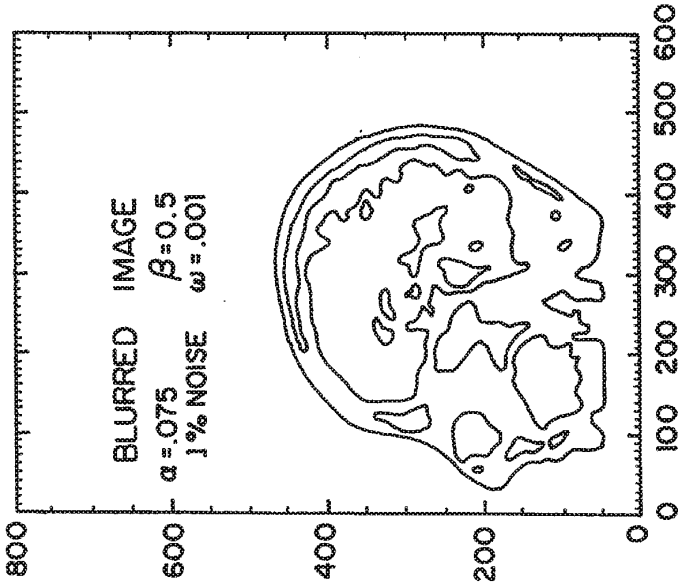

BLURRED IMAGE
α=.075 β=0.5
1% NOISE ω=.001
0
100
200
300
400
500
600
0
200
400
600
800

FIG. 4

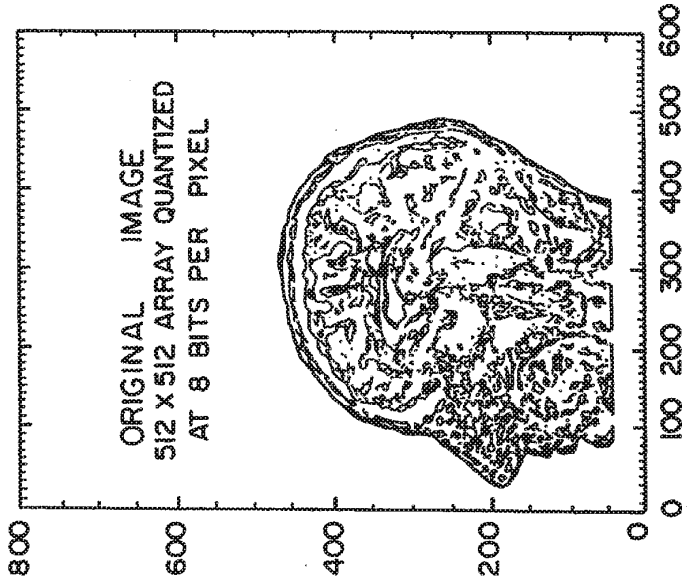

ORIGINAL IMAGE
512 X 512 ARRAY QUANTIZED
AT 8 BITS PER PIXEL
0
100
200
300
400
500
600
0
200
400
600
800

FIG. 3

PE

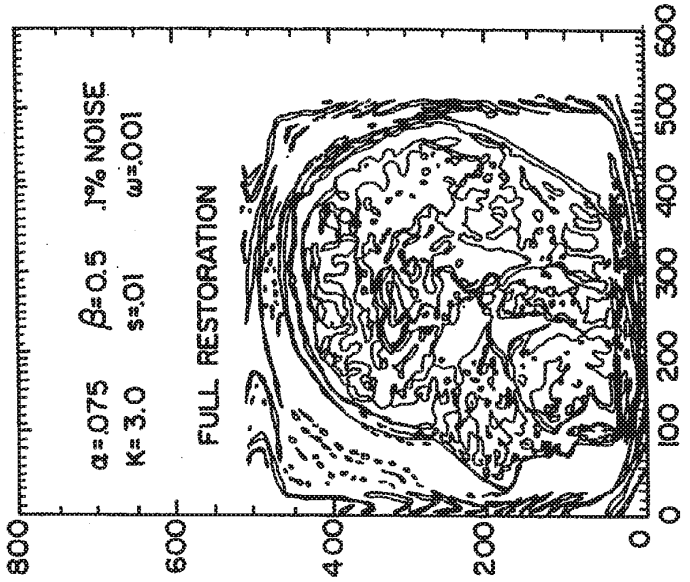

α=.075 β=0.5 1% NOISE
K=3.0 s=.01 ω=.001
FULL RESTORATION
0
100
200
300
400
500
600
0
200
400
600
800

FIG. 6

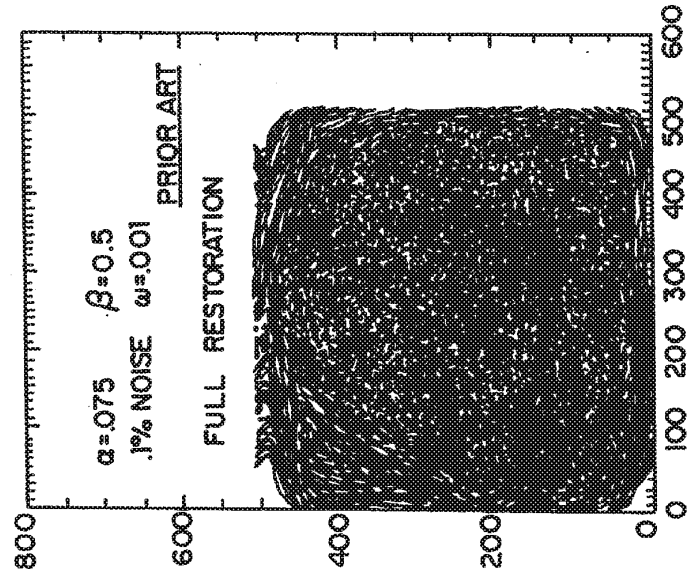

α=.075 β=0.5
.1% NOISE ω=.001
PRIOR ART
FULL RESTORATION
0
100
200
300
400
500
600
0
200
400
600
800

FIG. 5

PE

PROCEDURE FOR DIGITAL IMAGE RESTORATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to image processing, and, in particular, to image restoration.

2. Statement of Related Art

Comprehensive coverage of prior art in the field of image restoration relevant to the system and method may be found in H. C. Andrews and B. R. Hunt, *Digital Image Restoration*, Prentice-Hall Signal Processing Series, Prentice-Hall, Inc., Englewood Cliffs, N.J. (1977); W. K. Pratt, *Digital Image Processing*, 2nd Edition, John Wiley and Sons, New York (1988); H. Stark, *Image Recovery, Theory and Application*, Academic Press, Inc., Harcourt Brace Jovanovich, Publishers, New York (1987); R. C. Gonzalez and P. Wintz, *Digital Image Processing*, 2nd Edition, Addison-Wesley Publishing Company, Inc., Advanced Book Program, Reading, Mass. (1987); and R. L. Lagendijk and J. Biemond, *Iterative Identification and Restoration of Images*, Kluwer International Series in Engineering and Computer Science, Kluwer Academic Publishers, Boston, Mass. (1991). For space-invariant blurs, digital image restoration is associated with the solution of two dimensional ill-posed convolution integral equations of the form

$$g(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p(x-u,y-v)f(u,v)dudv, \quad \text{Equation (1)}$$

where g(x,y) is the degraded image, f(x,y) is the desired ideal image, and p(x,y) is the known point spread function of the imaging system. The point spread function acts so as to blur or smooth out the ideal image, making it impossible to distinguish fine details in the recorded image g(x,y). Separately, g(x,y) is further contaminated by measurement noise. Thus:

$$g(x,y)=g_o(x,y)+n(x,y), \quad (2)$$

where $g_o(x,y)$ is the blurred image that would have been recorded in the absence of noise, and n(x,y) represents the cumulative effects of all noise processes affecting final acquisition of the digitized array g(x,y). This includes the case of multiplicative noise, where n(x,y) is a function of f(x,y). The noise component n(x,y) is unknown, but may be presumed small. Likewise, $g_o(x,y)$ is unknown. The type and intensity of the blurring caused by p, together with the magnitude of the noise in g, ultimately limit the quality of the restoration that can be achieved. It is convenient to write Equation (1) in operator notation as:

$$Pf=g, \quad (3)$$

where P is the integral operator in $L^2(R^2)$ with kernel p(x-u,y-v).

The two dimensional Fourier transform plays a major role in the subsequent analysis. For a function a(x,y) of the space variables x,y, the Fourier transform $\hat{a}(\xi,\eta)$ may be expressed as:

$$\hat{a}(\xi,\eta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} a(x,y)e^{-2\pi i(\xi x+\eta y)}dxdy. \quad \text{Equation (4)}$$

The Fourier transform of the point spread function is called the optical transfer function and is an important tool in image analysis. The convolution theorem states that the transform of a convolution is the product of the individual transforms. The Parseval theorem states that the L^2 scalar product of two functions in the space variables x,y is equal to their scalar product in the transform variables ξ,η. These and other results from Fourier analysis in L^2 are well known in the art. For convolution equations such as Equation (1), it is advantageous to perform the analysis and computations in the Fourier domain. After image processing, the inverse Fourier transform is used to return to the space variables x,y.

The class G of point spread functions, described by Equation (5A) below, plays a key role in several civilian and military applications, including biomedical imaging; night vision systems; undersea imaging; imaging through the atmosphere; remote sensing; high definition television; and industrial applications. Consider first the class of point spread functions p(x,y) described as follows in the Fourier transform domain:

$$\hat{p}(\xi,\eta)=e^{-\lambda(\xi^2+\eta^2)^{\beta}},\ \lambda>0,\ 0<\beta\leq 1. \quad (5)$$

The case $\beta=1$ corresponds to a Gaussian point spread function. This case occurs in quite diverse applications, including undersea imaging (see H. T. Yura, 'Imaging in Clear Ocean Water,' *Applied Optics*, Vol. 12 (1973), pp. 1061–1066); low light-level electro-optical detection (see R. Weber, 'The Ground-Based Electro-Optical Detection of Deep-Space Satellites,' *Applications of Electronic Imaging Systems*, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 143, R. E. Franseen and D. K. Schroder, Eds. (1978), pp. 59–69); nuclear medicine gamma camera scintigrams (see S. Webb et al., 'Constrained Deconvolution of SPECT Liver Tomograms by Direct Digital Image Restoration,' *Medical Physics*, Vol. 12 (1985), pp. 53–58; U. Raff et al., 'Improvement of Lesion Detection in Scintigraphic Images by SVD Techniques for Resolution Recovery,' *IEEE Transactions on Medical Imaging*, Vol. MI-5 (1986), pp. 35–44; B. C. Penney et al., 'Constrained Least Squares Restoration of Nuclear Medicine Images: Selecting the Coarseness Function,' *Medical Physics*, Vol. 14 (1987), pp. 849–859; B. C. Penney et al., 'Relative Importance of the Error Sources in Wiener Restoration of Scintigrams,' *IEEE Transactions on Medical Imaging*, Vol. 9 (1990), pp. 60–70; K. S. Pentlow et al., 'Quantitative Imaging of I-124 Using Positron Emission Tomography with Applications to Radioimmunodiagnosis and Radioimmunotherapy,' *Medical Physics*, Vol. 18 (1991), pp. 357–366); magnetic resonance imaging (see S. M. Mohapatra et al., 'Transfer Function Measurement and Analysis for a Magnetic Resonance Imager,' *Medical Physics*, Vol. 18 (1991), pp. 1141–1144); and computed tomography scanners (see E. L. Nickoloff and R. Riley, 'A Simplified Approach for Modulation Transfer Function Determinations in Computed Tomography,' *Medical Physics*, Vol. 12 (1985), pp. 437–442).

The case $\beta=5/6$ describes blurring caused by atmospheric turbulence under long time exposure. This optical transfer function is important in post processing of

PE

Samsung Exhibit 1002, Page 139 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

degraded images obtained in airborne reconnaissance, in remote sensing from environmental or surveillance satellites, in the detection of deep-space satellites from ground-based telescopes, and in observational astronomy (see J. C. Wyant, Ed., *Imaging Through the Atmosphere*, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 75 (1976); N. S. Kopeika, 'Spectral Characteristics of Image Quality for Imaging Horizontally Through the Atmosphere,' *Applied Optics*, Vol. 16 (1977), pp. 2422–2426; R. Weber, 'The Ground-Based Electro-Optical Detection of Deep-Space Satellites,' *Applications of Electronic Imaging Systems*, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 143, R. E. Franseen and D. K. Schroder, Eds. (1978), pp. 59–69; N. S. Kopeika, 'Imaging Through the Atmosphere for Airborne Reconnaissance,' *Optical Engineering*, Vol. 26 (1987), pp. 1146–1154; J. D. Gonglewski and D. G. Voelz, 'Laboratory and Field Results in Low Light Post-detection Turbulence Compensation Using Self Referenced Speckle Holography,' *Digital Image Synthesis and Inverse Optics*, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 1351, A. F. Gmitro, P. S. Idell, and I. J. LaHaie, Eds. (1990), pp. 798–806).

The case $\beta=\frac{1}{2}$ corresponds to the Cauchy or Lorentzian density, and may be used to describe X-ray scattering in radiology (see F. C. Wagner et al., 'A Characterization of the Scatter Point Spread Function in Terms of Air Gaps,' *IEEE Transactions on Medical Imaging*, Vol. 7 (1988), pp. 337–344).

A wide variety of electron-optical devices obey Equation (5) with a value of β satisfying $\frac{1}{2}\leq\beta\leq 1$ (see C. B. Johnson, 'A Method for Characterizing Electro-Optical Device Modulation Transfer Functions,' *Photographic Science and Engineering*, Vol. 14 (1970), pp. 413–415; C. B. Johnson, 'Classification of Electron-Optical Device Modulation Transfer Function,' *Advances in Electronics and Electron Physics*, Vol. 33B . (1972), pp. 579–584; C. B. Johnson et al., 'High-Resolution Microchannel Plate Image Tube Development,' *Electron Image Tubes and Image Intensifiers II*, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 1449, I. F. Csorba, Ed. (1991), pp. 2–12).

Such devices constitute important elements of various biomedical imaging modalities, including image intensifier-video camera (II-TV) fluoroscopic systems (see S. Rudin et al., 'Improving Fluoroscopic Image Quality with Continuously Variable Zoom Magnification,' *Medical Physics*, Vol. 19 (1991), pp 972–977); radiographic film digitizers (see F. F. Yin et al., 'Measurement of the Presampling Transfer Function of Film Digitizers Using a Curve Fitting Technique,' *Medical Physics*, Vol. 17 (1990), pp. 962–966); radiographic selenium imaging plates (see P. J. Papin and H. K. Huang, 'A Prototype Amorphous Selenium Imaging Plate System for Digital Radiography,' *Medical Physics*, Vol. 14 (1987), pp. 322–329); computed radiography photostimulable phosphor systems (see S. Sanada et al., 'Comparison of Imaging Properties of a Computed Radiography System and Screen-Film Systems,' *Medical Physics*, Vol. 18 (1991), pp . 414–420; H. Fujita et al., 'A Simple Method for Determining the Modulation Transfer Function in Digital Radiography,' *IEEE Transactions on Medical Imaging*, Vol. 11 (1992), pp. 34–39); digital TV tomography systems (see M. Takahashi et al., 'Digital TV Tomography: Description and Physical Assessment,' *Medical Physics*, Vol. 17 (1990), pp. 681–685); and radiographic screen-film systems (see Y. Higashida et al., 'Dual-Film Cassette Technique for Studying the Effect of Radiographic Image Quality on Diagnostic Accuracy,' *Medical Physics*, Vol. 11 (1984), pp. 646–652; H. Kuhn and W. Knupfer, 'Imaging Characteristics of Different Mammographic Screens,' *Medical Physics*, Vol. 19 (1992), pp. 449–457).

Other important image tube/image intensifier applications include high definition television (HDTV) (see N. V. Rao, 'Development of a High-Resolution Camera Tube for 2000-Line TV System,' *Electron Tubes and Image Intensifiers*, Proceedings of the Society for Photo-Optical Instrumentation Engineers, Vol. 1243, I. P. Csorba, Ed. (1990), pp. 81–86; R. Barden et al., 'High Resolution MS-Type Saticon Pick-Up Tube with Optimized Electron-Optical Properties,' *Electron Tubes and Image Intensifiers II*, Proceedings of the Society for Photo-Optical Instrumentation Engineers, Vol. 1449, I. P. Csorba, Ed. (1991), pp. 136– 147), and night vision and undersea imaging systems (see K. A. Costello et al., 'Imagining GaAs Vacuum PhotoDiode with 40% Quantum Efficiency at 530 nm,' *Electron Tubes and Image Intensifiers*, Proceedings of the Society for Photo-Optical Instrumentation Engineers, Vol. 1243, I. P. Csorba, Ed. (1990), pp. 99–106.

In a typical imaging situation, several electron-optical devices may be cascaded together and used to image objects through a distorting medium such as the atmosphere or the ocean. The overall optical transfer function is then the product of finitely many functions of the type given by Equation (5), i.e.,

$$\tilde{p}(\xi,\eta)=e^{-J\sum_{i=1}^{J}\lambda_i^{(\xi^2+\eta^2)^{\beta_i}}},\quad \lambda_i\geq 0,\quad 0<\beta_i\leq 1. \qquad \text{Equation (5A)}$$

Each factor in this product represents a component of the total blur, and is described by Equation (5) with a particular value for λ and β. A method for determining λ_i and β_i for each component is discussed in C. B. Johnson, 'Classification of Electron-Optical Device Modulation Transfer Function,' Advances in Electronics and Electron Physics, Vol 33B (1972), pp. 579–584. Equation (5A) also describes cascaded electron-optical devices forming the imaging chain in many digital radiography systems. Frequency domain characterization of such systems is an important and ongoing task, as is evident from the above-cited references. In several industrial applications, the general functional form defined by Equation (5A) may be found to best-fit an empirically determined optical transfer function, by suitable choices of the parameters λ_i, β_i and J.

It is emphasized that while many imaging phenomena do not have optical transfer functions that can be well-described by Equation (5A), the latter nevertheless encompasses a significant set of imaging problems. We denote by G the class of optical transfer functions defined by Equation (5A). Note that Equation (5) is a special case of Equation (5A). The functions in G are infinitely divisible probability density functions.

Most current approaches to image restoration are based on linear system inverse filter theory, where the input is the degraded image, and the single output is an approximation to the ideal image. Using a priori constraints on the unknown ideal image, various regularization methods are employed in these approaches, in order to stabilize the deconvolution procedure in the

PE

Samsung Exhibit 1002, Page 140 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

presence of noise. Tikhonov regularization is one of the best-known examples of such procedures. This method is closely related to Wiener filtering. The Tikhonov regularization method is also known as constrained least squares. In its simplest form, Tikhonov restoration is based on the following a priori information concerning the unknown ideal image f(x,y) in Equation (1), and the noise n(x,y) in the degraded image g(x,y):

$$\|f\| \leq M, \quad \|n\| \leq \epsilon, \tag{6}$$

where $\|\ \|$ denotes the $L^2(R^2)$ norm. This leads to the following constrained restoration problem for Equation (3). Given ϵ, $M>0$, with $\epsilon/M<<1$, find all $f \in L^2(R^2)$ such that

$$\|Pf-g\| \leq \epsilon, \ \|f\| \leq M. \tag{7}$$

Let $\omega=\epsilon/M$. In this context, ω may be viewed as the L^2 noise-to-signal ratio. Tikhonov restoration provides a solution to Equation (7) by finding the function $f^T(x,y)$ which minimizes the Tikhonov functional:

$$\|Pf-g\|^2+\omega^2\|f\|^2, \tag{8}$$

over all f in L^2. Using the normal equations, $[P^*P+\omega^2 I]f^T=P^*g$, where P^* is the Hilbert space adjoint of P, together with Fourier transforms, it is easily shown that $f^T(x,y)$ satisfies $pf^T=g^T$, where $g^T(x,y)$ is defined in the Fourier domain as follows:

$$\hat{g}^T(\xi,\eta)=\hat{g}(\xi,\eta)/[1+\omega^2|\hat{p}(\xi,\eta)|^{-2}]. \tag{9}$$

In particular, Tikhonov restoration may be understood to solve Equation (3) with a modified right hand side g^T, obtained by filtering g in the frequency domain with a specific low-pass filter. The filter is a function of ω and the known optical transfer function $\hat{p}(\xi,\eta)$. The Tikhonov solution may be obtained by inverse Fourier transforming $\hat{f}^T(\xi,\eta)=\hat{g}^T(\xi,\eta)/\hat{p}(\xi,\eta)$ The a priori bound constraint on $\|f\|$ in Equation (6) prevents explosive growth of noise in the restoration process. However, that constraint is not strong enough to prevent substantial noise contamination from obscuring fine detail in the restored image.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a flow chart representation of the image restoration method of the present invention;

FIG. 2 shows a graphical description of the constraint in Equation (13);

FIG. 3 shows a contour map representation of an original image;

FIG. 4 shows a contour map representation of a blurred image corresponding to the original image of FIG. 3;

FIG. 5 shows a contour map representation of a restored image generated by applying the prior art Tikhonov restoration method to the blurred image of FIG. 4; and

FIG. 6 shows a contour map representation of a restored image generated by applying the restoration method of the present invention to the blurred image of FIG. 4.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, a flow chart representation of image restoration method 10 of the present invention is shown. It will be understood that the particular form of the optical transfer function in Equation (5A) plays no role in Tikhonov restoration. Indeed, Tikhonov regularization may be applied to a much wider class of image restoration problems. However, the fact that point spread functions in class G are infinitely divisible probability density functions plays an essential role in image restoration method 10. The blurred image g(x,y) is now viewed as the end result of a diffusion process applied to the desired ideal image f(x,y). This follows by recognizing Equation (5A) as the causal fundamental solution for the following parabolic initial value problem for the function w(x,y,t):

$$\frac{\partial w}{\partial t} = -\sum_{i=1}^{J} \gamma_i(-\Delta)^{\beta_i} w, \quad t>0, \quad x,y \in R^2 \qquad \text{Equation (10)}$$

$w(x,y,0)=f(x,y)$.

In Equation (10), $\gamma_i=\lambda_i(4\pi^2)^{-\beta_i}>0$, are the diffusion coefficients. If all $\beta_i=1$, Equation (10) is the classical heat equation. For $0<\beta_i<1$, Equation (10) represents a generalized diffusion process. Fourier analysis of Equation (10) shows that if Equation (3) holds with the kernel of P satisfying Equation (5A), then the blurred noiseless image $g_\epsilon(x,y)$ is the solution of Equation (10) at $t=1$,

$$g_\epsilon(x,y)=w(x,y,1) \tag{11}$$

For any t with $0 \leq t \leq 1$, Fourier analysis may be used to define the fractional powers p^t of the integral operator P when its kernel satisfies Equation (5A). The kernel of p^t is the optical transfer function given by Equation (5A) with λ_i replaced by $t\lambda_i$. Moreover, $p^t p^r=p^{t+r}$ for any $t,r \geq 0$ and $p^0=I$, where I is the identity operator on $L^2(R^2)$. The forward solution of Equation (10) is given by $w(x,y,t)=p^t f$. Consequently, for point spread functions in class G, image restoration is exactly equivalent to solving the partial differential equation problem in Equation (10) backwards in time, using the given degraded image g(x,y), rather than $g_\epsilon(x,y)$, as data at $t=1$. The desired ideal image is the corresponding solution at $t=0$,

$$f(x,y)=w(x,y,0) \tag{12}$$

For any t with $0<t<1$, w(x,y,t) constitutes a partial restoration, while w(x,y,0) is the full restoration. In the absence of noise, with data $g_\epsilon(x,y)$ in place of g(x,y), w(x,y,t) closely approximates f(x,y), provided t is sufficiently small, the λ_i are small, and f(x,y) is sufficiently well-behaved, i.e., high frequency components do not dominate the power spectrum of f(x,y). This is likely to be the case in the vast majority of images f(x,y) encountered in practical applications.

Thus, if $n(x,y)=0$ in Equation (2), then for some fixed small $s>0$, and a small constant δ, the inequality $\|w(.,s)-f\| \leq \delta$, holds. When $n(x,y) \neq 0$, such an inequality is not true because spurious high frequency noise artifacts can seriously contaminate the restoration process as $t \downarrow 0$. However, in the presence of noise, such an inequality may be imposed as an additional constraint. In this case, noise artifacts in the restored image may be expected to be substantially reduced.

Since $\|n\| \leq \epsilon$, it is convenient to put $\delta=K\epsilon$ for some small constant $K>0$. With $w(x,y,s)=P^s f$, this new constraint may then be expressed as follows: For fixed

PE

Samsung Exhibit 1002, Page 141 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

small $s>0$ and small constant $K>0$, where both s and K are determined on the basis of a priori information,

$$\| (I-P^s)f \| \leq K\epsilon. \quad (13)$$

Referring now to FIG. 2, there is shown graphical representation **30** of the constraint in Equation (13). The desired ideal image f(x,y) corresponds to w(x,y,0), the data at time $t=0$ in the partial differential equation problem, Equation (10). This corresponds to line **38** of representation **30**. It will be understood that line **38** corresponds to If of Equation (13). The blurred noiseless image, $g_e(x,y)=Pf=w(x,y,1)$, is the corresponding solution at time $t=1$ as shown at line **32**. At any intermediate time t with $0<t<1$, $w(x,y,t)=p^t f$ is a partial restoration, becoming the full restoration f, as $t \downarrow 0$. An example is shown at line **34** wherein $t=0.7$.

If $g_e(x,y)$ could be used as data at $t=1$ in the time-reversed problem, then for small $s>0$, $w(x,y,s)=P^s f$ would be a good approximation to f, i.e., $\| f-P^s f \|$ would be a small quantity. An example $t=s$ for a small value of s is shown at line **36**. In reality, one must use the noisy image g(x,y) as data at $t=1$. In that case, high frequency noise amplification in the Tikhonov restoration process causes $w(x,y,s)=P^s f$ to differ appreciably from f. In the present invention, the requirement that $\| f-P^s f \|$ be small is enforced as an explicit additional constraint, in Equation (13). An example with the explicit choice $s=0.01$ is indicated as reference numeral **40** in FIG. 2. This explicit requirement results in greatly reduced noise amplification.

Returning to the original problem, Equation (3), with the optical transfer function given by Equation (5A), a new constrained problem may be formulated. Given ϵ, M, K, $s>0$, with $s<1$ and $(\epsilon/M)<1$, find all $f \in L^2(R2)$ such that

$$\| Pf-g \| \leq \epsilon, \ \| f \| \leq M, \ \| (I-P^s)f \| \leq K\epsilon. \quad (14)$$

In an analogy with Tikhonov restoration, a solution to the new constrained problem may be determined by finding that function $f^\epsilon(x,y)$ which minimizes the functional of the present invention:

$$\| Pf-g \|^2 + \| (\epsilon/M)f + (1/K)(I-P^s)f \|^2, \quad (15)$$

over all f in L^2. With $\omega=\epsilon/M$, $\mu=1/(1+K\omega)$ and $B=I-\mu P^s$, the functional of the present invention may be written more compactly as

$$\| Pf-g \|^2 + (1/\mu K)^2 \| Bf \|^2. \quad (16)$$

As before, the normal equations $[P^*P+(1/\mu K)^2 B^*B]f^\epsilon=P^*g$, combined with Fourier analysis, show that $Pf^\epsilon=g^\epsilon$, with $g^\epsilon(x,y)$ defined as follows in the Fourier domain:

$$\hat{g}^\epsilon(\xi,\eta)=\hat{g}(\xi,\eta)/[1+(1/\mu K)^2|\hat{p}(\xi,\eta)|^{-2}(1-\mu\hat{p}(\xi,\eta)^s)^2]. \quad (17)$$

Image restoration method **10** of the present invention is performed by inverse Fourier transforming $\hat{f}^\epsilon(\xi,\eta)=\hat{g}^\epsilon(\xi,\eta)/\hat{p}(\xi,\eta)$. Note that with $s=0$, the new constraint set forth in Equation (13) is automatically satisfied. In that case, the inventive functional in Equation (15) reduces to the Tikhonov functional in Equation (8). At the same time, since $\omega=(1-\mu)/\mu K$, the inventive filter in Equation (17) reduces to the Tikhonov filter in Equation (9). Thus, $f^\epsilon(x,y)=f^T(x,y)$ if $s=0$. However, $f^\epsilon(x,y) \neq f^T(x,y)$ when $s>0$, as the two filters are then markedly different in their behavior at intermediate and high frequencies.

It will be understood that restoration procedures for point spread functions in class G may be mathematically compared. Furthermore, for point spread functions in class G, the fact that the new constraint in Equation (13) leads to a better restoration than does the constraint in Equation (6), can be proved mathematically. The improvement may be shown on the basis of error bounds for the restoration, as a function of the L^2 noise level ϵ in the degraded image g(x,y). It is useful in this proof to estimate the error in the partial restorations, $p^t f$ at any value of t with $0 \leq t \leq 1$. Consider first the Tikhonov restoration of the prior art. Let f(x,y) be any solution of the constrained restoration problem, Equation (7), with optical transfer function given by Equation (5A), and let $f^T(x,y)$ be the Tikhonov restoration. Then,

$$\| P^t(f-f^T) \| \leq (1+\sqrt{2})\, M^{1-t}\epsilon^t, \quad 0 \leq t \leq 1. \quad \text{Equation (18)}$$

The inequality in Equation (18) is obtained using logarithmic convexity theorems for the related diffusion equation, Equation (10), and is understood by those skilled in the art to be best-possible. See Theorem 2 in Alfred S. Carasso et al., 'Digital Removal of Random Media Image Degradations by Solving the Diffusion Equation Backwards in Time,' *SIAM Journal on Numerical Analysis*, Vol. 15, (1978), pp. 344–367. Thus, a stronger error bound in the L^2 norm cannot be obtained for the constrained restoration problem in Equation (7). The behavior of the Tikhonov error as $t \downarrow 0$ is of major concern. If $\epsilon=10^{-4}$ in Equation (6), then $\epsilon^t=10^{-0.04} \simeq 0.912$ at $t=0.01$. The inequality in Equation (18) implies a systematic loss of significant information as $t \downarrow 0$. In particular, at $t=0$, we have $\| f-f^T \| \leq (1+\sqrt{2})M$. Thus, although the difference between f and f^T is bounded, there is no guarantee that noise artifacts in the Tikhonov restoration are necessarily small.

However, in image restoration process **10** of the present invention, the following result may be proven. Let f(x,y) be any solution of the new constrained restoration problem, Equation (14), with an optical transfer function given by Equation (5A) and let $f^\epsilon(x,y)$ be the restoration of an image according to image restoration method **10**. Then,

$$\| P^t(f-f^\epsilon) \| \leq 2\sqrt{5}\, \Gamma^{1-t}\epsilon, \quad 0 \leq t \leq 1, \quad \text{Equation (19)}$$

where Γ is the unique solution of the transcendental equation $z=K+z^{1-s}$ and $1<\Gamma<<M/\epsilon$, provided $s>>s^*=K\epsilon/(M \ \mathrm{Log}(M/\epsilon))$.

The significant difference between the results of Equation (18) and the results of Equation (19) is that ϵ rather than ϵ^t appears on the right hand side of the inequality in Equation (19). This is the result of the additional constraint, Equation (13), which greatly reduces the possibility that spurious high frequency noise components in the data g(x,y) will contaminate the restoration near $t=0$. Thus, with $M=10$, $\epsilon=10^{-4}$, $s=0.01$, and $K=3$, it will be understood that $\Gamma \simeq 72$ and that $\| f-f^\epsilon \| \leq 0.0322$. However, it will also be understood that $\| f-f^T \| \leq 24.2$. In this example, the error bound in the restoration according to image restoration method **10** is approximately seven hundred fifty times

PE

Samsung Exhibit 1002, Page 142 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

smaller than that for the Tikhonov restoration of the prior art, provided the desired image satisfies Equation (13).

Computational implementation of image restoration method **10** will be understood by those skilled as follows. The essential idea in the implementation of image restoration method **10** is the use of the discrete Fourier transform to mimic the operations described above in the continuous Fourier transform domain. These computations are fast because of the use of the fast fourier transform to implement discrete Fourier transform operations. The close connection between the continuous and discrete Fourier transforms, under appropriate conditions, is taught in detail in E. O. Brigham, The Fast Fourier Transform, Prentice-Hall, Inc., Englewood Cliffs, N.J., (1974).

Method **10** of the present invention may be performed upon the degraded image $g(x_j,y_k)$ expressed as a digitized N×N array, where N is a power of 2, and where j,k are integers with $0 \leqq j, k \leqq N-1$. With l the width of the image, let $\Delta x=\Delta y=1/N$ be the sampling interval, so that $x_j=j\Delta x$, $y_k=k\Delta y$. The actual image transformed by image restoration method **10** is assumed to be surrounded by a border of zeroes of sufficient width to eliminate wrap-around errors in discrete convolutions. The N×N array includes the actual image and its border. The optical transfer function for the imaging process is assumed given by Equation (5A) with known λ_i and β_i. Likewise, the positive constants ϵ, M, K, and s in Equation (14) are assumed to be known on the basis of a priori information.

Referring again to FIG. **1**, reference is made to the identifying numerals of the representation of image restoration method **10** of the present invention. As shown in centering block **12** of image restoration method **10**, the first step is to center the origin in the frequency array. This may be done by forming:

$$g(x_j,y_k)=(-1)^{j+k}g(x_j,y_k),\ 0 \leqq j,k \leqq N-1$$

In forward transform block **14** a forward two-dimensional fast Fourier transform is performed upon $g(x_j,y_k)$ as determined in centering block **12**. The fast fourier transform of block **14** may be performed by forming:

$$G(\xi_m,\eta_n)=\Delta x\Delta y\Sigma_{j=0}^{N-1}\Sigma_{k=0}^{N-1}g(x_j,y_k)\exp\{-2\pi i(mj+nk)/N\},$$

where $0 \leqq m,n \leqq N-1$ and $\xi_m=(m-N/2)/l, \eta_n=(n-N/2)/l$, $l=N\Delta x$.

The inventive filter of image restoration method **10** is then constructed in Fourier space as represented by filter construction block **16**. This filter is constructed with known λ_i, β_i, ϵ, M, K, $s>0$. In order to construct the novel filter of image restoration method **10** let $\omega=\epsilon/M$, $\mu=1/(1+K\omega)$, and let

$$p_{mn}=\exp\{-\Sigma_{i=1}^{I}\lambda_i(\xi_m^2+\eta_n^2)^{\beta_i}\},\ \text{for } 0 \leqq m, n \leqq N-1.$$

Then form:

$$G(\xi_m,\eta_n)=p_{mn}^2G(\xi_m,\eta_n)/\{p_{mn}^2+(1/\mu K)^2(1-\mu p_{mn}^s)^2\},$$

where $0 \leqq m, n \leqq N-1$.

In partial restoration block **18** of image restoration method **10**, a partial restoration at t, $0 \leqq t \leqq 1$, is constructed by forming:

$$G(\xi_m,\eta_n)=p_{mn}^{t-1}G(\xi_m,\eta_n),$$

where $0 \leqq m, n \leqq N-1$.

In inverse transform block **20** an inverse two-dimensional fast Fourier transform is performed upon $G(\xi_m,\eta_n)$ which was constructed in restoration block **18**. The inverse transform shown in inverse transform block **20** may be obtained by forming

$$f(x_j,y_k,t)=l^{-2}\Sigma_{m=0}^{N-1}\Sigma_{n=0}^{N-1}G(\xi_m,\eta_n)\exp\{2\pi i(mj+nk)/N\},$$

where $0 \leqq j, k \leqq N-1$. The centering of centering block **12** is then undone in block **22** of image restoration method **10** by forming

$$f(x_j,y_k,t)=(-1)^{j+k}f(x_j,y_k,t),$$

where $0 \leqq j,k \leqq N-1$. Execution of image restoration method **10** may then return to partial restoration block **18** for any other desired value of t.

The result of performing the operations of block **22** is a partial restoration of an image according to image restoration method **10** at the preselected value of t. The user of image restoration method **10** may dispense with partial restoration and proceed directly to full restoration by setting t=0 when restoration block **18** is executed.

The scaling of the fast Fourier transforms in blocks **14**, **20** was chosen so as to correspond to continuous Fourier transform operations in a manner well known to those skilled in the art. However, the factor $\Delta x\Delta y$ may be omitted from the forward transform block **14** provided l^{-2} is replaced with N^{-2} in reverse transform block **20**. It is straightforward to modify the procedure so as to handle rectangular $N_1 \times N_2$ images; see e.g., R. C. Gonzalez and P. Wintz, Digital Signal Processing, Second Edition, Addison-Wesley, Reading, Mass. (1987).

The system of method **10** may be implemented with tentative values of some of the parameters λ_i, β_i, ϵ, M, K, s. Image restoration method **10** may be repeated with adjusted values. A sequence of partial restorations as $t \downarrow 0$ is a useful option in that context because noise and ringing usually increase as $t \downarrow 0$. Thus, by performing the restoration in 'slow-motion,' an experienced user may more easily determine the influence of various parameter values and more quickly arrive at corrected values. Tikhonov restoration is obtained by setting s=0 in filter construction block **16**.

Image restoration method **10** may be experimentally verified in the following manner. In a simulation of blurring caused by X-ray scattering, an undegraded phantom image $f(x_j,y_k)$ was artificially blurred by convolution with an optical transfer function given by Equation (5). The image, shown in FIG. **3**, consisted of a five hundred twelve by five hundred twelve array, quantized at eight bits per pixel. Blurring was accomplished in the Fourier domain, by multiplying $F(\xi_m,\eta_n)$, obtained as in forward transform block **14** above by $q_{mn}=\exp\{-\alpha([l\xi_m]^2+[l\eta_n]^2)^\beta\}$, where $\alpha=0.075$ and $\beta=0.5$. An inverse Fast Fourier Transform, followed by the operations of block **22**, produces the blurred substantially noiseless image $g_e(x_j,y_k)$ in Equation (2).

Multiplicative noise was simulated by adding 0.1% uniformly distributed random noise to g_e. Thus, $n(x_j,y_k)=0.001v_{jk}g_e(x_j,y_k)$, where v_{jk} is a random num-

PE

Samsung Exhibit 1002, Page 143 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

ber drawn from a uniform distribution in the range $[-1,1]$. This yields $\|n\| \leqq \epsilon \leqq 0.001 \|g_\epsilon\|$. Further, since $\|g_\epsilon\| \leqq \|f\|$, we find $\omega = \epsilon \|f\|^{-1} \leqq 0.001$. The value $g(x_j,y_k) = g_\epsilon(x_j,y_k) + n(x_j,y_k)$ is referred to as the blurred image. The blurred image is shown in FIG. 4.

Tikhonov restoration was applied to the blurred image using $\omega = 0.001$. The full restoration was contaminated by noise artifacts that made it impossible to visualize the image. See FIG. 5. A sequence of partial Tikhonov restorations was obtained at $t=0.35$, $t=0.25$, $t=0.15$, $t=0.005$, in addition to the full restoration at $t=0$. It will be understood that the partial restorations became sharper and noisier as $t \downarrow 0$. One may use the evolution as $t \downarrow 0$ to identify features that become obscured by noise at $t=0$. The growing influence of noise as $t \downarrow 0$ is a reflection of the $O(\epsilon^0)$ error bound characteristic of Tikhonov regularization as shown in Equation (18).

Image restoration method **10** was applied to the same blurred image, using $\omega = 0.001$, $K=3$, and $s=0.01$. In view of the conservatively small value for s, the assumption that f satisfies Equation (13) is sound. Indeed, the full restoration is now found to be relatively free from noise, and to provide substantial improvement over the full prior art Tikhonov restoration. See FIG. 6. This is in accordance with Equation (19) in Theorem 2. The sequence of partial restorations at $t=0.35$, $t=0.25$, $t=0.15$, and $t=0.05$ in image restoration method **10** is likewise found to be better behaved than the corresponding prior art Tikhonov sequence.

The above experiment illustrates the preceding theoretical developments set forth with respect to image restoration method **10**. At the same time, the experiment demonstrates the soundness of the computational implementation. Thus, image restoration method **10** may be reduced to practice as shown, for point spread functions in class G.

It is believed that image restoration method **10** may be advantageously applied in biomedical imaging, night vision systems, undersea imaging, imaging through the atmosphere, remote sensing, high definition television, as well as several other scientific and industrial applications where electron optics and class G point spread functions play a major role. Two key ideas make image restoration method **10** useful as a diagnostic tool in these and other fields. First, the substantial qualitative improvement in the full restoration that results from the additional constraint in Equation (13). Second, the display of the evolution of the restoration as t approaches 0. Together, these factors offer the possibility of greatly improved diagnostic capabilities, and provide a useful addition to current image restoration technology.

It is believed that method **10** is useful in this manner because it is based on mathematical tools which are different from prior art restoration algorithms. In contrast to the input-output linear system theory familiar to researchers with backgrounds in electrical engineering or computer science, and exemplified by Tikhonov restoration or Wiener filtering, method **10** is based upon partial differential equations, semi-group theory, and the mathematics of diffusion phenomena. The two key ideas mentioned in the preceding paragraph stem from this particular mathematical basis.

It will be understood that method **10** may be implemented on a general purpose computer programmed to perform the operations of blocks **12–22**. Alternately method **10** may be performed using dedicated conventional hardware to perform such conventional operations as the transforms of blocks **14**, **20**. Additionally it will be understood by those skilled in the art that dedicated hardware may be provided, using conventional synthesis and fabrication techniques, for performing other operations within method **10**.

I claim:

1. An image restoration method in a system having an image sensor and a digitizer, comprising the steps of:

(a) providing an imaging system described by an integral operator P;

(b) transmitting an ideal image f(x,y) through an image blurring and degrading transmission medium to provide a degraded image g(x,y) wherein the degraded image g(x,y) may be represented as $Pf=g$;

(c) receiving said degraded image g(x,y) from said transmission medium by said image sensor;

(d) digitizing said degraded image g(x,y) by said digitizer;

(e) transforming said degraded image g(x,y) to provide a time modified representation $w(x,y,t)=P^t f$ wherein $w(x,y,0)=P^0 f$ represents the ideal image f(x,y) at time $t=0$ prior to the operation of the integral operator P upon f and $w(x,y,1)=Pf=g$ represents the degraded image g(x,y) when the image is received by said image sensor;

(f) requiring the magnitude of the difference between the ideal image f and a blurred version of f to be less than a preassigned tolerance value by minimizing $\|f-P^s f\|$ wherein $P^s f$ represents an image at time $t=s$ as s approaches 0;

(g) determining a plurality of values of w(x,y,t) in accordance with said minimizing;

(h) adjusting said image in accordance with said determined plurality of values to provide a plurality of adjusted images;

(i) selecting an adjusted image of said plurality of adjusted images; and

(j) displaying said selected image.

2. The image restoration method of claim **1**, comprising the further steps of:

displaying a sequence of partially restored images represented as w(x,y,t) for a plurality of values of t as t approaches 0; and

determining an optimum image of said plurality of partially restored images in accordance with said displayed sequence.

3. The image restoration method of claim **1**, wherein said constraining comprises the step of imposing the constraint $\|f-P^s f\| \leqq K\epsilon$, where K is a constant and ϵ is representative of at least one image restoration parameter.

4. The image restoration method of claim **3**, comprising the further step of imposing the constraint $\|Pf-g\| \leq \epsilon$, wherein ϵ is representative of at least one image restoration parameter.

5. The image restoration method of claim **4**, comprising the further step of imposing the constraint $\|f\| \leqq M$, wherein $M >> \epsilon$.

6. The image restoration method of claim **5**, comprising the further step of determining a restored image f(x,y) which minimizes the quantity

$$\{\|Pf-g\|^2 + \|(\epsilon/M)f+(1/K)(f-P^s f)\|^2\}.$$

7. The image restoration method of claim **6**, wherein a plurality of images $w(x,y,t)=P^t f$ are determined for a corresponding plurality of values of the time t.

PE

Samsung Exhibit 1002, Page 144 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

8. The image restoration method of claim 7, wherein said plurality of values of time comprises a sequence of progressively smaller values.

9. The image restoration method of claim 8, wherein the values of said restoration parameters are adjusted in accordance with said plurality of images for successively smaller values of time.

10. The image restoration method of claim 7, wherein each image $w(x,y,t)=P^t f$ is determined in the Fourier Transform domain by $\hat{w}(\xi,\eta,t)=\hat{p}(\xi,\eta)^t\hat{f}(\xi,\eta)$, wherein $\hat{w}(\xi,\eta,t)$ is the Fourier transform of $w(x,y,t)$, $\hat{p}(\xi,\eta)$ is an optical transfer function of said system, and $\hat{f}(\xi,\eta)$ is the Fourier transform of $f(x,y)$.

11. The image restoration method of claim 6, wherein said restored image $f(x,y)$ is determined through algebraic operations performed in the Fourier Transform domain.

12. The image restoration method of claim 1, wherein $\hat{f}(\xi,\eta)$, the Fourier Transform of $f(x,y)$, is determined by $\hat{f}(\xi,\eta)=\hat{g}(\xi,\eta)/\{\hat{p}(\xi,\eta)[1+(\mu K|\hat{p}(\xi,\eta)|)^{-2}(1-\mu\hat{p}(\xi,\eta)^s)^2]\}$, wherein $\hat{g}(\xi,\eta)$ is the Fourier Transform of the degraded image $g(x,y)$, $\hat{p}(\xi,\eta)$ is an optical transfer function of said system, ϵ is representative of at least one constant, K is a constant, $\mu=(1+K\epsilon/M)^{-1}$, $M>>\epsilon$ and s is a substantially small value of time.

* * * * *

PE

United States Patent [19]

Dobbins, III

[11] **Patent Number: 4,903,204**

[45] **Date of Patent: Feb. 20, 1990**

[54] **MATRIX INVERSION TOMOSYNTHESIS IMPROVEMENTS IN LONGITUDINAL X-RAY SLICE IMAGING**

[75] Inventor: **James T. Dobbins, III**, Durham, N.C.

[73] Assignee: **Duke University**, Durham, N.C.

[21] Appl. No.: **126,793**

[22] Filed: **Dec. 1, 1987**

[51] **Int. Cl.**[4] **G06F 15/42**

[52] **U.S. Cl.** **364/413.24**; 364/413.13; 378/901

[58] **Field of Search** 364/414, 413.13, 413.21; 378/901

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,499,146	3/1970	Richards .	
4,147,936	4/1979	Eickel .	
4,506,327	3/1985	Tam .	
4,598,369	7/1986	Wang et al. .	

OTHER PUBLICATIONS

IEEE Transactions on Nuclear Sci., vol. NS-23, No. 1, Feb. 1976, "Axial Tomography and Three Dimensional Image Reconstruction", L. T. Chang, B. Macdonald & V. Perez---Mendez, pp. 568-572.

Phys. Med. Biol. 1978, vol. 23, No. 2, 235-244, "Object Reconstruction from Focused Positron Tomograms," D. Townsend, C. Piney & A. Jeavons.

"Tomosynthesis: A Three---Dimensional Radiographic Imaging Technique", David G. Grant, IEEE Transactions on Biomedical Engineering, vol., BMF-19, No. 1, Jan. 1972, pp. 20-28.

"Selective Plane Removal in Limited Angle Tomographic Imaging", D. N. Ghosh, Roy, R. A. Kruger, B. Yih, & P. Del Rio, Med. Phys. 12(1) Jan./Feb. 1985, pp. 65-70.

IEEE Transactions on Biomedical Engineering, vol. BME-27, No. 11, May 1980, "Ectomography---A New Radiographic Reconstruction Method---1, Theory and Error Estimates", Hans E. Knutsson, Paul Edholm, Goesta H. Granlund, & Christer U. Petersson, pp. 640-648.

IEEE Trans. on Nuclear Sci., vol. NS-25, Feb. 1978, "Three Dimensional in Planar Positron Cameras Using Fourier Deconvolution of Generalized Tomographs",

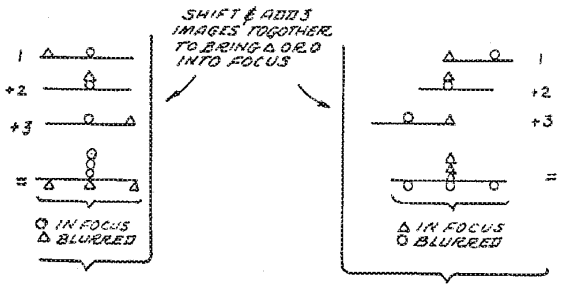
(List continued on next page.)

Primary Examiner---Jerry Smith
Assistant Examiner---Gail O. Hughes
Attorney, Agent, or Firm---Cushman, Darby & Cushman

[57] **ABSTRACT**

The present invention describes improvements to digital tomosynethesis, whereby a plurality of x-ray projection images are shifted and summed to form a matrix of tomographs at variable plane heights. Prior to tomosynthesis, the projection images are weighted by a weighting function which falls off towards shallower angles of the x-ray tube during acquisition, in order to improve the reconstructability of between-plane structures. A matrix of blurring functions is then determined, describing the blurring of structures in all planes for every tomosynthesis reconstruction. Actual patient structures are then reconstructed by solving a matrix equation containing the matrix of tomosynthesized images and the matrix of blurring functions. The patient structure images are then improved by a hybrid correction routine which combines low spatial frequencies from a wide swing of the x-ray source with high and mid spatial frequencies from a narrow swing of the x-ray source. The data, once hybrid corrected, is further corrected using an interative technique to improve the reconstruction of low spatial frequencies. This iterative technique corrects each column of each image by sequentially determining if errant frequency components are present at the edge of the images where the patient is not present. If errant frequency components are found, they are subtracted from the entire image column. Lastly, a DC level correction is performed which corrects for errant zero frequency components by adding a constant value to each image column to force the edge of each image to zero. The data is finally displayed on a display monitor. An interleaving technique is used to vary reconstructed plane heights in order to permit improved interplane resolution.

94 Claims, 10 Drawing Sheets



PE

OTHER PUBLICATIONS

K. S. Tam, G. Chu. V. Perez—Mendez and C. B. Lim, Lawrence Berkeley Laboratory, pp. 152–159.
"Three—Dimensional Imaging in the Positron Camera Using Fourier Techniques", pp. 245–265, Gilbert Chu & Kwok—Cheong Tam.
"Theory of Imaging with a Very Limited Number of Projections", Jorge Llacer, pp. 596–602.
"Tomographic Image Reconstruction by Eigenvector Decomposition: Its Limitations and Areas of Applicability", Jorge Llacer, pp. 34–42.
H. H. Barrett & W. Swindell, Radiological Imaging, vol. 2, Academic Press, New York, 1981, pp. 549–553.
"Three Dimensional Image Reconstruction with Large—Area Positron Cameras", Digest of the 4th International Conf. on Med. Physics, Ottawa, Canada, 1976, (one page).
"Visual Simulation and Image Realism II", K. S. L. Setty, Scientific Library, Aug. 27–28, 1981, pp. 52–66.

PE

FIG. 1
(PRIOR ART)

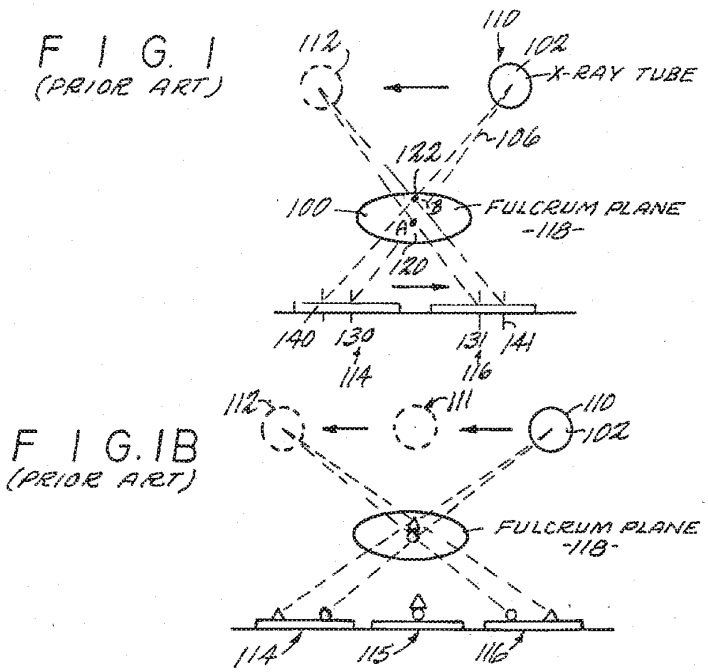


FIG. 1B
(PRIOR ART)

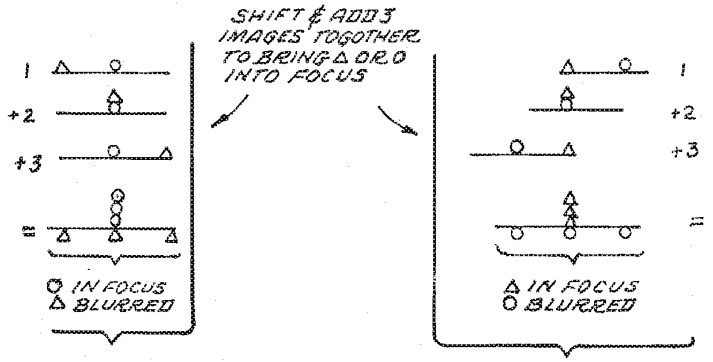
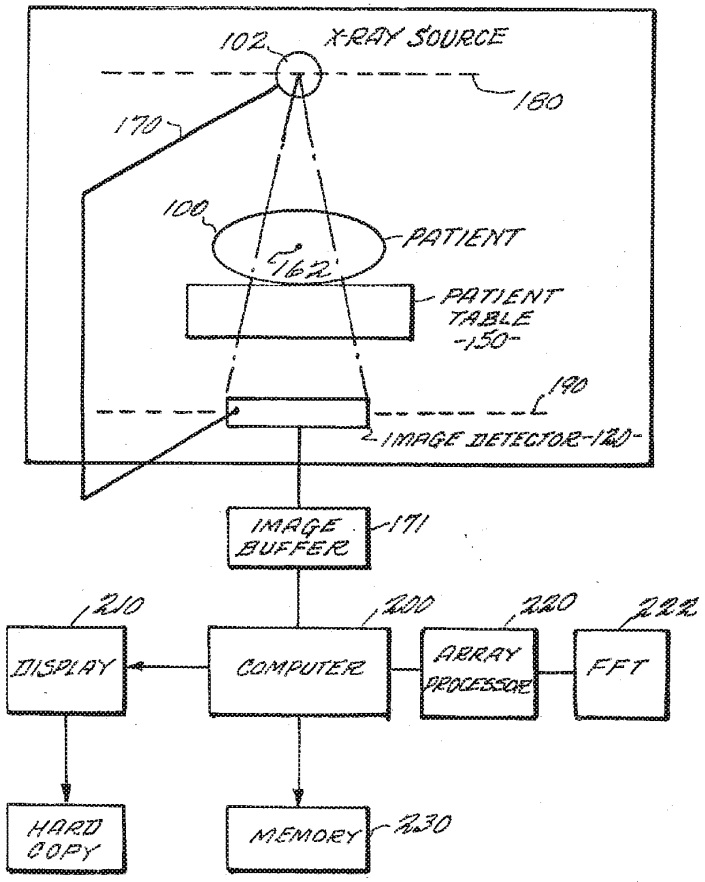


FIG. 1C FIG. 1D

PE


102
X-RAY SOURCE
180
170
100
PATIENT
162
PATIENT TABLE -150-
190
IMAGE DETECTOR-120-
IMAGE BUFFER
171
210
200
220
222
DISPLAY
COMPUTER
ARRAY PROCESSOR
FFT
HARD COPY
MEMORY
230

F I G. 2

PE

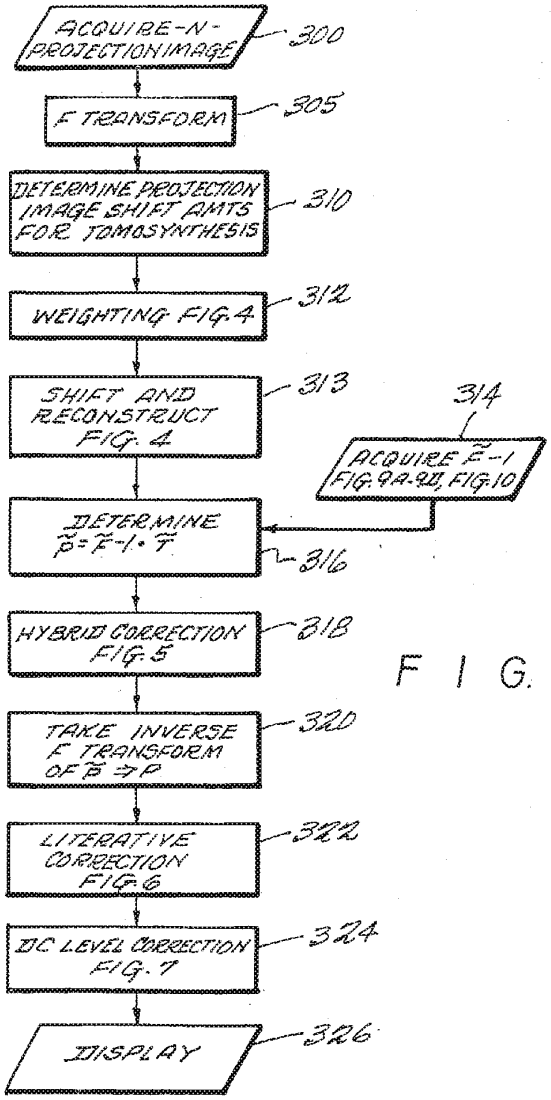
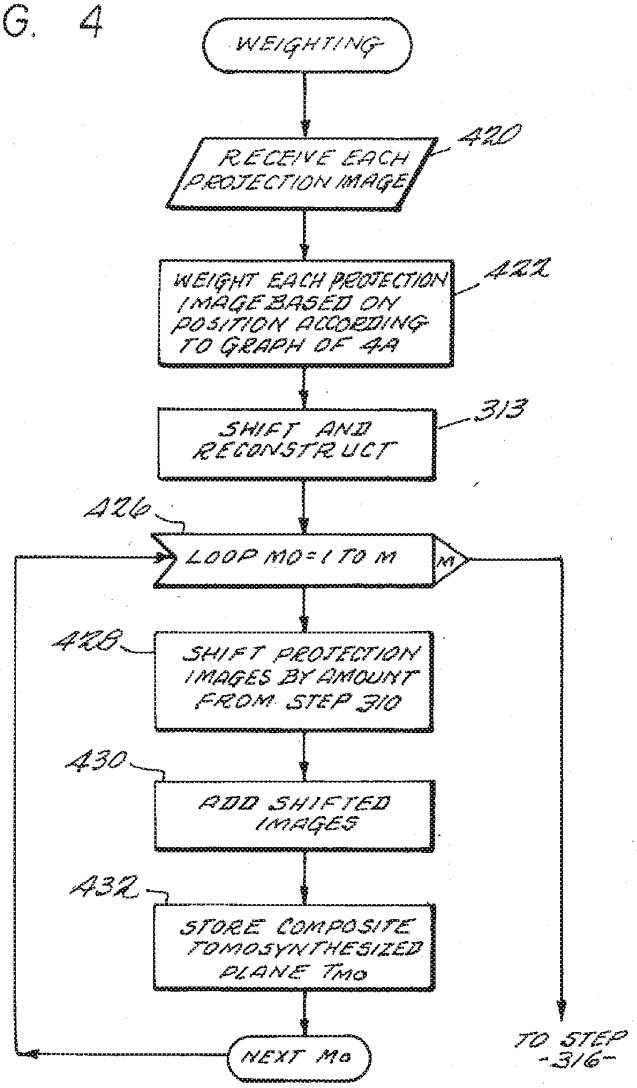

ACQUIRE-N-PROJECTION IMAGE
300
F TRANSFORM
305
DETERMINE PROJECTION IMAGE SHIFT AMTS FOR TOMOSYNTHESIS
310
WEIGHTING FIG. 4
312
SHIFT AND RECONSTRUCT FIG. 4
313
314
ACQUIRE F-1 FIG. 9A-9D, FIG. 10
DETERMINE P=F-1 • F
316
HYBRID CORRECTION FIG. 5
318
TAKE INVERSE F TRANSFORM OF P → P
320
ITERATIVE CORRECTION FIG. 6
322
DC LEVEL CORRECTION FIG. 7
324
DISPLAY
326

FIG. 3

PE

FIG. 4


WEIGHTING
RECEIVE EACH PROJECTION IMAGE
420
WEIGHT EACH PROJECTION IMAGE BASED ON POSITION ACCORDING TO GRAPH OF 4A
422
SHIFT AND RECONSTRUCT
313
426
LOOP MO=1 TO M
M
428
SHIFT PROJECTION IMAGES BY AMOUNT FROM STEP 310
430
ADD SHIFTED IMAGES
432
STORE COMPOSITE TOMOSYNTHESIZED PLANE TMO
NEXT MO
TO STEP -316-

PE

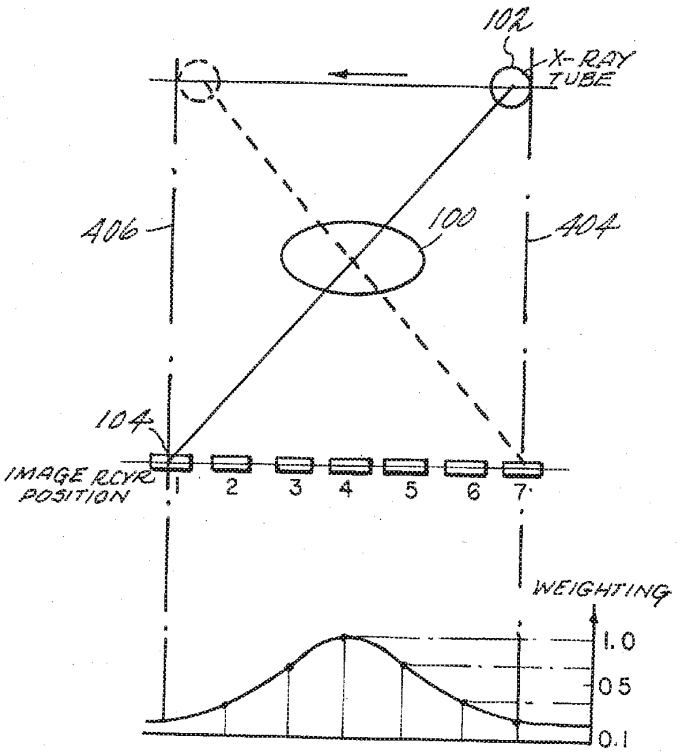

102
X-RAY TUBE
406
100
404
104
IMAGE RCVR POSITION
1
2
3
4
5
6
7
WEIGHTING
1.0
0.5
0.1

FIG. 4A

PE

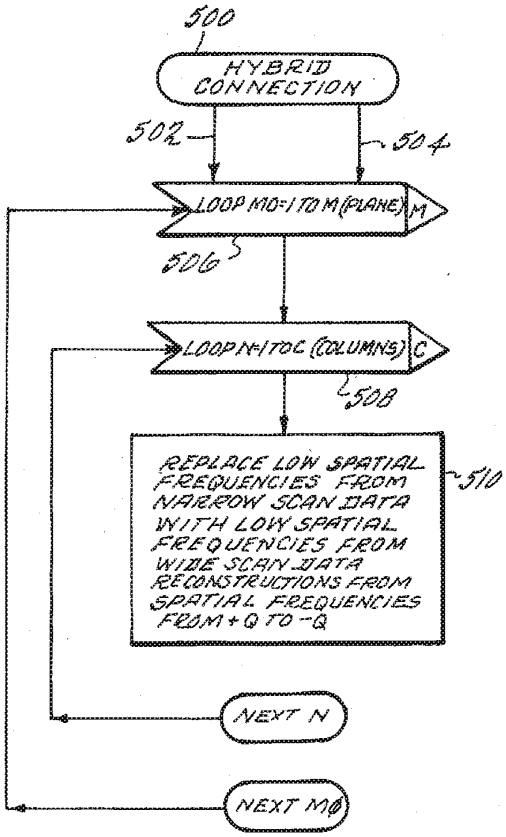
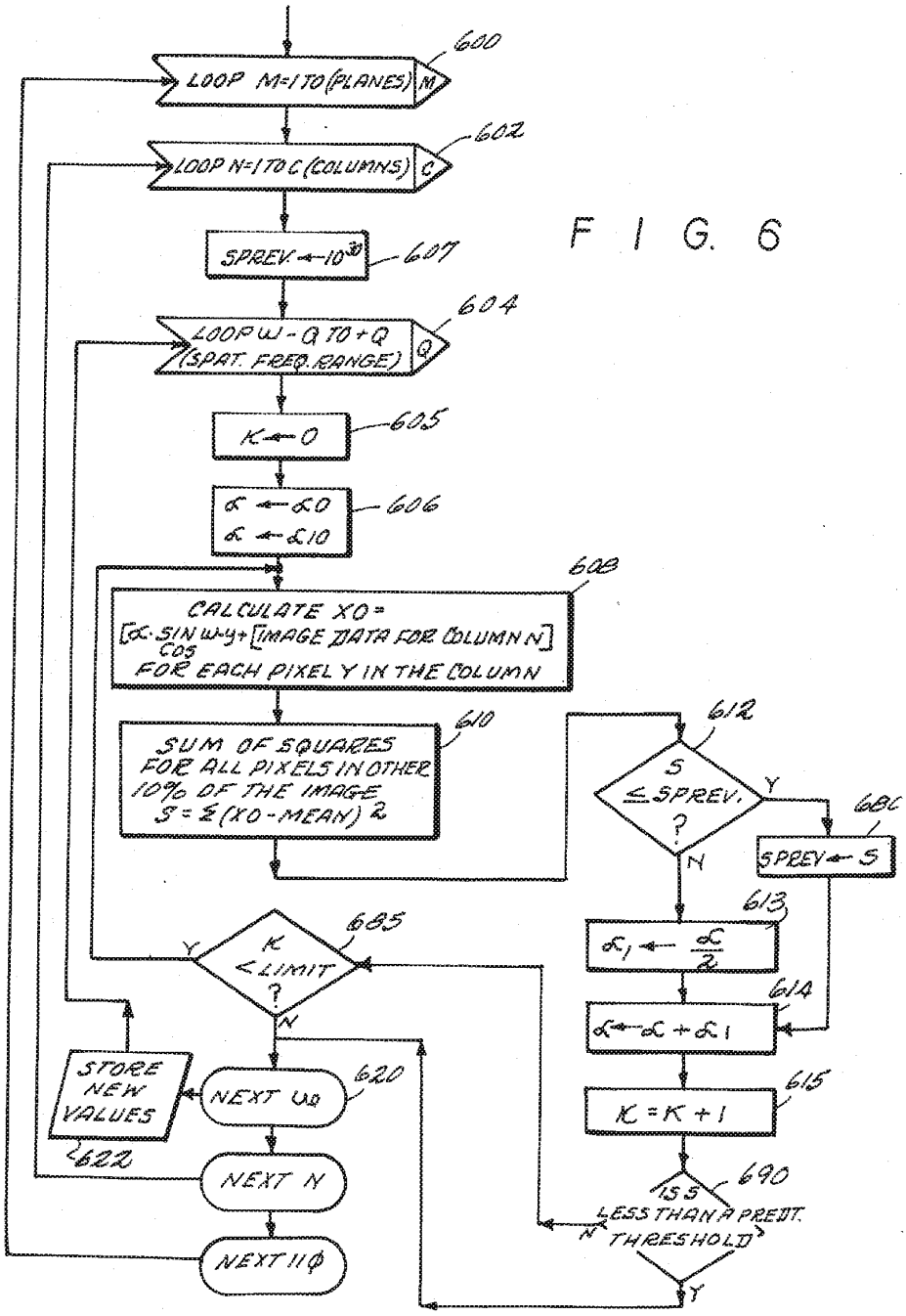

500
HYBRID CONNECTION
502
504
LOOP M0=1 TO M (PLANE) M
506
LOOP N=1 TO C (COLUMNS) C
508
REPLACE LOW SPATIAL FREQUENCIES FROM NARROW SCAN DATA WITH LOW SPATIAL FREQUENCIES FROM WIDE SCAN DATA RECONSTRUCTIONS FROM SPATIAL FREQUENCIES FROM +Q TO -Q
510
NEXT N
NEXT M0

FIG. 5

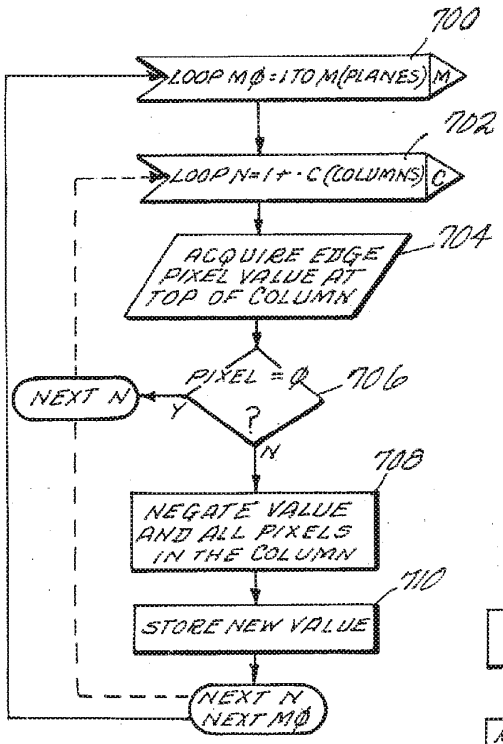
PE


600
LOOP M=1 TO (PLANES) M
602
LOOP N=1 TO C (COLUMNS) C
SPREV ← 10^30
607
604
LOOP W = Q TO + Q (SPAT. FREQ. RANGE) Q
K ← 0
605
α ← α0
α ← α10
606
608
CALCULATE XO = [α · SIN wy + [IMAGE DATA FOR COLUMN N]
COS
FOR EACH PIXEL Y IN THE COLUMN
610
SUM OF SQUARES FOR ALL PIXELS IN OTHER 10% OF THE IMAGE
S = Σ (XO - MEAN) 2
612
S ≤ SPREV. ?
Y
N
680
SPREV ← S
613
α1 ← α/2
614
α ← α + α1
615
K = K + 1
690
IS S LESS THAN A PREDT. THRESHOLD
N
Y
685
K < LIMIT ?
Y
N
620
NEXT W
NEXT N
NEXT M
STORE NEW VALUES
622

F I G. 6

PE

FIG. 7


700
LOOP MØ = 1 TO M(PLANES) M
702
LOOP N = 1 TO C (COLUMNS) C
704
ACQUIRE EDGE PIXEL VALUE AT TOP OF COLUMN
706
PIXEL = Ø ?
Y
N
NEXT N
708
NEGATE VALUE AND ALL PIXELS IN THE COLUMN
710
STORE NEW VALUE
NEXT N
NEXT MØ

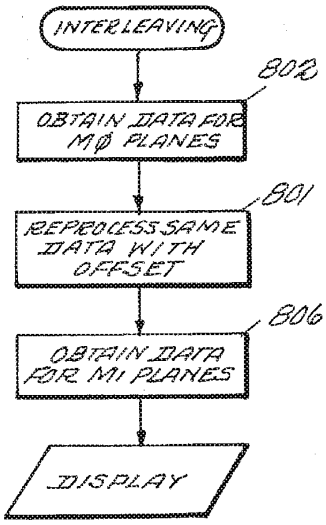

INTERLEAVING
802
OBTAIN DATA FOR MØ PLANES
801
REPROCESS SAME DATA WITH OFFSET
806
OBTAIN DATA FOR M1 PLANES
DISPLAY

FIG. 8

PE

FIG. 9A

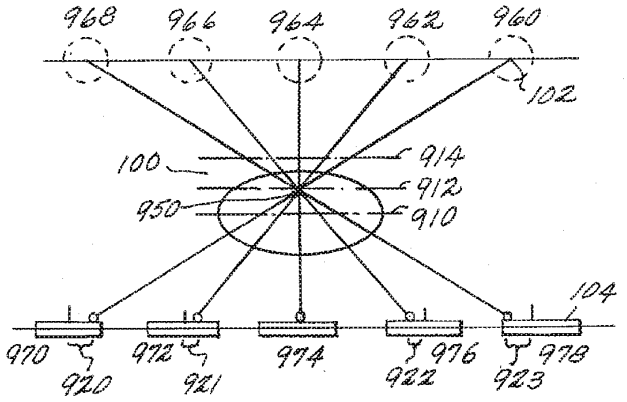


FIG. 9B

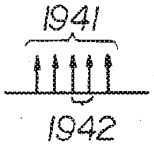


FIG. 9C

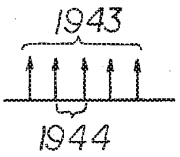
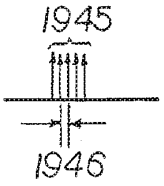
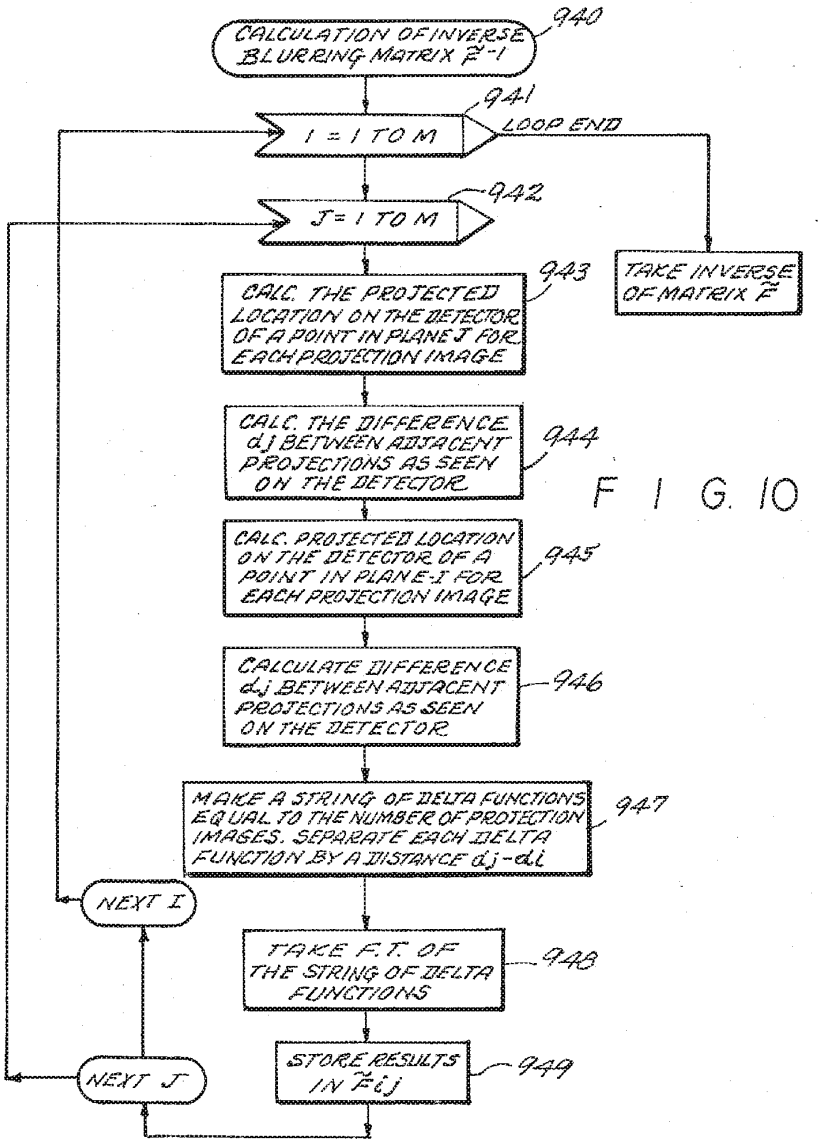


FIG. 9D



PE


CALCULATION OF INVERSE BLURRING MATRIX F-1
940
I = 1 TO M
941
LOOP END
J = 1 TO M
942
CALC. THE PROJECTED LOCATION ON THE DETECTOR OF A POINT IN PLANE J FOR EACH PROJECTION IMAGE
943
TAKE INVERSE OF MATRIX F
CALC. THE DIFFERENCE dj BETWEEN ADJACENT PROJECTIONS AS SEEN ON THE DETECTOR
944
CALC. PROJECTED LOCATION ON THE DETECTOR OF A POINT IN PLANE I FOR EACH PROJECTION IMAGE
945
CALCULATE DIFFERENCE dj BETWEEN ADJACENT PROJECTIONS AS SEEN ON THE DETECTOR
946
MAKE A STRING OF DELTA FUNCTIONS EQUAL TO THE NUMBER OF PROJECTION IMAGES. SEPARATE EACH DELTA FUNCTION BY A DISTANCE dj-di
947
NEXT I
TAKE F.T. OF THE STRING OF DELTA FUNCTIONS
948
STORE RESULTS IN Fij
949
NEXT J

F I G. 10

PE

MATRIX INVERSION TOMOSYNTHESIS IMPROVEMENTS IN LONGITUDINAL X-RAY SLICE IMAGING

BACKGROUND AND SUMMARY OF THE INVENTION

The present invention relates to the field of radiological imaging, and particularly to an improvement in digital x-ray tomosynthesis. More specifically, the present invention describes a number of improvement algorithms which are used in combination with matrix inversion mathematics and digital tomosynthesis in order to allow improved longitudinal slice images of a patient to be obtained.

One of the main functions of the science of radiology is the visualizing of structures internal to the patient. Historically, the visualizing of patient structures has most commonly employed projection imaging techniques, whereby all structures in the area of interest in the patient are displayed superimposed on a single sheet of film. It is sometimes difficult, however, to visualize adequately the anatomy of interest in a projection image due to the complex superposition of patient structures.

A great advancement in radiological imaging was achieved in the 1970s with the advent of computed tomography (CT). CT generates an image of a transverse slice of a patient, and has improved upon projection imaging in many instances. CT has proven very useful in allowing the radiologist to examine images of particular cross-sectional slices of the patient in order to isolate the appearance of specific internal structures.

It would be helpful to certain radiological diagnoses to be able to view not only transverse slice images, but also slice images oriented along a longitudinal axis of the patient. However, there does not currently exist a method of generating practical, high-quality longitudinal x-ray slice images. CT, for example, is excellent at producing high-quality images of transverse slices, but is not capable of producing longitudinal images of many parts of patient anatomy due to the difficulty of orienting the patient properly in the small CT gantry. More contemporary techniques of using image processors with CT images to simulate longitudinal slices have also met with limited success. These more recent techniques acquire a set of contiguous CT slices which are "stacked" in a three-dimensional orientation in a computer image processor to render the appearance of slice images at arbitrary angles. These images have limited spatial resolution in the longitudinal direction, however, due to the finite separation between contiguous CT slices. Therefore, it has proven difficult to obtain adequate longitudinal slice images with a CT apparatus.

Many investigators have turned to older techniques in an effort to develop adequate longitudinal x-ray slice imaging. One such technique is classical geometric tomography, which has been known to the art for many years. Geometric tomography does not render perfect longitudinal slice images by itself, but has proven to be a foundation upon which many modern improvements have been built. Geometric tomography has several embodiments, such as linear tomography and circular tomography, each case being described by the geometry of motion of the x-ray tube and imaging device. Linear tomography is most illustrative to the present invention and will be described below.

The basic principle of geometric linear tomography will be explained with reference to FIG. 1. According to this basic tomographic system, patient **100** is located in a stationary position. X-ray tube **102** is located on one side of patient **100**, and film **104** is located on the other side of patient **100**. X-ray tube **102** emits x-rays **106** which pass through the patient and are received by film **104**.

According to the principles of linear tomography, x-ray tube **102** and film **104** move in a coordinated fashion along linear paths on opposite sides of the patient **100**. The x-ray tube **102** and film **104** move in opposite directions, each with a specified linear velocity. During the course of the movement, x-ray tube **102** moves from point **110** to point **112**, and film **104** moves from point **114** to point **116**. There is a fulcrum plane **118** which contains the point **120** about which the tube **102**/film **104** combination pivots. The height of this fulcrum plane **118** is determined by the relative linear velocities of the tube **102** and film **104**.

In theory, any patient structures which lie within the fulcrum plane **118** will be in focus on the exposed film following the tomography scan. This effect is a result of the geometry of movement, which causes the projected positions of structures in the fulcrum plane to maintain the same position on the film as the film and the tube move. However, any structures that do not lie in fulcrum plane **118** will be blurred out on the exposed film, since the projected position of these structures will not move at the same velocity as the film. For example, consider points **120** and **122** in the patient. Point **120** lies in the fulcrum plane **118**. At the initial film position **114**, the point **120** projects onto the film at location **130**. After complete movement of the tube **102** and film **104**, the projected position of point **120** is location **131**. Due to the motion of film **104**, points **130** and **131** are at the same location on the film. Hence, any structure at point **120** in the patient would appear in sharp focus on the exposed film **104**. In contrast, consider the motion of point **122** which lies outside the fulcrum plane **118**. At the initial film position **114**, the projected position of point **122** is at location **140**. After film movement, the projected location of point **122** is at location **141**. Points **140** and **141** are not at the same location on the film. Hence, the projected position of point **122** has swept over a large portion of the film, resulting in a blurred appearance. Therefore, linear tomography allows an image to be formed on the film which contains structures from fulcrum plane **118** in sharp focus, and which also contains out-of-plane structures blurred by varying amounts.

Linear tomography permits an improved examination of structures in the region of the fulcrum plane relative to other superposed patient structures. However, the presence of blurry, out-of-plane structures degrades the ability to visualize low-contrast objects in the plane of interest (fulcrum plane). For example, linear tomography is commonly used for examining the urinary system, since the kidneys, ureters, and bladder may be considered to be in one "thick" plane, or "slice". This technique requires, however, the use of intravenous contrast agent, without which the urinary system structures would lack adequate visible contrast to distinguish them from the blurry overlying abdominal structures. Therefore, although geometric tomography permits an improved view of a specified plane, or slice, of interest, it still is not suitable for general longitudinal imaging except in cases of imaging high contrast objects.

PE

Samsung Exhibit 1002, Page 158 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Various improvements have been made to classical geometric tomography. One such improvement is digital tomosynthesis, as described in the reference by D. G. Grant: "Tomosynthesis: A three-dimensional radiographic imaging technique." IEEE Trans. Biomed. Eng., 19(1):20–28, 1972, the disclosure of which is incorporated herein by reference. Digital tomosynthesis is a technique similar to geometric tomography, except that it permits retrospective reconstruction of tomographic images at variable in-focus plane heights. The ability to reconstruct an arbitrary number of images with in-focus planes different than the original fulcrum plane is the strength of tomosynthesis. This process is achieved by taking a set of discrete images while the x-ray tube and film are moving, as opposed to one continuous image with traditional geometric tomography. Using the digital tomosynthesis technique, the projection images are then shifted relative to one another and added together to give the tomosynthesized image. The amount of shifting of each image determines which projected structures in the patient will be made to appear as though they did not move relative to the film. Hence, the amount of shifting of projection images determines the height of the reconstructed focal plane.

The tomosynthesis reconstruction process is depicted in more detail in FIGS. 1B, 1C and 1D. The tomosynthesis device is shown in FIG. 1B. X-ray tube **102** moves from position **110** to position **111** finally to position **112**. At each of these positions a discrete image is obtained. The image from position **110** is recorded at film position **114**. Images from positions **111** and **112** are recorded at film positions **115** and **116**, respectively.

FIG. 1C shows the process for shifting and adding the three images to bring one of the patient planes into focus. FIG. 1C, specifically, shows the process for obtaining the ° into focus. In order to obtain this structure in focus, the images are added without shifting, since the ° lies in the fulcrum plane. When this occurs, the ° will be in focus and the Δ will be blurred.

FIG. 1D shows the process for obtaining the Δ in focus with the ° blurred. Film position 1 is shifted with respect to film position 2 which is shifted with respect to film position 3. The three images are then added to obtain the Δ in focus and the ° blurred.

Digital tomosynthesis, like classical geometric tomography, results in images that contain blurry structures from all planes in the patient, in addition to the in-focus structures from the plane of interest. Hence, while tomosynthesis is far more flexible than traditional geometric tomography, it still suffers from the same image degradation from blurry out-of-plane structures.

There have been a number of other techniques investigated for improving the quality of longitudinal slice images. These techniques basically attempt to remove the blurry artifacts from out-of-plane structures from tomographic or tomosynthetic images. These techniques fall into various categories which will be described below. First, various authors have described matrix algebra approaches to the solution of exact longitudinal tomographic images. Matrix algebra approaches basically use the knowledge of the imaging process in combination with a finite set of rendered tomographic or projection images to solve for patient structures in a finite set of planes. References to this approach include: L. T. Chang, B. Macdonald, V. Perez-Mendez: "Axial Tomography and Three Dimensional Image Reconstruction." IEEE Trans. Nuc. Sci. 23(1):568–572, 1976; and D. Townsend, C. Piney, A. Jeavons: "Object Reconstruction from Focused Positron Tomograms." Phys. Med. Bio. 23(2):235–244, 1978; the disclosures of all of which are incorporated by reference. Each of these techniques teaches a matrix algebra approach to tomographic image reconstruction. However, the application envisioned by Chang, et al. and Townsend, et al. was nuclear medicine, not x-ray transmission imaging. Moreover, the reference to Chang, et al. does not teach methods for overcoming difficulties in reconstructing low spatial frequencies in the images, such problems arising from matrix difficulties in the presence of image noise. (A further elaboration of the problem of image noise in matrix algebra reconstruction will be provided later). Townsend, on the other hand, teaches a method for addressing the problem of reconstructing low spatial frequencies by invoking an approximation of the matrix describing the imaging process. Townsend, does not, however, teach methods for improving the rendering of structures that lie between reconstructed image planes, and hence would be subject to some contamination of the images by structures not lying exactly in one of the reconstructed planes.

A second category of longitudinal imaging techniques uses a summation of appropriately filtered tomographic or projection images to eliminate the blurry artifacts from longitudinal slice images. These techniques are akin to the matrix techniques except for the methodology used for determining the nature of the blurry artifacts to subtract. Example references include: H. E. Knutsson, P. Edholm, G. H. Granlund, C. U. Petersson: "Ectomography—a new radiographic reconstruction method—1. theory and error estimates." IEEE Trans. Biomed. Eng. 27(11):640–648, 1980; D. N. Ghosh Roy, R. A. Kruger, B. Yih, P. Del Rio: "Selective plane removal in limited angle tomographic imaging." Med. Phys. 12(1):65–70, 1985; and S. P. Wang, R. H. Morgan and D. F. Specht: U.S. Pat. No. 4,598,369, all of which are incorporated by reference. In each of these techniques, an estimation of the blurry artifacts from structures in all planes of the patient are made. These estimated blurred artifacts are then subtracted from the individual tomographic images. The reference to Knutsson, et al., however, introduces other structured artifacts into the images. The technique of Ghosh Roy, et al. also introduces edge artifacts into the plane of interest. In other words, the methods of Ghosh Roy and of Knutsson do not render unaltered versions of the plane of interest. Wang, et al., on the other hand, teach clarification of tomographic images by successive subtracted of blurred adjacent tomographic images. The approach of Wang permits successive approximation to the desired image, but does not teach the exact solution of said image as is taught by the various matrix inversion techniques. Hence, great tedium could be required with the technique of Wang in establishing the desired subtraction and blurring procedures.

To address the aforementioned problems in the prior art, the present invention teaches new methods for producing improved longitudinal x-ray slice images. These methods eliminate the blurry out-of-plane artifacts without introducing substantial artifacts in the planes of interest. These methods also provide improved reconstruction of low spatial frequencies in the presence of image noise, and enable more suitable rendering of patient structures not lying exactly in one of the reconstructed planes.

The present invention uses an x-ray source and x-ray detector which move in opposite directions along linear

PE

Samsung Exhibit 1002, Page 159 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

paths on either side of the patient, in accordance with the technique of linear tomography. A plurality of x-ray images are produced at predetermined intervals along the movement path of the x-ray source and detector. This set of discrete images is then loaded into a computer memory in which they are shifted and added together to form tomosynthesized images. Tomosynthesized images are generated for a predetermined number of planes in the patient. These tomosynthesized images contain blurry structures from the entire patient in addition to the structures from the planes of interest. Since the geometry of x-ray source/detector movement is well known, the precise amount of blurring which has occurred for structures at any plane in the patient can be calculated. The set of tomosynthesized images in conjunction with the known blurring properties of every plane will permit exact solution of the structures in each plane.

The method of solution for the structures in each plane is a matrix algebra approach similar to that described in Chang, et al. and Townsend, et al. Specifically, the tomosynthesized image of each plane can be written as an equation including actual structure from that plane and blurred structures from every other plane. The plurality of equations for all planes thus defines a matrix equation which contains information about all structures in the chosen planes inside the patient. The matrix in this matrix equation describes the nature of the blurring artifacts that occur when any plane is tomosynthesized. Once the matrix has been calculated, matrix algebra may be used to remove the blurred structures from any given plane. Specifically, a matrix equation is produced in which the left-hand side represents the tomosynthesized images of every plane. The right-hand side contains the matrix of blurring functions convolved with the as yet unknown patient structures in every plane. The Fourier transform is taken of both sides of the equation, and the inverse of the matrix of blurring functions is calculated. The inverse matrix then multiplies both sides of the matrix equation in order to eliminate the blurring matrix from the equation. The inverse Fourier transform of the equation is then taken to yield a matrix equation in which the unknown patient structures are solved for in terms of the known tomosynthesized images. Any of the set of planes in the patient may be chosen and an image produced of that plane without blurred structures from other planes.

There are certain properties of the matrix inversion mathematics that lead to undesirable results. For example, the low spatial frequency components of the reconstructed images are poorly determined under certain circumstances. In particular, the presence of noise in the projection images gives rise to inaccurate reconstruction of low spatial frequencies due to poor conditioning of the imaging matrices at low spatial frequencies. Moreover, the matrix inversion technique does not permit the zero spatial frequency component (i.e., the "DC" image component) to be reconstructed at all (as pointed out in Chang et al) as a solution to the mathematical equation for the zero spatial frequency is indeterminate. The present invention solves these problems in new and advantageous ways.

There is an additional problem; namely, that patients are not exactly described by a finite set of planes, but rather contain a continuum of structures. The matrix inversion approach solves in an exact manner only for those structures actually lying in one of the preselected planes. Hence, the structures in the patient lying between planes are reconstructed only in an approximate fashion. If the imaging geometry is not chosen carefully, these between-plane structures may be reconstructed in an unsuitable manner such that they show up as contaminating artifacts in the other planes. The present invention defines a new technique to minimize the problem with reconstruction of between plane structures.

In order to permit the solution of the zero spatial frequency components, and in order to minimize any problems from low spatial frequency reconstruction with matrix inversion techniques, and in order to improve the reconstruction of between-plane structures, the present invention uses a plurality of advantageous techniques as described below.

A first technique uses weighting factors or digital filtering for the original projection images in order to tailor the appearance of between-plane structures in the final reconstructed planes. Each discrete x-ray image taken by the moving x-ray tube and detector is weighted with a different factor, in order to modify the effective modulation transfer function for between-plane structures.

A second aspect of the invention determines the zero spatial frequency component of each image by subtracting an appropriate overall constant from each reconstructed line of each plane. This forces the edge of each image plane to zero, since outside the patient the image values should all be zero. Accordingly, this procedure reconstructs proper zero spatial frequency values for each image.

A third aspect of the invention is the use of an iterative technique to correct for errors in determining the lowest spatial frequency components in the reconstructed images. The iterative technique adds varying amounts of low spatial frequency components to the reconstructed images. The iterative technique adds varying amounts of low spatial frequency components to each reconstructed line of each image plane until the region at the very edge of the image becomes flat. Using this technique, approximately ten percent of the image on either side of the patient is used to calculate the errant low frequency components present in all the reconstructed image. The values are then subtracted from the overall images to yield flat images in the image edge regions.

A fourth aspect of the invention uses a hybrid technique that improves calculation of low spatial frequency components, while also improving the reconstruction of between-plane structures. Specifically, the mid- and high-frequencies are reconstructed from image data acquired from a narrow swing of the x-ray tube. The narrow swing provides better handling of between-plane structures but demonstrates worse reconstruction of low frequencies due to an increased sensitivity to image noise. A second set of image data is then also acquired from a very wide swing of the x-ray tube. The wide swing data is much less subject to noise problems at low spatial frequencies. The low spatial frequency components from the wide swing data are then substituted for the low spatial frequencies in the narrow swing reconstruction. The result is good reconstruction of between-plane structures and reduced problems at low spatial frequencies. In practice, the wide and narrow data sets may be both acquired during the same pass of the x-ray tube.

The approximation of Townsend is not necessary according to the present invention, which reduces

PE

Samsung Exhibit 1002, Page 160 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

noise-induced low spatial frequency reconstruction problems using iterative and hybrid evaluations of data outside the patient.

In summary, the present invention combines geometric x-ray tomography, digital tomosynthesis, matrix inversion mathematics, variable weighting of original projection images for improved reconstruction of between-plane structures, calculation of zero spatial frequency image components, iterative or hybrid techniques for improving low spatial frequency components in the presence of image noise, and a hybrid technique for improved rendering of between-plane structure. The resulting apparatus and method allow improved longitudinal x-ray slice imaging. In addition, this device should be less expensive than a computerized tomography machine with the potential for acquiring multiple slice images more quickly than CT. The present invention also applies matrix inversion longitudinal slice reconstruction to x-ray imaging, while many of the previous schemes envisioned application only in nuclear medicine. Further advantages of the system will be described throughout the specification.

BRIEF DESCRIPTION OF THE DRAWINGS

An exemplary and presently preferred embodiment of the invention will be described in detail with reference to the accompanying drawings wherein:

FIG. **1** shows the basic technique and layout of linear tomography;

FIGS. **1B–1D** show the basic technique of digital tomosynthesis.

FIG. **2** shows a block diagram embodiment of the present invention;

FIG. **3** shows the main flowchart loop executed by the computer of FIG. **2**;

FIG. **4** shows the weighting and the shift and reconstruct functions executed by the flowchart of FIG. **3**;

FIG. **4A** shows the weighting function used according to FIG. **4**;

FIG. **5** shows a flowchart of the hybrid correction routine of FIG. **3**;

FIG. **6** shows a flowchart-type diagram of the iterative correction technique;

FIG. **7** shows a flowchart-type diagram of the DC correction technique;

FIG. **8** shows a flowchart diagram of the interleaving technique; and

FIGS. **9A–9D** shows how the inverse blurring matrix is obtained; and

FIG. **10** shows a flowchart diagram of the technique for calculating the inverse blurring matrix.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Matrix inversion mathematics, which have been described in the prior art, are essential to the understanding of the technique of the present invention. Accordingly, such matrix inversion mathematics will be described first herein.

Conceptually, the matrix inversion technique solves for the in-focus structures, and therefore eliminates out-of-focus structures. The blurring of all structures in a patient can be controlled by the geometry of tube/film movement. Experience will tell a skilled artisan precisely how much blurring has occurred for structures at any plane in the patient, since the imaging geometry is known. Matrix inversion techniques basically use the knowledge of how much blurring occurs in a given plane reconstruction based on the structures in every other plane. Using this information, an equation is written to describe each reconstructed tomosynthesis plane. This equation is solved, yielding a mathematical representation of what each plane must look like without the attendant blurring. In other words, matrix inversion undoes the blurring that occurs in each plane, and subtracts an appropriate amount of undesired blurring from each image reconstruction.

Matrix inversion mathematics are most adequately described by using the shorthand notation typically used in matrix algebra.

Assume for purposes of explanation of the matrix inversion mathematics that a patient is comprised of N planes, each plane containing a number of structures. $t_i(X,Y)$ defined as the tomosynthesized image of plane i. The t images are thus the standard tomosynthesized images including the desired structures in plane i and the undesired blurred images from the other N−1 planes. If we use $P_i(X,Y)$ as the actual structures in plane i (such as the attenuation coefficient of the tissues at pixel (X,Y) for x-ray imaging), the tomosynthesized images t may be described in terms of the patient structures for each plane as:

$$t_i = f_{i1}*P_1 + f_{i2}*P_2 \ldots f_{in}*P_n \tag{1}$$

In this equation, f_{ij} represents the blurring function describing the blurring of patient structures from plane j in the tomosynthesized image of plane i with the component $f_{ii}*P_i$ representing the unblurred contribution of structures from plane i (f_{ii} being a delta function since $\delta*P_i = P_i$). The "*" terminology denotes a spatial convolution which is a mathematical term for blurring. The (x,y) coordinates have been suppressed in equation (1) for simplicity.

An equation such as equation (1) may be written for each of the reconstructed tomosynthesized planes **1** through n as:

$$\begin{aligned} t_1 &= f_{11}*p_1 + f_{12}*p_2 + \ldots f_{1n}*p_n \\ t_2 &= f_{21}*p_1 + f_{22}*p_2 + \ldots f_{2n}*p_n \\ &\cdot \\ &\cdot \\ &\cdot \\ t_n &= f_{n1}*p_1 + f_{n2}*p_2 + \ldots f_{nn}*p_n \end{aligned} \tag{2}$$

These equations may be defined in matrix notation as

$$\begin{bmatrix} t_1 \\ t_2 \\ \cdot \\ \cdot \\ \cdot \\ t_n \end{bmatrix} = \begin{bmatrix} f_{11} f_{12} \ldots f_{1n} \\ f_{21} f_{22} \ldots f_{2n} \\ \cdot \\ \cdot \\ \cdot \\ f_{n1} f_{n2} \ldots f_{nn} \end{bmatrix} * \begin{bmatrix} p_1 \\ p_2 \\ \cdot \\ \cdot \\ \cdot \\ p_n \end{bmatrix} \tag{3}$$

Equation (3) can be defined more succinctly by letting T and P be shorthand notations for the N component vectors t_1 through t_n, and p_1 through p_n, respectively. Using the notation F for the matrix of blurring functions f_{ij}, we obtain:

PE

Samsung Exhibit 1002, Page 161 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

$$T=F*P \quad (4).$$

Accordingly, the actual patient structures P, without any blurring from other planes, are a factor in this equation. Since the actual patient planes are the desired data, one desires to solve equation (4) for P.

In the present invention, this is done by first taking the Fourier transform of both sides of equation (4). This is done to simplify the calculation, because Fourier transformation converts convolution into the simple mathematical procedure of multiplication. The fourier transform yields the equation:

$$\tilde{T}=\tilde{F}.\tilde{P} \quad (5).$$

where the ~ indicates a Fourier transform has been taken. $\tilde{P}$ can then be determined in a straight-forward manner if the matrix $\tilde{F}$ has an inverse. A matrix inverse is well known as being the matrix which yields the unit matrix when multiplied by the original matrix, or:

$$\tilde{F}^{-1}.\tilde{F}=1 \quad (6).$$

It may be shown by trial and error that matrix inverst $\tilde{F}^{-1}$ exists for all spatial frequencies except $f_s=0$. Therefore, since this inverse matrix exists, we multiply both sides of equation (5) by the inverse matrix to obtain:

$$\tilde{F}^{-1}.\tilde{T}=\tilde{F}^{-1}.\tilde{F}.\tilde{P}=\tilde{P} \quad (7).$$

Therefore, a solution for P may be exactly obtained by multiplying the tomosynthesized hector $\tilde{T}$ by the inverse matrix $\tilde{F}^{-1}$.$\tilde{F}^{-1}$ may be easily calculated since $\tilde{F}$ is known or can be determined by the geometry of tube/film movement. This is described in detail later in reference to FIGS. 9A–9D.

The above-discussed procedure is the basis of matrix inversion mathematics. There will be a matrix equation (7) for each spatial frequency in the image, since $\tilde{T}$, $\tilde{P}$ and the matrix $\tilde{F}$ are all functions of spatial frequency. Once equation (7) has been generated, the actual patient structure vector P may be determined by taking the inverse Fourier transform of $\tilde{P}$ as:

$$P=F.T.^{-1}\{P\} \quad (8).$$

An embodiment of the invention will now be defined with reference to the accompanying drawings.

It is assumed herewith that one having ordinary skill in the art knows the basic functions and layouts of a typical tomographic x-ray-apparatus. For example, such structure is described in U.S. Pat. No. 4,570,263, the disclosure of which is expressly incorporated herein by reference. Other similar patents are also known by those of skill in the art. The present invention is carried out using the structure shown in FIG. 2. X-ray source 102 is used over patient 100. Patient 100 is positioned on a patient table 150. An image-receiving structure 160 is located under patient 100 such that the emanations from x-ray source 102 are received by image-receiving structure 160. A mechanical gantry 170 must also be connected between image receiving structure 160 and x-ray source 102 to allow the two structures to pivot with respect to one another and maintain the same pivot point 162. The x-ray source 102 moves in linear fashion along trajectory 180 and the image receiving device 160 moves linearly along trajectory 190.

The image-receiving device 160 can be any image-receiving device. Film has been very common in the prior art, but would require additional structures in order to digitize the picture, once taken. Therefore, an electronic detector is more advantageous. Electronic detectors typically generate signals which are connected to some processing device. Many different detectors may be used. One such detector is the photostimulable phosphor detector such as the Philips Computed Radiography device from Philips Medical Systems Inc. This photostimulable phosor detector, or PSP, includes a solid state material that temporarily stores a latent image proportional to the detected x-ray flux. The detector plate is subsequently read-ont by laser scanning. A disadvantage of this device is that the sheets must be moved into and out of the x-ray beam and sent to the read-out device. In the present invention, such PSP detectors would be located, for instance, on a conveyor belt under the patient table, so that they could be easily moved in a mechanized fashion.

An alternate image receiving structure which could be used is, for example, an image intensifier. Image intensifiers receive x-rays as an input and convert these x-rays to visible photons and then to electrical signals by means of an attached video camera. Image intensifiers are advantageous due to the ease with which images can be acquired in rapid sequence and transferred to a computer device. However, image intensifiers have a disadvantage of causing geometric distortion near the image edges.

The ideal detector would be a large area flat, fully electronic detector. However, such detectors are not in practical use at this time. Therefore, either the PSP or the image intensifier can be used as the image receiving structure according to the present invention.

The output of image receiving structure 160 is connected to image buffer 171 which includes the necessary circuitry for converting the output from image receiving device 160 into a digital signal suitable for use with a programmed computer. The output of buffer 171 is connected to computer 200. Computer 200 performs the various processing steps on the input data and generates the matrix inversion tomosynthesis images. The resulting images are converted to an electrical signal and sent to an appropriate image display 210. An optional array processor 220 is connected to computer 200 in order to speed up the computations necessary for the matrix inversion and/or the Fourier and inverse-Fourier transform. Array processor 220 may include a hardware Fast-Fourier transform (FFT) device 222.

The computer 200 also will typically include a memory device 230 such as a hard disk or the like. Any other desired external structures can also be used with this device. The computer can be of any known type which performs processing functions, such as a VAX 11/780 or Sun 3/160.

In operation, tomographic images are obtained by the linear tomography machine 98, which includes source 102, gantry 170, and image receiver 160, and are connected to image buffer 171, which couples this data to computer 200. Computer 200 then operates according to the flow charts of FIGS. 3–10.

FIG. 3 shows the flow chart used by computer 200 of FIG. 2 in summary form. More detail is shown in the accompanying FIGS. 4, 4A and 5–8. As a summary, however, step 300 of FIG. 3 shows acquiring the N projection image from image receiving structure 160 through buffer 171 into computer 200. These projection images are Fourier transformed at step 305, and appropriate shift amounts for tomosynthesis are determined at

PE

Samsung Exhibit 1002, Page 162 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

step 310. The shifting necessary for such tomosynthesis is described in the Grant reference, which has been incorporated herein by reference. Following this determination of proper image shift, the first correction routine according to the present invention is executed at step 312. Step 312 describes the weighting function used according to the present invention to improve the rendering of between-plane structures. This weighting function is described in more detail with reference to FIGS. 4 and 4A.

After this weighting function is completed, the vector which was described above as $\tilde{T}$ is formed at step 313 by shifting and reconstructing according to the Grant teaching.

Step 314 shows the steps of acquiring the inverse blurring matrix $\tilde{F}^{-1}$. The steps of acquiring this matrix are shown, herein with reference to FIGS. 9A–9D, 10. Step 314 is entitled acquiring of the $\tilde{F}^{-1}$ matrix, and may include the steps of calculating this matrix or may merely include the steps of reading the terms of this matrix from a memory where it is prestored.

Accordingly, both $\tilde{T}$ and $\tilde{F}^{-1}$ are received as input parameters to step 316. Step 316 uses this data according to the matrix inversion mathematics to determine $\tilde{P}$. This array multiplication may be done by array processor 220 in order to speed processing.

Step 318 follows the calculation of $\tilde{P}$ and is the second correction routine according to the present invention. Step 318 represents the hybrid correction routine. This hybrid correction routine is shown in more detail in FIG. 5. In step 320, after the hybrid correction, the inverse Fourier transform of $\tilde{P}$ is taken to yield the vector P. Step 322 shows the third correction algorithm according to the present invention. This represents the iterative correction routine shown in more detail in FIG. 6. After the iterative correction is completed, the DC level correction is executed at step 324 and in more detail in FIG. 7. The DC level corrected signal is then displayed at step 326.

The detailed steps discussed herein will be described in more detail with reference to the remaining figures and throughout this application. It should be noted by one having ordinary skill in the art that any of the weighting correction of step 312, the hybrid correction of step 318, the iterative correction of step 322, or the DC level correction of step 324 can be independently performed. That is, any one of these steps can be performed without any of the others or with any combination of these steps.

The detailed flow chart describing the weighting routine will now be described herein with reference to FIG. 4. FIG. 4 shows the weighting routine according to the present invention as shown at step 312 at FIG. 3. The input flow to the weighting routine should receive a plurality of projection images. In addition, the projection image shift amounts for tomosynthesis have been determined at step 310. Accordingly, the first step in this process is to weight each projection image according to a weighting function. According to this embodiment, the weighting function is shown in FIG. 4A.

X-ray source 102 and image detector 104 are shown in FIG. 4A. There are also indicated seven positions of the image detector 104, identified by numerals 1–7 in this example and corresponding to the positions described above in FIG. 1B. These seven positions of detector 104 represent the locations of the projection images acquired during the tomographic scan. As can be seen in FIG. 4A, a weighting function is assigned to each projection image based on its proximity to the ninety-degree orientation of tube and detector. At the furthest outward positions 1 and 7, the weighting is very low, for example in the range of 0.15. This weighting gradually increases to 1.0 for the projection image taken with ninety-degree orientation of tube and film (position 4).

Therefore, in operation of FIG. 4, each projection image is received at step 420. Each image is then weighted appropriately according to the graph of FIG. 4A at step 422. In this way, the projection images depicting patient structures shifted the most aggressively are weighted by an amount much less than the weighting of the ninety-degree projection image.

Structures that lie between planes are not capable of being reconstructed exactly, since the matrix inversion only solves exactly for structures that lie on the preselected planes. However, it is clearly desired that the matrix inversion tomosynthesis technique handle between-plane structures in a manner consistent with proper anatomical interpretation of the images. For example, it would inappropriate for structures between planes 1 and 2 to show up in all other reconstructed images of the patient. Moreover one would like to maintain as many as possible of the between-plane structures in order to give some finite thickness to the reconstructed plane images. The inventors of the present invention have found that weighting the projection images each by a constant value as given in FIG. 4A has the advantageous effect of improving the reconstruction of between-plane structures. Specifically, using a weighting function such as a Gaussian function improves the reconstruction of between-plane structures by minimizing the degree to which between-plane structures appear in images of planes other than the nearest neighboring planes. Furthermore, if a narrow swing of the x-ray tube is used for data acquisition, in conjunction with the weighting technique, then the between-plane structures are shared almost entirely by their two nearest neighboring planes, in a proportion equal to the relative distance between the two planes. One skilled in the art may further optimize the parameters of this weighting technique for other imaging geometrics.

After each image is weighted in step 422, the shift and reconstruct routine begins at step 313. This routine begins by setting up a loop of 1 to M at step 426, where M is the preselected number of planes chosen to span the patient. At step 428, the projection images are shifted by an amount previously determined at step 310. Since the Fourier transform has already been taken in step 305, the shifting of images is accomplished by multiplying the Fourier transform of each projection image by a phase factor $\exp(-2\pi i\mu a)$, where μ is the spatial frequency and "a" is the amount of the desired shift. This shifting technique is the well-known Fourier shift theorem. The shifted images are then added together at step 430 and are stored as a tomosynthesized image t at step 432. The loop then returns step 426 where the function is incremented so that the next plane can be shifted and added to be stored as the next tomosynthesized plane. At the end of the loop, control passes to step 316 of FIG. 3.

The hybrid correction routine of step 318 will now be discussed with reference to FIG. 5.

It has been found by the present inventors that a narrow swing of the x-ray source, provides better handling of between-plane structures in matrix inversion

PE

Samsung Exhibit 1002, Page 163 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

tomosynthesis. However, this narrow swing demonstrates worse reconstruction of low frequencies due to an increased sensitivity to image noise. Contrastingly, image data acquired from a wide swing of the x-ray source is much less subject to noise problems in reconstruction of low frequencies, but has somewhat less optimal handling of between-plane structures. The inventors of the present invention have determined a technique in order to combine the advantages of both techniques---by using the mid-and high-frequency reconstructions from image data from a narrow swing of the x-ray source, and using the low frequency reconstructions from images from a wide swing of the x-ray source. In practice, both data acquisitions can be acquired during a same pass of the x-ray source.

The detailed flowchart for this technique is shown in FIG. 5. FIG. 5 acts on the Fourier transformed reconstructed vector $\bar{P}$. Therefore, the hybrid technique operates in "frequency space" on a Fourier transformed element. The operation is shown beginning at step **500**. Two sets of tomosynthesis images are used, a wide data scan set **502** and a narrow data scan set **504**. Each of these scans has M planes of tomographic images, as above in the weighting technique. According to the hybrid correction technique, however, two sets of nested loops are formed. A first set of loops is formed as loop **506**, which loops from 1 to M, where M is the number of reconstruction planes. Within each of the passes of main loop **506**, a second loop is formed from 1 to C, where C is the number of columns of the image, the columns being parallel to the direction of motion of the x-ray tube and detector. Step **510** is executed for each column of each plane. Specifically, step **510** executes an operation to replace the low spatial frequency reconstructions from a narrow scan with the low spatial frequency reconstructions from the wide scan data. This is straightfowardly accomplished, as this operation occurs in the frequency domain (Fourier transformed data).

Upon finishing this correction for all of the data in all columns of all planes, control passes to step **320** in FIG. **3** where the inverse Fourier transform of P is taken to yield the vector P. Two correction routines are then executed on this vector P in the spatial domain. These correction techniques are for the purpose of improving low spatial frequency reconstruction, and for regenerating the proper image zero spatial frequency values.

First among these techniques is the iterative correction of step **322**, which is shown in FIG. **6**. The iterative technique bases its operation on about 10% of the image which lies on either side of the patient in a location where the pixel values should all be zero. This area is then used to calculate what value of errant low spatial frequencies are present in the reconstructed matrix inversion tomosynthesis images. These values are then subtracted from the images to yield flat images in the 10% edge regions. This iterative correction technique works well for the very lowest spatial frequencies.

To conceptualize this correction, once matrix inversion tomosynthesis has been used to reconstruct the image, there will be some inaccurate low frequencies that cause problems in the image, owing to the poor conditioning of the low frequency matrices. These low frequencies will typically have a spatial frequency of 1 to 5 periods across the image. An area of each image outside the patient is used to determine when the best correction for low frequencies has been achieved. Varying amounts of low spatial frequency components are added to the image to flatten out this area outside the patient. Therefore, this system will be used to correct for a plurality of different spatial frequencies one by one, until the entire system zeros out. The correction procedure may iterate several times for improved accuracy.

The detailed software necessary to effect this operation is shown in FIG. **6**. A first loop is formed from 1 to M at step **600**, where M is the number of planes. Step **602** forms a loop from 1 to C, where C is the number of columns. A third nested loop is formed within the spatial frequency range of $-Q$ to Q at step **604**. The range of $-Q$ to Q can be any desired frequency range, but will typically be the low frequency ranges below which correction is necessary (e.g., ~5 cycles per image width).

At step **605** a loop counter K is initialized. At step **606**, a weighting constant α is set to its initial value of α_0, and a weighting increment α_1 is also initialized. Step **608** then calculates a weighted trigonometric function as α times the sine or cosine of ωy (where ω is the current spatial frequency value of loop **604** and y is the pixel number) and adds this to the image data for the current column N, where N is the current column number according to the loop of step **602**. The result of the calculation at step **608** is then used by step **610** to form a sum of squares for all pixels in the outer 10% of the column on both sides of the patient.

A sum of square's S, is taken of the modified image in the two 10% edge regions. (The previous sum of squares value, S_{prev}, is initialized to a large number higher than any expected value in Step **607**, prior to the loop over spatial frequencies).

The result of the sum of squares from step **610** is tested for comparison to its previous value at Step **612**. If the sum of squares is greater than the previous value, control passes to the "no" side of the decision block of the of step **612** where α_1 is modified to equal $\alpha_1/2$ at step **613**, and then α is incremented by the amount α_1 at step **614**, by control passing to step **615** where the loop counter K is incremented. K is then tested against a predetermined limit at decision block **685**. If K is less than the limit, control goes to decision block **690** where S is tested against on predetermined threshold. If S is not less than the threshold, the loop returns to step **608**, where x_0 is recalculated using the new α. That is, each image data for column N is again added to the new α times a sine or cosine of the particular frequency ω. If the result of the test at Step **612** is positive, that is S is less than S_{prev}, S_{prev} is set to S at Step **680**. This is followed by an incrementing of α at Step **614** and an incrementing of K at Step **615**. The tests of Steps **685** and **690** are then carried out as described above. This progressive weighting is continually carried out using different weighting factors α until the counter K exceeds its predetermined limit or S becomes less than its threshold, at which time the control passes to step **620** which increments the ω loop **604** and stores the new value for α at step **622**. The next frequency in the loop is then used. The entire loop including steps **605–622** is then again executed for this new frequency to determine a new weighting factor α. When the last frequency within the frequency range of loop **604** is reached, control passes to step **602**, which chooses the next value in loop **602**. In this way, all of the columns of loop **602** are repeatedly corrected for respective values of spatial frequency ω.

PE

Samsung Exhibit 1002, Page 164 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

All of the values for all of the columns for all of the planes are repeatedly corrected in an interative fashion until all the sum of squares have been minimized. The low spatial frequency components are therefore corrected in this iterative fashion.

The final correction is the DC level correction shown in step **324** and explained in more detail with reference to FIG. **7**. This DC level correction will prove necessary for good image reconstructions. The matrix equation cannot regenerate zero frequency at all, as a mathematical solution is not possible. Therefore, a solution for the DC value cannot be obtained by the matrix approach However, if the DC is not solved for, the DC value used will be different, and will be likely wrong, for all columns in the image. The present invention corrects this DC level in a similar way to the iterative correction. Specifically, the DC value is corrected by examining the image value at the edge of each image column. This value of the patient image should be zero, since there is nothing there. If this value is not zero, it will be forced to zero according to the DC correction technique, by adding a DC component thereto and to all other pixels in that image column. This technique is repeated for all columns in all planes.

The specific technique is shown in flowchart form in FIG. **7**. First loop **700** is formed from **1** to M, where M is number of planes. A second nested loop from **1** to C, where C is the number of columns, is formed at step **702**. Within the nested loop at step **704**, the edge pixel at the top of each column is acquired. A determination is then made at step **706** if this edge pixel has a value equal to zero. If this determination is "yes", the loop continues to the next column. However, if the pixel is not equal to zero, the value of the pixel is negated, and this value is added to all pixels in the column at step **708**. The new pixel values are stored at step **710**, followed by the calculation for the next columns and planes.

A final correcting technique can be used as part of the display step **326** of FIG. **3**. This final technique is shown in FIG. **8**.

Specifically, a problem exists in that a trade off must be made between the number of planes which are obtained and the precision of the data which can be obtained from this technique. If there are too many planes, the matrices becomes poorly conditioned, and the data obtainable therefrom becomes degraded. It has been found by experiment that between 10 to 20 planes is the optimal limit. However, this yields relatively thick slices of the patient. If thinner slices are desired, these slices will be more poorly reconstructed.

Accordingly, an interleaving technique has been conceived by the inventors of the present invention in order to attempt to break this trade off. This is done specifically by obtaining data for a number M_o of planes, for instance 10, at step **802**. Thereafter, the same data is reprocessed by the matrix inversion tomosynthesis technique, using an offset value in the height of the reconstruction planes. This offset amount is set to a value equal to half the plane spacing for example. New data is then obtained using offset for a set of planes M1 at step **806**. In this way, slices may be spaced more closely without the requirement of making too many planes, which could cause the matrices to be poorly conditioned. This technique uses the original data but reconstructs it as though it were in a different location. It should be noted that the various sets of images generated with the interleaving technique are not completely independent, but they may provide some improvement in interplane resolution. One skilled in the art will recognize that may sets of interleaved planes may be obtained in this fashion.

Finally, FIG. **9** will be used herewith to describe the steps necessary to obtain the inverse blurring matrix $\tilde{F}^{-1}$.

FIG. **9** depicts the projected geometry for tomosynthetic imaging acquisition wherein there are five projections taken, for example, with x-ray tube **102** positioned at locations **960–968** and the imaging detector positioned at locations **970–978**, respectively. Three planes **910**, **912** and **914** are depicted, for sake of example, inside patient **100** which are to be reconstructed by matrix inversion tomosynthesis.

Consider the location of the object point **950** in the patient. As the tube/film combination moves, the projected image of the point appears at various locations on the film. In particular, at film location **970**, the projected position of point **950** relative to the center of the film is given by a distance **920**. Likewise, at film positions **972**, **976** and **978** the projected positions of the point are at distances of **921**, **922** and **923** respectively. The projected position at film location **974** is the center of the film in this example. If one were to add these five projection images together without any shifting, one could represent the location of the five projected positions of point **950** by the five delta functions **1941** shown in FIG. **9B**, each of which is separated by a distance **1942**.

If one repeats this same procedure for an object point in plane **914**, for example, one might find a set of projected positions as given by delta functions **1943** of FIG. **9C**. It is the distances, **942** and **1944**, between the delta functions in these two examples that specify the amount of shift that is necessary to tomosynthesize planes **910** and **914** respectively. Hence, if one tomosynthesized plane **914** by shifting all the projection images by an amount **1944**, then the locations of the projections of point **950** would be given by the delta functions **1945** of FIG. **9D**. The spacing between delta functions **1945** is a distance **1946**, which is equal to **1944** minus **1942**. The set of delta functions **1945** represents the blurring function for structures in plane **910** when plane **914** is tomosynthesized. The Fourier transform of the string of delta functions is then taken to give one element of the matrix $\tilde{F}$. All other elements in the matrix of blurring functions may be calculated in an equivalent manner.

The flowchart for the calculation of the inverse blurring matrix is shown in summary form in FIG. **10**. Two nested loops, **941** and **942** are formed, each over the number of planes to reconstruct, M. Step **943** calculates the projected positions of an object in plane j for each projection image, in accordance with the diagram in FIG. **9**. Then in Step **944** the difference between these projected points in the detected image is calculated for two adjacent projection images. Steps **945** and **946** repeat the procedure of Steps **943** and **944**, except that now an object in plane i is considered. Step **947** takes the difference between the values calculated in Steps **944** and **946** and generates a string of delta functions with a spacing of $d_j - d_i$ between them. These delta functions represent the image replication, or blurring, found for structures in plane j when plane i is tomosynthesized. The Fourier transform of this string of delta functions is taken in Step **948** and is stored as $\tilde{F}_{ij}$ in **949**. Once both loops end, the inverse of the matrix F is found and control returns to Step **316**.

To summarize, then, the present invention describes a technique of reconstructing longitudinal x-ray transmis-

PE

Samsung Exhibit 1002, Page 165 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

sion images using an x-ray geometric tomography device to obtain the initial images. These initial images are then processed using digital tomosynthesis to generate tomographic images at various reconstruction plane heights. Matrix inversion mathematics can then be used to solve exactly for structures in the tomosynthesized reconstruction planes, allowing elimination of blurred artifacts from the other planes. Weighting factors or digital filtering can be used for the original projection images in order to tailor the appearance of between-plane structures in the final reconstructed planes. The determination of zero frequency components of the images are then made by subtracting an overall constant from each reconstructed line of each plane, in order to make the edge of each plane approach zero. This depends on the fact that outside of the patient the image should have a value of zero. The use of an iterative technique is also discussed in order to correct for errors in determining the lowest spatial frequency components in the reconstructed images. This iterative technique adds varying amounts of low spatial frequency components to each reconstructed image line until the region at the very edge of the film becomes flat. A hybrid technique is also discussed that improves calculation of those spatial frequency components. This hybrid technique substitutes low spatial frequencies from wide tomographic scan data into images reconstructed from a narrow tomographic scan. This narrow scan geometry provides better reconstruction of the structures between planes, but the wide scan data is less susceptible to problems resulting from image noise in the reconstruction of low spatial frequencies. Finally, a plurality of data from different reconstructions can be interleaved in order to simulate thin slices of structures within the patient's body.

Although only a few exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims.

What is claimed is:

1. A tomosynthesis apparatus, comprising:

an x-ray tomography machine for producing a plurality of x-ray projection images of a subject including an x-ray source, and detection means; and

processing means, connected to receive said plurality of projection images, for:

(a) shifting and reconstructing said projection x-ray images to obtain a tomosynthesis matrix of images T;

(b) acquiring a blurring matrix F having components which represent out-of-focus and in-focus components of said matrix T;

(c) obtaining a matrix P representing only in-focus components of said imaged subject by solving a matrix equation including said matrix T and said matrix F;

(d) correcting said matrix P for low spatial frequency components; and

(e) displaying images indicative of contents of said matrix P.

2. An apparatus as in claim 1 wherein said processing means is also for correcting said images to improve reconstruction of between-plane structures.

3. An apparatus as in claim 1 wherein said processing means is also for weighting said projection images before said shifting and reconstructing, each said image being weighted in a way such that images obtained towards a ninety-degree orientation of said x-ray source and detection means are more heavily weighted than images obtained towards shallower angle orientation of said x-ray source and detection means.

4. An apparatus as in claim 3 wherein said processing means includes means for imaging an area outside said subject and correcting all of said image by an amount to cancel non-zero image components of said area outside said subject, to correct for said low spatial frequencies.

5. An apparatus as in claim 4 wherein said imaging means includes means for imaging an area outside said subject, means for determining a DC level in a predetermined area of said area outside of the subject, and means for adding a correction factor to said image to reduce said DC level to zero in said predetermined area.

6. An apparatus as in claim 5 wherein said imaging means includes means for iteratively determining low spatial frequency components of said area outside the subject, means for determining inverses of said low spatial frequency components, and means for adding said inverses to said image to zero out said low spatial frequency components in said area outside the subject.

7. An apparatus as in claim 6 wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

8. An apparatus as in claim 7 wherein said x-ray tomography machine comprises:

a patient table for receiving a patient;

an x-ray source on one side of said patient; and

means for receiving an x-ray image on the other side of said patient.

9. An apparatus as in claim 8 further comprising an array processor coupled to said processing means, for Fourier transforming said plurality of x-ray images and for solving said matrix equation, thereby accelerating said processing means.

10. An apparatus as in claim 1 wherein said processing means includes means for imaging an area outside said subject and correcting all of said image by an amount to cancel non-zero image components of said area outside said subject, to correct for said low spatial frequencies.

11. An apparatus as in claim 10 wherein said imaging means includes means for determining a DC level in a predetermined area of said area outside of the subject, and means for adding a correction factor to said image to reduce said DC level to zero in said predetermined area.

12. An apparatus as in claim 10 wherein said imaging means includes means for iteratively determining low spatial frequency components of said area outside the subject, means for determining inverses of said low spatial frequency components, and means for adding said inverses to said image to zero out said low spatial frequency components in said area outside the subject.

13. An apparatus as in claim 1 wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from

PE

Samsung Exhibit 1002, Page 166 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

14. A tomosynthesis apparatus, comprising:

an x-ray tomography machine for producing a plurality of x-ray projection images of a subject including an x-ray source, and detection means; and

processing means, connected to receive said plurality of projection images, for:

(a) weighting each said projection image according to a position of each said image, such that images obtained toward a ninety degree orientation of said x-ray source and detection means are more heavily weighted than images obtained towards shallower angle orientations of said x-ray source and detection means;

(b) shifting and reconstructing said projection images to obtain a tomosynthesis matrix of images T;

(c) acquiring a blurring matrix F representing out-of-focus and in-focus components of said matrix T;

(d) obtaining a matrix P representing only in-focus components of said x-ray imaged subject by solving a matrix equation including said matrix T and said matrix F; and

(e) displaying images indicative of the contents of said matrix P.

15. An apparatus as in claim 14 wherein said processing means includes means for imaging an area outside said subject and correcting for non-zero components thereof.

16. An apparatus as in claim 15 further comprising:

means for analyzing an image area of a particular column of a particular image of said matrix P, said image area being one outside the subject;

means for determining a non-zero component of said image area and producing a correction value substantially equal to said non-zero component, but having a negative value compared therewith;

means for adding said correction value to said column to zero out said area outside said subject; and

means for controlling said analyzing means, said determining means and said adding means to operate for all of said columns in all of said images in said matrix P.

17. An apparatus as in claim 16 wherein said processing means further comprises:

means for imaging an area outside the subject;

means for iteratively determining a plurality of low spatial frequencies;

means for determining non-zero components of said area outside the subject respectively occurring at said plurality of low spatial frequencies; and

means for adding a value of each of said spatial frequencies to said image which cancels said low spatial frequencies in said area.

18. An apparatus as in claim 17 wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

19. An apparatus as in claim 14 further comprising:

means for analyzing an image area of a particular column of a particular image of said matrix P, said image area being one outside the subject;

means for determining a non-zero component of said image area and producing a correction value substantially equal to said non-zero component, but having a negative value compared therewith;

means for adding said correction value to said column to zero out said area outside said subject; and

means for controlling said analyzing means, said determining means and said adding means to operate, for all of said columns in all of aid images in said matrix P.

20. An apparatus as in claim 14 wherein said processing means further comprises:

means for imaging an area outside the subject;

means for iteratively determining a plurality of low spatial frequencies;

means for determining non-zero components of said area outside the subject respectively occurring at said plurality of low spatial frequencies; and

means for adding a value of each of said spatial frequencies to said image which cancels said low spatial frequencies in said area.

21. An apparatus as in claim 20 wherein said processing means further comprises a column counter and a frequency counter for maintaining a count of respective columns and frequencies, respectively.

22. An apparatus as in claim 14 wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

23. An apparatus as in claim 12 wherein said processing means is also for receiving said plurality of images and Fourier transforming said plurality of images.

24. An apparatus as in claim 14 wherein said processing means is also for:

(f) initiating an image counter which points to a specific image contained in said matrix P;

(g) initiating a frequency counter which maintains a spatial frequency value ω;

(h) determining if areas outside said subject for said image represented by said image counter have a non-zero value at said frequency ω;

(i) determining a value to cancel said non-zero value, and adding said value to said image of said subject;

(j) determining if said frequency value ω is below a limit;

(k) incrementing said frequency value ω if below said limit and repeating said functions (h)-(k) until above said limit;

(l) determining if said image counter is above a limit;

(m) incrementing said image counter if below said limit and repeating said functions (g)-(m) until said image counter is above said limit; and

(n) displaying images indicative of contents of said matrix P as corrected by said functions (f)-(m).

25. An apparatus as in claim 24 wherein said processing means includes means for imaging an area outside said subject and correcting all of said image by an amount to cancel non-zero image components of said area outside said subject, to correct for low spatial frequencies.

26. An apparatus as in claim 25 wherein said imaging means includes means for imaging an area outside said subject, means for determining a DC level in a predetermined area of said area outside of the subject, and means for adding a correction factor to said image to cancel out said DC level in said predetermined area.

PE

Samsung Exhibit 1002, Page 167 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

27. An apparatus as in claim 26 wherein said imaging means includes means for iteratively determining non-zero components of said area outside the subject and adding a correction for specific spatial frequency components to zero out said non-zero areas.

28. An apparatus as in claim 27 wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

29. An apparatus as in claim 28 wherein said x-ray tomography machine comprises a patient table for receiving a patient;

an x-ray source on one side of said patient; and

means for receiving an x-ray image on the other side of said patient.

30. An apparatus as in claim 29 wherein said imaging means further comprises:

a frequency counter for maintaining a count of a particular spatial frequency;

a column counter for maintaining a count of a particular image column;

means for analyzing an image area which is outside the subject for said particular image column to determine a value of said particular frequency;

means for adding a value of said frequency to said column in order to cancel out said particular frequency;

means for incrementing said frequency counter; and

means for incrementing said column counter.

31. A tomosynthesis apparatus, comprising:

an x-ray tomography machine for producing a plurality of x-ray projection images of a subject and of an area outside said subject including an x-ray source, and detection means; and

processing means, connected to receive said plurality of images, for:

(a) shifting and reconstructing said projection x-ray images to obtain a tomosynthesis matrix of images T;

(b) acquiring a blurring matrix F having components which represent out-of-focus and in-focus components of said matrix T;

(c) obtaining a matrix P representing only in-focus components of said x-ray imaged subject by solving a matrix equation including said matrix T and said matrix F;

(d) determining a DC level in at least a portion of said area outside of the subject;

(e) adding a correction factor to said image to substantially zero out said DC level in said predetermined area, to form a corrected matrix P; and

(f) displaying images indicative of contents of said corrected matrix P.

32. An apparatus as in claim 31 wherein said processing means is also for weighting said projection images before shifting and correcting, each image being weighted in a way such that images obtained towards a ninety-degree orientation of said x-ray source and detection means are weighted higher than images obtained towards shallower angle orientation on said x-ray source and detection means.

33. An apparatus as in claim 32 wherein said processing means includes means for iteratively determining non-zero components of said area outside the subject and adding a correction for specific spatial frequency components to zero out said non-zero areas.

34. An apparatus as in claim 33 wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

35. An apparatus as in claim 34 wherein said processing means comprises:

means for analyzing an image area outside the subject for a particular column in a particular image;

means for determining a non-zero DC component of said column; and

means for adding values to each of said columns in said images which zeros out said area outside said subject.

36. An apparatus as in claim 31 wherein said processing means includes means for iteratively determining non-zero components of said area outside the subject and adding a correction for specific spatial frequency components to zero out said non-zero areas.

37. An apparatus as in claim 31 wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

38. An apparatus as in claim 31 wherein said processing means comprises:

means for analyzing an image area outside the subject for a particular column in a particular image;

means for determining a non-zero DC component of said column; and

means for adding values to each of said columns in said images which zero out said area outside said subject.

39. An apparatus as in claim 31 wherein said imaging means further comprises: a frequency counter for maintaining a count of a particular spatial frequency:

a column counter for maintaining a count of a particular image column;

means for analyzing an image area outside the subject for said particular column to determine a value of said particular frequency;

means for adding a value of said frequency to said column which zeros out said particular frequency;

means for incrementing said frequency counter; and

means for incrementing said column counter.

40. A tomosynthesis apparatus, comprising:

an x-ray tomography machine including an x-ray source, and detection means for producing a plurality of x-ray images of a subject including data from a wide scan of said x-ray source and data from a narrow scan of an x-ray source; and

processing means, connected to receive said plurality of images, for;

(a) Fourier transforming said plurality of x-ray images;

(b) shifting and reconstructing said x-ray images to obtain tomosynthesis matrices of images T_N and T_W representing said narrow and wide swings of said x-ray tube respectively;

(c) acquiring blurring matrices F_N and F_W having components which represent out-of-focus and in-

PE

Samsung Exhibit 1002, Page 168 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

focus components of said matrices $\tilde{T}_N$ and $\tilde{T}_W$ respectively;

(d) multiplying said matrices $\tilde{T}_N$ and $\tilde{T}_W$ by inverses of said matrices $\tilde{F}_N$ and $\tilde{F}_W$ respectively, to obtain matrices $\tilde{P}N$ and $\tilde{P}W$ respectively, each representing only in-focus components of said x-ray imaged subject;

(e) replacing low spatial frequencies in said matrix $\tilde{P}_N$ with low spatial frequencies from said matrix $\tilde{P}_W$ to obtain a matrix $\tilde{P}$;

(f) inverse Fourier transforming said matrix $\tilde{P}$ to obtain a matrix $\tilde{P}$; and

(g) displaying images indicative of contents of said matrix P.

41. An apparatus as in claim 40 wherein said processing means is also for weighting said projection images before shifting and correcting, each image being weighted in a way such that images obtained towards a ninety-degree orientation of said x-ray source and detection means are weighted heavier than images obtained towards shallower angle orientation of said x-ray source and detection means.

42. An apparatus as in claim 41 wherein said correcting means is also for imaging an area outside said subject and correcting for non-zero spatial frequency components of said area outside said subject.

43. An apparatus as in claim 42 wherein said processing means further includes means for imaging an area outside said subject, means for determining a DC level in a predetermined area outside of said subject, and means for adding a correction factor to said image to zero out said DC level in said predetermined area.

44. An apparatus as in claim 43 wherein said processing means includes means for iteratively determining non-zero spatial frequency components of said area outside the subject and adding a correction to said image to zero out said non-zero areas.

45. An apparatus as in claim 44 wherein said processing means includes an array processor for Fourier transforming said images and for performing matrix operations.

46. An apparatus as in claim 45 wherein said imaging means further comprises:

a frequency counter for maintaining a count of a particular image column;

a column counter for maintaining a count of a particular image column;

means for analyzing an image area which is outside the subject for said particular column to determine a value of said particular frequency;

means for adding a value of said spatial frequency to said column in said image which cancels out said particular frequency in said area outside the subject;

means for incrementing said frequency counter; and

means for incrementing said column counter.

47. An apparatus as in claim 40 wherein said processing means is also for imaging an area outside said subject and correcting for non-zero spatial frequency components of said area outside said subject.

48. An apparatus as in claim 47 wherein said processing means further includes means for determining a DC level in a predetermined area outside of said subject, and means for adding a correction factor to said image to zero out said DC level in said predetermined area.

49. An apparatus as in claim 47 wherein said processing means includes means for iteratively determining non-zero spatial frequency components of said area outside the subject and adding a correction to said image to zero out said non-zero areas.

50. An apparatus as in claim 40 wherein said processing means includes an array processor for Fourier transforming said images and for performing said matrix operations.

51. An apparatus as in claim 40 wherein said imaging means further comprises:

a frequency counter for maintaining a count of a particular frequency;

a column counter for maintaining a count of a particular image column;

means for analyzing an image area which is outside the subject for said particular column to determine a value of said particular frequency;

means for adding a value of said spatial frequency to said column in said image which conceals out said particular frequency in said area outside the subject;

means for incrementing said frequency counter; and

means for incrementing said column counter.

52. A tomosynthesis apparatus, comprising:

an x-ray tomography machine for producing a plurality of x-ray projection images of a subject and of areas outside said subject including an x-ray source, and detection means; and

processing means, connected to receive said plurality of images, for:

(a) shifting and reconstructing said x-ray images to obtain a tomosynthesis matrix of images T;

(b) acquiring a blurring matrix F having components which represent out-of-focus and in-focus components of said matrix T;

(c) obtaining a matrix P representing only in-focus components of said x-ray imaged subject by solving a matrix equation including said matrix T and said matrix F;

(d) initiating an image counter which points to a specific image in said matrix P;

(e) initiating a frequency counter which maintains a spatial frequency value ω;

(f) determining if said areas outside said subject at said image of said image counter have a non-zero value at said spatial frequency ω;

(g) determining a value of said spatial frequency ω to cancel said non-zero value, and adding said value to said image of said subject;

(h) determining if said frequency value ω is below a limit;

(i) incrementing said frequency value ω if below said limit and repeating said functions (f), (g), (h) and (i) until above said limit;

(j) determining if said image counter is above a limit;

(k) incrementing said image counter if below said limit and repeating said functions (e)–(k) until said image counter is above said limit; and

(l) displaying images indicative of contents of said matrix P as corrected by said functions (d)–(k).

53. An apparatus as in claim 52 wherein said processing means is also for weighting said projection images before shifting and correcting, each image being weighted in a way such that images obtained towards a ninety-degree orientation of said x-ray source and detection means are weighted higher than images obtained towards shallower angle orientation of said x-ray source and detection means.

54. An apparatus as in claim 53 wherein said processing means is also for imaging an area outside said sub-

PE

Samsung Exhibit 1002, Page 169 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

ject, determining a DC level in a predetermined area outside of the subject, and for adding a correction factor to said image to zero out said DC level of said predetermined area.

55. An apparatus as in claim **54** wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

56. An apparatus as in claim **55** wherein said x-ray tomography machine comprises a patient table for receiving a patient;

an x-ray source on one side of said patient; and

means for receiving an x-ray image on the other side of said patient.

57. An apparatus as in claim **52** wherein said processing means is also for determining a DC level in a predetermined area outside of the subject, and for adding a correction factor to said image to zero out said DC level of said predetermined area.

58. An apparatus as in claim **52** wherein said tomography machine includes means for producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

59. A tomosynthesis apparatus, comprising:

an x-ray tomography machine for producing a plurality of x-ray images of a subject and of areas outside said subject; and

processing means, connected to receive said plurality of x-ray images of a subject and of areas outside said subject; and

processing means, connected to receive said plurality of images, for:

(a) Fourier transforming said plurality of x-ray images;

(b) shifting and reconstructing said x-ray images to obtain tomosynthesis matrices of images $\tilde{T}_N$ and $\tilde{T}_W$ representing narrow and wide swings of said x-ray tube respectively;

(c) acquiring blurring matrices $\tilde{F}_N$ and $\tilde{F}_W$ having components which represent out-of-focus and in-focus components of said matrices $\tilde{T}_N$ and $\tilde{T}_W$;

(d) multiplying said matrices $\tilde{T}_N$ and $\tilde{T}_W$ by inverses of said matrices $\tilde{F}_N$ and $\tilde{F}_W$ respectively to obtain matrices $\tilde{P}_N$ and $\tilde{P}_W$ respectively, each representing only in-focus components of said x-ray imaged subject;

(e) replacing low spatial frequencies in said matrix $\tilde{P}_N$ with low spatial frequencies from said matrix $\tilde{P}_W$ to obtain a matrix $\tilde{P}$;

(f) inverse Fourier transforming said matrix $\tilde{P}$ to obtain a matrix P;

(g) initiating an image counter which points to a specific image of said matrix P;

(h) initiating a frequency counter which maintains a spatial frequency value ω;

(i) determining if said areas outside said subject at said image of said image counter have a non-zero value at said frequency ω;

(j) determining a value of said spatial frequency to cancel said non-zero value, and adding said value to said image of said subject;

(k) determining if said frequency value ω is below said limit and repeating said functions (f), (g), (h) and (i) until above said limit;

(l) incrementing said frequency value ω if below said limit and repeating said functions (f), (g), (h) and (i) until above said limit;

(m) determining if said image counter is above a limit;

(n) incrementing said image counter if below said limit and repeating said functions (e)–(k) until said image counter is above said limit; and

(o) determining a DC level in at least a portion of said area outside of the subject;

(p) adding a correction factor to said image to substantially zero out said DC level in said portion; and

(q) displaying images indicative of contents of a corrected matrix P.

60. A method of matrix-inversion tomosynthesis correction, comprising the steps of:

(a) producing a plurality of x-ray images of a subject and images of an area outside said subject;

(b) shifting and reconstructing said x-ray images for tomosynthesis to obtain a matrix of images T;

(c) acquiring a blurring matrix F having components which represent out-of-focus and in-focus components of said matrix T;

(d) obtaining a matrix P representing only in-focus components of said x-ray imaged subject by solving a matrix equation including said matrix T and said matrix F;

(e) determining a non-zero value of at least a portion of said area outside the subject;

(f) adding a value to said image to cancel said non-zero value; and

(g) displaying images indicative of contents of said matrix P as corrected in steps (e) and (f).

61. A method as in claim **60** comprising the further step of weighting said images before shifting and correcting, each plane being weighted in a way such that images obtained toward a ninety degree orientation of said x-ray source and detection means are more heavily weighted than images obtained towards shallower angle orientations of said x-ray source and detection means.

62. A method as in claim **61** comprising the further steps of iteratively determining non-zero components of said area outside the subject and adding a correction for specified spatial frequency components to zero out said non-zero areas.

63. A method as in claim **60** comprising the further steps of iteratively determining non-zero components of said area outside the subject and adding a correction for specific spatial frequency components to zero out said non-zero areas.

64. A method as in claim **60** comprising the further steps of producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and wherein said processing means is also for replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

65. A method of matrix-inversion tomosynthesis correction, comprising the steps of:

producing a plurality of x-ray projection images of a subject;

weighting each said projection image according to a position of each said image, such that images obtained toward a ninety degree orientation of an x-ray source and detection means are more heavily

PE

Samsung Exhibit 1002, Page 170 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

weighted than images obtained towards shallower angle orientations of said x-ray source and detection means;

shifting and reconstructing said projection images to obtain a tomosynthesis matrix of images T;

acquiring a blurring matrix F representing out-of-focus and in-focus components of said matrix T;

obtaining a matrix P representing only in-focus components of said x-ray imaged subject by solving a matrix equation including said matrix T and said matrix F; and

displaying images indicative of the contents of said matrix P.

66. A method as in claim 65 comprising the further step of imaging an area outside said subject and correcting for non-zero components thereof.

67. A method as in claim 66 comprising the further steps of:

analyzing an image area of a particular column of a particular image of said matrix P, said image area being one outside the subject;

determining a non-zero component of said image area and producing a correction value substantially equal to said non-zero component, but having a negative value compared therewith;

adding said correction value to said column to zero out said area outside said subject; and

controlling said analyzing step, said determining step and said adding step to operate for all of said columns in all of said images in said matrix P.

68. A method as in claim 67 comprising the further steps of:

imaging an area outside the subject;

iteratively determining a plurality of low spatial frequencies;

determining non-zero components of said area outside the subject respectively occurring at said plurality of low spatial frequencies; and

adding a value of each of said spatial frequencies to said image which cancels said low spatial frequencies in said area.

69. A method as in claim 68 comprising the further steps of:

producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and

replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

70. A method as in claim 65 comprising the further steps of:

analyzing an image area of a particular column of a particular image of said matrix P, said image area being one outside the subject;

determining a non-zero component of said image area and producing a correction value substantially equal to said non-zero component, but having a negative value compared therewith;

adding said correction value to said column to zero out said area outside said subject; and

controlling said analyzing step, said determining step and said adding step to operate for all of said columns in all of said images in said matrix P.

71. A method as in claim 65 comprising the further steps of:

imaging an area outside the subject;

iteratively determining a plurality of low spatial frequencies;

determining non-zero components of said area outside the subject respectively occurring at said plurality of low spatial frequencies; and

adding a value of each of said spatial frequencies to said image which cancels said low spatial frequencies in said area.

72. A method as in claim 71 comprising the further step of:

maintaining a count of respective columns and frequencies, respectively.

73. A method as in claim 65 comprising the steps of:

producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and

replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

74. A method as in claim 65 comprising the further steps of:

(a) initiating an image counter which points to a specific image contained in said matrix P;

(b) initiating a frequency counter which maintains a spatial frequency value ω;

(c) determining if areas outside said subject for said image represented by said image counter have a non-zero value at said frequency ω;

(d) determining a value to cancel said non-zero value, and adding said value to said image of said subject;

(e) determining if said frequency value ω is below a limit;

(f) incrementing said frequency value ω if below said limit and repeating said steps (c)–(f) until above said limit;

(g) determining if said image counter is above a limit;

(h) incrementing said image counter if below said limit and repeating said steps (b)–(h) until said image counter is above said limit; and

(i) displaying images indicative of contents of said matrix P as corrected.

75. A method as in claim 65 comprising the further steps of:

maintaining a count of a particular spatial frequency;

maintaining a count of a particular image column;

analyzing an image area which is outside the subject for said particular image column to determine a value of said particular frequency;

adding a value of said frequency to said column in order to cancel out said particular frequency;

incrementing said frequency counter; and

incrementing said column counter.

76. A method of matrix-inversion tomosynthesis correction, comprising the steps of:

producing a plurality of x-ray projection images of a subject and of an area outside said subject;

shifting and reconstructing said projection x-ray images to obtain a tomosynthesis matrix of images T;

acquiring a blurring matrix F having components which represent out-of-focus and in-focus components of said matrix T;

obtaining a matrix P representing only in-focus components of said x-ray imaged subject by solving a matrix equation including said matrix T and said matrix F;

determining a DC level in at least a portion of said area outside of the subject;

adding a correction factor to said image to substantially zero out said DC level in said predetermined area, to form a corrected matrix P; and

PE

displaying images indicative of contents of said corrected matrix P.

77. A method as in claim 76 comprising the further step of:

weighting said projection images before shifting and correcting, each image being weighted in a way such that images obtained towards a ninety-degree orientation of an x-ray source and detection means are weighted higher than images obtained towards shallower angle orientations of said x-ray source and detection means.

78. A method as in claim 77 comprising the further step of:

iteratively determining non-zero components of said area outside the subject and adding a correction for specific spatial frequency components to zero out said non-zero areas.

79. A method as in claim 78 comprising the further steps of:

producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and

replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

80. A method as in claim 79 comprising the further steps of:

analyzing an image area outside the subject for a particular column in a particular image;

determining a non-zero DC component of said column; and

adding values to each of said columns in said images which zero out said area outside said subject.

81. A method as in claim 76 comprising the further step of:

iteratively determining non-zero components of said area outside the subject and adding a correction for specific spatial frequency components to zero out said non-zero areas.

82. A method as in claim 76 comprising the further step of:

producing data from a wide scan of an x-ray source and data from a narrow scan of an x-ray source, and replacing low spatial frequencies from said narrow scan of said x-ray source with low spatial frequencies from said wide scan of said x-ray source.

83. A method as in claim 76 comprising the further steps of:

analyzing an image area outside the subject for a particular column in a particular image;

determining a non-zero DC component of said column; and

adding values to each of said columns in said images which zero out said area outside said subject.

84. A method as in claim 76 comprising the further steps of:

maintaining a count of a particular spatial frequency;

maintaining a count of a particular image column;

analyzing an image area outside the subject for said particular column to determine a value of said particular frequency;

adding a value of said frequency to said column which zeros out said particular frequency;

incrementing said frequency counter; and

incrementing said column counter.

85. A method of matrix-inversion tomosynthesis correction, comprising the steps of:

producing a plurality of x-ray images of a subject including data from a wide scan of said x-ray source and data from a narrow scan of an x-ray source;

Fourier transforming said plurality of x-ray images;

shifting and reconstructing said x-ray images to obtain tomosynthesis matrices of images $\tilde{T}_N$ and $\tilde{T}_W$ representing said narrow and wide scans of said x-ray tube respectively;

acquiring blurring matrices $\tilde{F}_N$ and $\tilde{F}_W$ having components which represent out-of focus and in-focus components of said matrices $\tilde{T}_N$ and $\tilde{T}_W$ respectively;

multiplying said matrices $\tilde{T}_N$ and $\tilde{T}_W$ by inverses of said matrices $\tilde{F}_N$ and $\tilde{F}_W$ respectively, to obtain matrices $\tilde{P}_N$ and $\tilde{P}_W$ respectively, each representing only in-focus components of said x-ray imaged subject;

replacing low spatial frequencies in said matrix $\tilde{P}_N$ with low spatial frequencies from said matrix $\tilde{P}_W$ to obtain a matrix $\tilde{P}$;

inverse Fourier transforming said matrix $\tilde{P}$ to obtain a matrix P; and

displaying images indicative of contents of said matrix P.

86. A method as in claim 85 comprising the further steps of weighting said projection images before shifting and correcting, each image being weighted in a way such that images obtained towards a ninety-degree orientation of said x-ray source and detection means are weighted heavier than images obtained towards shallower angle orientations of said x-ray source and detection means.

87. A method as in claim 86 comprising the further steps of imaging an area outside said subject and correcting for non-zero spatial frequency components of said area outside said subject.

88. A method as in claim 87 comprising the further steps of imaging an area outside said subject, determining a DC level in a predetermined area outside of said subject, adding a correction factor to said image to zero out said DC level in said image to zero out said DC level in said predetermined area.

89. A method as in claim 88 comprising the further steps of iteratively determining non-zero spatial frequency components of said area outside the subject and adding a correction to said image to zero out said non-zero areas.

90. A method as in claim 85 comprising the further steps of imaging an area outside said subject and correcting for non-zero spatial frequency components of said area outside said subject.

91. A method as in claim 90 comprising the further steps of determining a DC level in a predetermined area outside of said subject, and adding a correction factor to said image to zero said DC level in said predetermined area.

92. A method as in claim 90 comprising the further steps of iteratively determining non-zero spatial frequency component of said area outside the subject and adding a correction to said image to zero out said non-zero areas.

93. A method of matrix-inversion correction comprising the steps of:

(a) producing a plurality of x-ray projection images of a subject and of areas outside said subject including an x-ray source, and detection means;

PE

(b) shifting and reconstructing said x-ray images to obtain a tomosynthesis matrix of images T;

(c) acquiring a blurring matrix F having components which represent out-of-focus and in-focus components of said matrix T;

(d) obtaining a matrix P representing only in-focus components of said x-ray imaged subject by solving a matrix equation including said matrix T and said matrix F;

(e) initiating an image counter which points to a specific image in said matrix P;

(f) initiating a frequency counter which maintains a spatial frequency value ω;

(g) determining if said areas outside said subject at said image of said image counter have a non-zero value at said spatial frequency ω;

(i) determining a value of said spatial frequency ω to cancel said non-zero value, and adding said value to said image of said subject;

(j) determining if said frequency value ω is below a limit;

(k) incrementing said frequency value ω if below said limit and repeating said steps (g)-(k) until above said limit;

(l) determining if said image counter is above a limit;

(m) incrementing said image counter if below said limit and repeating said steps (f)-(m) until said image counter is above said limit; and

(n) displaying images indicative of contents of said matrix P as corrected by said steps (e)-(m).

94. A method of matrix-inversion tomosynthesis correction, comprising the steps of:

(a) producing a plurality of x-ray images of a subject and of areas outside said subject;

(b) Fourier transforming said plurality of x-ray images;

(c) shifting and reconstructing said x-ray images to obtain tomosynthesis matrices of images $\tilde{T}_N$ and $\tilde{T}_W$ representing narrow and wide swings of said x-ray tube respectively;

(d) acquiring blurring matrices $\tilde{F}_N$ and $\tilde{F}_W$ having components which represent out-of-focus and in-focus components of said matrices $\tilde{T}_N$ and $\tilde{T}_W$;

(e) multiplying said matrices $\tilde{T}_N$ and $\tilde{T}_W$ by inverses of said matrices $\tilde{F}_N$ and $\tilde{F}_W$ respectively to obtain matrices $\tilde{P}_N$ and $\tilde{P}_W$ respectively, each representing only in-focus components of said x-ray imaged subject;

(f) replacing low spatial frequencies in said matrix $\tilde{P}_N$ with low spatial frequencies from said matrix $\tilde{P}_W$ to obtain a matrix $\tilde{P}$;

(g) inverse Fourier transforming said matrix $\tilde{P}$ to obtain a matrix P;

(g) initiating an image counter which points to a specific image of said matrix P;

(h) initiating a frequency counter which maintains a spatial frequency value ω;

(i) determining if said areas outside said subject at said image of said image counter have a non-zero value at said frequency ω;

(j) determining a value of said spatial frequency to cancel said non-zero value, and adding said value to said image of said subject;

(k) determining if said frequency value ω is below a limit;

(l) incrementing said frequency value ω if below said limit and repeating said steps (i)-l) until above said limit;

(m) determining if said image counter is above a limit;

(n) incrementing said image counter if below said limit and repeating said steps (h)-n) until said image counter is above said limit; and

(o) determining a DC level in at least a portion of said area outside of the subject;

(p) adding a correction factor to said image to substantially zero out said DC level in said portion; and

(q) displaying images indicative of contents of a corrected matrix P.

* * * * *

PE

US007245319B1

(12) **United States Patent**
Enomoto

(10) **Patent No.: US 7,245,319 B1**
(45) **Date of Patent: Jul. 17, 2007**

(54) **DIGITAL IMAGE SHOOTING DEVICE WITH LENS CHARACTERISTIC CORRECTION UNIT**

(75) Inventor: **Jun Enomoto**, Kanagawa (JP)

(73) Assignee: **Fujifilm Corporation**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/330,096**

(22) Filed: **Jun. 11, 1999**

(30) **Foreign Application Priority Data**

Jun. 11, 1998 (JP) 10-163194

(51) **Int. Cl.**
H04N 5/228 (2006.01)
H04N 5/217 (2006.01)

(52) **U.S. Cl.** **348/222.1**; 348/241

(58) **Field of Classification Search** 348/360, 348/355, 96, 97, 105, 222.1, 241, 335, 231.99, 348/231.6, 231.3; 382/298, 300; 235/462.05, 235/462.11
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,185,667	A *	2/1993	Zimmermann	358/209
5,276,519	A *	1/1994	Richards et al.	358/209
5,818,527	A *	10/1998	Yamaguchi et al.	348/335
5,905,530	A *	5/1999	Yokota et al.	348/240.99
6,097,430	A *	8/2000	Komiya et al.	348/218.1
6,219,446	B1 *	4/2001	Kiriki et al.	382/167
6,323,934	B1 *	11/2001	Enomoto	355/40
6,343,146	B1 *	1/2002	Tsuruoka et al.	382/163
6,476,869	B1 *	11/2002	Sekine et al.	348/335
6,538,691	B1 *	3/2003	Macy et al.	348/222.1
6,587,224	B1 *	7/2003	Nabeshima et al.	358/1.9
6,618,081	B1 *	9/2003	Harada et al.	348/231.6
6,775,419	B2 *	8/2004	Maeda et al.	382/275

FOREIGN PATENT DOCUMENTS

JP	6-98170	A	4/1994
JP	6-178197	A	6/1994
JP	6-181530	A	6/1994
JP	6-205273	A	7/1994
JP	6-319106	A	11/1994
JP	7-67028	A	3/1995
JP	9-74514	A	3/1997

* cited by examiner

Primary Examiner—Vivek Srivastava
Assistant Examiner—Justin Misleh
(74) *Attorney, Agent, or Firm*—Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

The digital image shooting device is composed of an image forming lens, an image sensor element, a data processing unit for processing an output signal from the image sensor element into digital image data, an image memory for storing the digital image data; and a lens characteristic correction unit for performing a process of correcting a deterioration of an image quality derived from the image forming lens upon the digital image data by using a lens characteristic of the image forming lens and a position of a frame image photographed. The digital image shooting device is capable of obtaining the image quality which is high enough for the utilization even by using the comparatively low-price lens which does not exhibit a high performance.

12 Claims, 3 Drawing Sheets

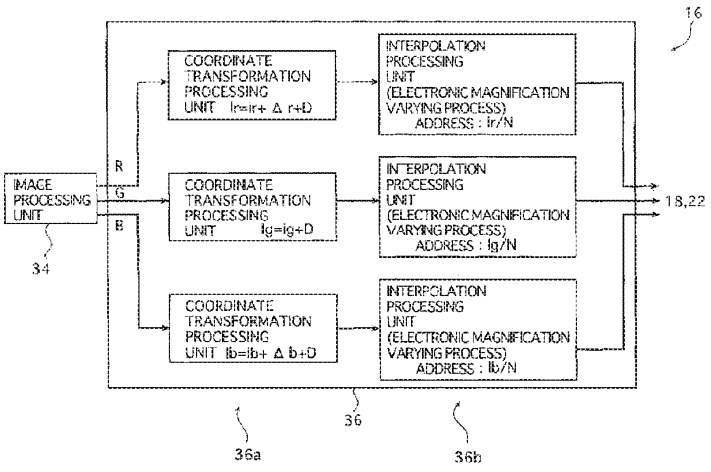


FIG. 1

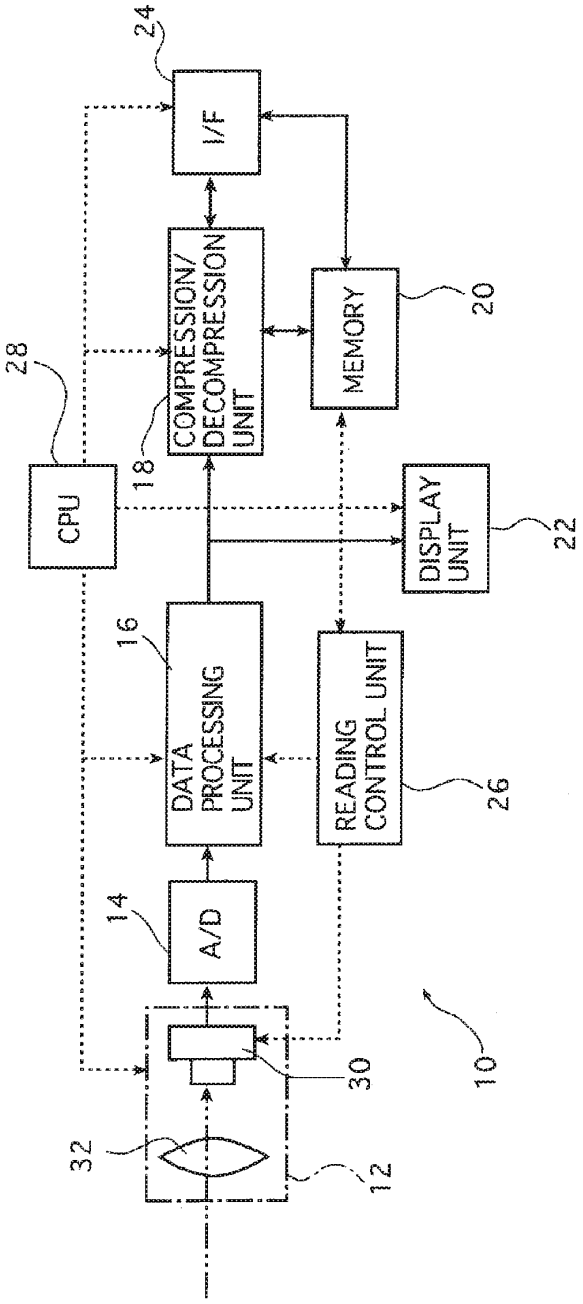

24
I/F
COMPRESSION/
DECOMPRESSION
UNIT
MEMORY
20
28
18
CPU
DISPLAY
UNIT
22
16
DATA
PROCESSING
UNIT
READING
CONTROL UNIT
26
14
A/D
30
10
32
12

FIG. 2

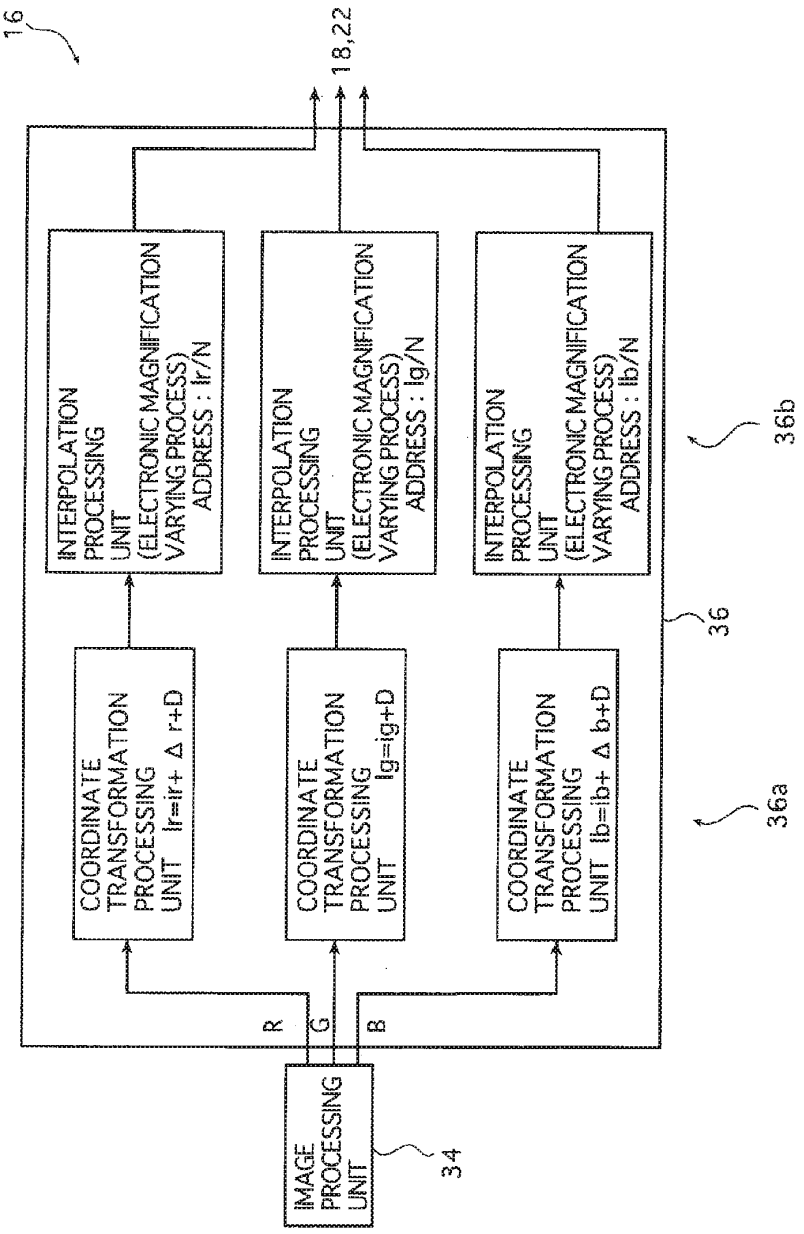

16
18,22
INTERPOLATION PROCESSING UNIT (ELECTRONIC MAGNIFICATION VARYING PROCESS) ADDRESS : Ir/N
INTERPOLATION PROCESSING UNIT (ELECTRONIC MAGNIFICATION VARYING PROCESS) ADDRESS : Ig/N
INTERPOLATION PROCESSING UNIT (ELECTRONIC MAGNIFICATION VARYING PROCESS) ADDRESS : Ib/N
36b
36
COORDINATE TRANSFORMATION PROCESSING UNIT Ir=ir+ Δ r+D
COORDINATE TRANSFORMATION PROCESSING UNIT Ig=ig+D
COORDINATE TRANSFORMATION PROCESSING UNIT Ib=ib+ Δ b+D
36a
R
G
B
IMAGE PROCESSING UNIT
34

FIG. 3A

FIG. 3B

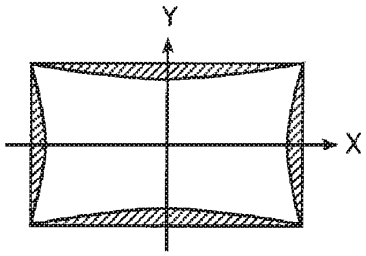
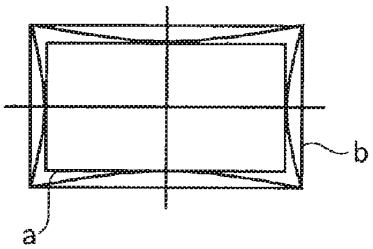


FIG. 3C



DIGITAL IMAGE SHOOTING DEVICE WITH LENS CHARACTERISTIC CORRECTION UNIT

BACKGROUND OF THE INVENTION

The present invention relates generally to a technical filed of a digital image shooting device such as a digital camera, and more particularly to a digital image shooting device capable of photographing (outputting) a high-quality image of which aberrations are corrected even in a case of incorporating a comparatively low-price lens which performance is not so good.

A digital camera, which had initially a small number of pixels and of which representation was in monochrome, has therefore been limited its use to a special application. With a remarkable decrease in costs for the electronic parts of CCD sensors, etc., however, a color representation becomes possible easily, and the application of image data processing expands with a spread of a personal computer. Under such circumstances, the digital camera sharply decreases in price and seems to be popularized.

Recently, a high quality digital camera of which pixel number exceeds 1,000,000 have been commercialized one after another, and also with regard to a memory for storing (recording) the image, there is a tendency of the digital camera to shift from a type of being built in the body of it to a type of using a removable storage medium having a larger capacity.

In the latter type of the digital camera using the removable storage medium, a process of taking the recorded image data into a personal computer becomes highly simple.

As explained above, an enhancement of the image quality in the digital camera is largely influenced by, in addition to an increase in the number of recordable pixels, a performance improvement of an image forming lens, and an improvement of an image processing technology of the photographed image data.

For instance, some of the digital cameras (DS-300 made by Fuji Photo Film Co.,Ltd.) use a 3-powered zoom lens as an image forming lens, of which a lens configuration is based on 3 lens units containing 9 lens elements, and this type of the digital camera becomes substantially equal to a compact camera in terms of the image quality.

However, by using the high-accuracy and high-performance lens, the digital camera which can output the high-quality image can be realized and, while on the other hand, it might be a factor for raising the costs of the digital camera.

conversely, by using the comparatively low-price lens, it is possible to decrease the costs of the digital camera. However it can not be denied that the low-price lens is inferior in performance so that for example, there might occur a chromatic aberration of magnification, a distortion aberration and a decrease in marginal lumination, and quality of the image falls down such that a distortion and a density gradient occur with the outputted image.

SUMMARY OF THE INVENTION

The present invention has been accomplished under these circumstances and has as an object providing a low cost digital image shooting device capable of obtaining the image quality which is high enough for the utilization even by using the comparatively low-price lens which performance is not so high.

In order to attain the object described above, the invention provides a digital image shooting device comprising: an image forming lens; an image sensor element; a data processing unit for processing an output signal from the image sensor element into digital image data; an image memory for storing the digital image data; and a lens characteristic correction unit for performing, by using a lens characteristic of the image forming lens and a position of a frame image photographed, a process of correcting a deterioration of an image quality derived from the image forming lens upon the digital image data.

It is preferable that the image quality deterioration corrected by the lens characteristic correction unit is at least one of a chromatic aberration of magnification, a distortion aberration, defocusing and a decrease in marginal lumination.

It is also preferable that the lens characteristic correction unit corrects the deterioration of the image quality before a process of compressing the digital image data.

It is further preferable that the lens characteristic correction unit performs the correction before the photographing of a next frame or during the photographing of the next frame onward, and the digital image data of the frame which is performed the correction by the lens characteristic correction unit is stored in the image memory.

It is also further preferable that the image memory is a built-in image recording medium or a removable image recording medium.

It is still further preferable that the digital image shooting device of the invention further comprises an image display unit for displaying the photographed image, wherein an image based on the digital image data which is or is not performed the correction process in the lens characteristic correction unit, is displayed on the image display unit, and the digital image data performed the correction process in the lens characteristic correction unit, is stored in a memory.

It is also still further preferable that an image of a region larger than a photographic region confirmed by a photographer is formed on the image sensor element in accordance with missing of pixels which is caused as a result of the correction by the lens characteristic correction unit.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1** is a block diagram schematically showing one example of the digital camera according to the present invention.

FIG. **2** is a block diagram schematically showing a data processing unit of the digital camera shown in FIG. **1**; and

FIGS. **3**A, **3**B and **3**C are conceptual diagrams each showing an image deformation by aberration correction.

DETAILED DESCRIPTION OF THE INVENTION

The digital image shooting device of the present invention will hereinafter be described in details based on a preferred embodiment which will be illustrated in the accompanying drawings.

FIG. **1** is a block diagram showing one example of the digital camera according to the present invention.

Referring to FIG. **1**, a digital camera **10** includes an image shooting unit **12**, an A/D (analog-to-digital) converter **14**, a data processing unit **16**, a data compressing unit (which is hereinafter simply termed a compression unit) **18**, an image memory **20**, a display unit **22**, an I/F (interface) unit **24**, a reading control unit **26**, and a CPU **28** for managing and controlling these units and the whole digital camera **10**.

Note that solid lines indicate a flow of image signals (image data), and dotted lines indicate a flow of control signals respectively in FIG. **1**.

The image shooting unit **12**, which shoots a photographic subject (a scene) and outputs signals after photoelectric conversion, has a color CCD sensor (hereinafter simply referred to as a sensor) **30** for photoelectrically reading the image by separating the image into three primary colors red (R), green (G) and blue (B), an image forming lens **32** for forming the subject image on the sensor **30** and, in addition, though not illustrated, a variable stop for controlling a quantity of light beams incident in the sensor **30**, and an amplifier for amplifying output signals from the sensor **30**.

The output signals (the image signals) from the imaging unit **12** are converted to digital image signals by the A/D converter **14**, and thereafter transmitted to the data processing unit **16**.

Note that the reading control unit **26** controls such as an image reading (sampling) timing of the sensor **30**, an electronic shutter speed (a storage time), and a processing timing of the image signal in the data processing unit **16**, corresponding thereto.

The data processing unit **16**, which makes a predetermined data processing on the digital image signals converted by the A/D converter **14** and outputs it as an output image data (hereinafter simply referred to as image data) to the compression unit **18** and the display unit **22**, as illustrated in FIG. **2**, includes an image processing unit **34** and a lens characteristic correction unit **36** that is particular to the present invention. It is to be noted that a processing condition in the data processing unit **16** is set by, e.g., the CPU **28**.

The image processing unit **34** makes a variety of image processes such as a conversion of the image signal into the image (density) data, white balance control of the image, gray balance control thereof, density control thereof, color balance control thereof and a sharpness (sharpening) process.

On the other hand, the lens characteristic correction unit (hereinafter be simply called a characteristic correction unit) **36** corrects deterioration of image quality origination in lens characteristics of the image forming lens **32** by using the lens characteristics of the image forming lens **32** an image position. The characteristic correction unit **36**, in the embodiment illustrated herein, corrects a chromatic aberration of magnification and a distortion aberration originating in the lens characteristic and, more preferably, corrects aberrations such as a decrease in marginal lumination and defocusing.

As known well, a color image is formed of the three primary colors of R, G and B, however, a refractive index (an image forming magnification) of the lens is subtly different depending on a wavelength, and therefore the image forming magnifications of light of R, G and B is different, viz., the chromatic aberration of magnification occurs. Hence, if the image formed on the sensor **30** is just reproduced as a visible image, a color deviation occurs on the obtained image.

Further, it is required for obtaining a high-quality photographic image that a plane perpendicular to the optical axis is formed on the image forming plane corresponding thereto. In a lens which performance is not so good, however, a deviation of the image forming position occurs in the optical-axis direction and a distortion i.e. distortion aberration occurs on the formed image. Consequently, if the image formed on the sensor **30** is just reproduced as the visible image, the distortion might occur on the obtained image.

As described above, if the image containing the chromatic aberration of magnification and the distortion aberration is shown on a display, and just reproduced as the visible image in the form of a hardcopy or etc., on outputted image becomes an image which has a color deviation, a peripheral distortion, a decrease in the marginal lumination and defocusing and so on.

Therefore, the digital camera **10** according to the present invention includes the characteristic correction unit **36** to correct the chromatic aberration of magnification and the distortion aberration originating in the lens characteristics so that even when using a low-price lens, the digital camera **10** is able to output the high-quality image with a stability that there is neither the distortion nor the color deviation, and a cost for the digital camera can be remarkably reduced.

The characteristic correction unit **36** memorizes the lens characteristics of the image forming lens **32** incorporated into the digital camera **10**, and corrects the chromatic aberration of magnification and the distortion aberration, etc. of the image on the basis of the lens characteristics.

The lens characteristics is not limited particularly. However, generally the characteristics of the chromatic aberration of magnification and the distortion aberration of the lens and the characteristics of the aberrations such as the decrease in the marginal lumination and the defocusing, can be approximated to some extent by a cubic function which uses a distance (which is expressed by, e.g., x-y) from the optical axis of the lens, i.e., from the center of the image as a parameter. Hence, corresponding to the image forming lens **32** mounted on the camera, a function representing the characteristic of the chromatic aberration of magnification and a function representing the distortion aberration corresponding thereto, may be stored as lens characteristics.

The characteristic correction unit **36** performs the process of correcting the chromatic aberration of magnification and the distortion aberration by use of the above-mentioned lens characteristics and the image position i.e., an information of the position of the image data (pixels), e.g., a coordinate position (pixel number from the center) from the center of the image.

Note that the coordinates in this case may be the x-y coordinates or the polar coordinates. Further, the information of the position of the image data is not restricted to the center of the image as a basis, but various kind of things can be used. For example, a corner portion (such as a left upper corner, etc.) of the image and a certain pixel (e.g., a pixel of a pixel number No.1) may be set as a basis. Namely, according to the present invention, the various kind of position information can be used, which detects the position of the image (pixels) relatively.

Herein, however, if the chromatic aberration of magnification and the distortion aberration are separately corrected by using the lens characteristics and the position information (hereinafter referred to as pixel position), the calculation takes a long time and an interpolating calculation needs to be done a plurality of times so that there arises a problem that the image quality might be deteriorated.

Therefore, in the embodiment illustrated herein, a preferable mode is that image magnifications of R and B are converted with "G" being normally a basic color among the three primary colors of R, G, and B, the chromatic aberration of magnification is corrected by matching the R and B images with the G image, and thereafter the distortion aberration is corrected. A proper position of each pixel is thereby calculated, and the image data of each pixel is subjected to the interpolating calculation, thereby making it feasible to obtain the image data in which the chromatic

aberration of magnification and the distortion aberration of the photographed image are corrected.

Accordingly, the calculation for the G image may suffice for the distortion aberration, and hence the chromatic aberration of magnification and the distortion aberration can be corrected under a more preferable condition because of a reduction in quantity of normal and interpolating calculations.

The characteristic correction unit **36** for carrying out the correcting method described above, as shown in the conceptual diagram in FIG. **2**, includes a coordinate transformation processing unit **36***a* and an interpolation processing unit **36***b*.

Incidentally, referring to FIG. **2**, Ir, Ig and Ib designate the pixel positions (addresses) of the image data (input image data) supplied from the image processing unit **34**, ir, ib and ib represent the pixel positions of the image data of which the chromatic aberration of magnification and the distortion aberration are corrected, Δr and Δb denote the deviation quantities (i.e., the correction quantities) of the R- and B-pixel positions from the G-pixel position due to the chromatic aberration of magnification, and D designates the deviation quantity of the G-pixel position due to the distortion aberration.

The characteristic correction unit **36**, when supplied with the image data from the image processing unit **34**, makes the coordinate transformation processing unit **36***a* calculate the deviation quantities Δr and Δb of the pixel values ir and ib of the R- and B-image data from the G-image data ig due to the chromatic aberration of magnification by use of the lens characteristics described above, and further calculate the deviation quantity D of the input G-image data ig due to the distortion aberration.

Next, as shown in FIG. **2**, the coordinate transformation processing unit **36***a* calculates the pixel position Ir of the R-image data of which the chromatic aberration of magnification and the distortion aberration are corrected by adding Δr and D to each pixel position ir of the input R-image data. Then, the coordinate transformation processing unit **36***a* calculates the pixel position Ib of the B-image data of which the chromatic aberration of magnification and the distortion are corrected by adding Δb and D to each pixel position ib of the input B-image data. Further, the coordinate transformation processing unit **36***a* calculates the pixel position Ig of the G-image data of which the distortion is corrected by adding D to each pixel position ig of the input G-image data.

That is, the calculation proceeds such as correcting the chromatic aberrations of magnification of the R- and B-images with the G-image as a basis, making the positional alignment of the whole images with the G-image, correcting the distortion aberration of the whole by use of the deviation quantity D of the G-image due to the distortion aberration, and thus calculating the pixel positions of the R- G- and B-images of which the chromatic aberrations of magnification and the distortion aberration are corrected.

The interpolation processing unit **36***b* calculates the image data of which the chromatic aberration of magnification and the distortion aberration are corrected by executing a data interpolating process (N-times interpolation), which involves the use of the pixel positions Ir, Ig and Ib with the chromatic aberration of magnification and the distortion aberration being corrected in the coordinate transformation processing unit **36***a*, and supplies the thus calculated image data to a decompression unit **18** and/or a display unit **22**. Namely, according to this method, the deviation quantity of the pixel position which is attributed to the chromatic aberration of magnification and the distortion aberration, is calculated, thereby recognizing which position each pixel (the image data concerned) should normally exist in. Then, the interpolating (calculating) process of the image data is executed in accordance with that proper position, thereby obtaining the image data of which the chromatic aberration of magnification and the distortion aberration are corrected.

The interpolation processing method is not particularly limited, and a variety of known methods such as, e.g., a bilinear interpolation and a spline interpolation, etc. can be utilized.

There have been in recent years many types of digital cameras **10**, to which a zooming function is added, capable of the photography to form an image by changing the magnification through a zoom lens.

The zooming photography is optically conducted by principally changing the image forming magnification of the image forming lens **32**. If the optical variable power of the image forming lens **32** is not sufficient enough to cover a photographic magnification variable range, however, an electronic magnification varying process based on the image data is executed, thereby enlarging or reducing the image.

Note that if photographed by use of the zoom lens, the aberrations described above may be corrected preferably based on the lens characteristics corresponding to each focal length. In this case, it is preferable to store the lens characteristics at a plurality of focal lengths of the zoom lens, convert the lens characteristics at the plurality of focal lengths with the focal length when photographed, and obtain the lens characteristic at the focal length when photographed through the lens. Herein, as for the lens characteristics, each of the lens characteristics at switchable focal lengths may be held (stored), or the lens characteristic at each focal length exhibiting a high photographic probability, may respectively be stored, or the lens characteristics on the order of three stages such as T (Telephoto), M (Middle, or Standard) and W (Wide-angle) may be stored. Note that a lens characteristic at a focal length which is not stored can be obtained by effecting the interpolating calculation from the lens characteristics at focal lengths anterior and posterior to that non-stored focal length.

On the other hand, the digital cameras **10** each having an interchangeable lens has been recently put on the market, and the interchangeable lens of the conventional camera using the photographic film is usable in some of those cameras. In the case of taking a photo using such an interchangeable lens, there are required the lens characteristics of the interchangeable lens. Therefore, the lens characteristics corresponding to lens data are stored for every usable interchangeable lens, the interchangeable lens data are received from the interchangeable lens on the occasion of the photography, and the aberrations described above may be corrected based on the lens characteristics.

Incidentally, the distortion aberration normally takes a bobbin winder shape shown in FIG. **3**B at the telephoto, and a barrel shape in contrast with the bobbin winder at the wide angle, and may be corrected in both cases. The chromatic aberration of magnification is not, however, conspicuous at the wide angle, and therefore the correcting process may be omitted.

Thus, in the case of performing the photography using the zoom lens and the interchangeable lens, it is preferable that the image aberrations derived from the lens through which the subject image is photographed be corrected by using the data on the focal length of the lens when photographing the subject image, the lens characteristics at that focal length, and the positional data of the image. It is also preferable on the occasion of correcting the aberrations described above

that the lens characteristics at the plurality of focal lengths stored are converted with the focal length when photographing, the lens characteristic at the focal length when photographing through this lens are obtained, or the lens characteristic at the focal length of the interchangeable lens used are obtained, there is calculated using the obtained lens characteristic the deviation quantities, attributed to the chromatic aberration of magnification, of the image positions of the colors other than the color which is fiducial for the three primary colors, a proper position of each image of which the distortion aberration and the chromatic aberration of magnification are corrected is calculated by use of the deviation quantity due to the chromatic aberration of magnification and the deviation quantity of the fiducial color image position which is attributed to the distortion aberration, and the distortion aberration and the chromatic aberration of magnification are corrected using this proper position, or the electronic magnification varying process is executed using this proper position.

Such processes being thus implemented, in the case of even the subject image photographed by a comparatively low-price digital camera using the lens which does not exhibit a high lens performance, it is feasible to correct the deterioration of the image quality by executing the image processing, which is derived from the image aberration, viz., the image quality deterioration induced from the aberration of the lens, and output stably the high-quality image with no distortion and no color deviation, depending on neither the photographic magnification nor the focal length.

As known well, the electronic magnification varying process is executed by effecting the interpolating process on the image data, however, the interpolating process is followed by the deterioration of the image quality, and therefore it is preferable that the number of interpolating processes be minimized.

Accordingly, the interpolation processing unit **36***b* in the embodiment illustrated herein, by way of a preferable mode on the occasion of executing the electronic magnification varying process, controls a magnification (N-powered interpolation) in the interpolating calculation in accordance with an electronic magnification varying rate when effecting the interpolating process for obtaining the image data of which the above-mentioned aberrations are corrected, and simultaneously executes the electronic magnification varying process. It is feasible in this embodiment to correct the chromatic aberration of magnification and the distortion aberration, and execute the electronic magnification varying process by performing the interpolating process once.

Incidentally, as discussed above, the image exhibiting neither the color deviation nor the distortion can be obtained after correcting the chromatic aberration of magnification and the distortion aberration. When these aberrations are corrected, however, there might be a case where a configuration and a size of the image change.

For instance, if the image before being corrected presents the bobbin winder shaped distortion aberration as shown in FIG. **3**A, the image after the correction, as illustrated in FIG. **3**B, takes a configuration that the central portions of face-to-face sides of the rectangular shape largely shrink from both side ends toward the center in X- and Y-directions, wherein there might occur so-called vignetting which corresponds to oblique-line regions where the image can not be reproduced.

The digital camera **10** performs the photographing while confirming the photographic region on the display device **22**. In this case, however, when displaying on the display device **22** the image whose aberrations have been corrected, the image containing the vignetting as shown in FIG. **3**B is displayed thereon, and it follows that the image to be outputted outside similarly becomes the vignetted image.

Therefore, in the digital camera **10** of the present invention, assuming previously the vignetting caused as a result of correcting the aberrations, as illustrated in FIG. **3**C, it is preferable that a region **1** of the image data to be taken in after being actually photographed (after forming the image on the sensor **30**) is set larger than an image region a (a visual field of a viewfinder) to be reproduced on the display device **22**, and that the image region to be outputted outside is coincident with the image region a to be reproduced on the display device **22**. Alternatively, the image region to be reproduced on the display device **22** may be set smaller than the region to be actually photographed, and the same outside outputting may be carried out. Further, the image after being corrected is displayed, and the image vignetted region and a cut-out region may be framed.

Moreover, the interpolating magnification in the interpolation processing unit **36***b* is set corresponding to a degree of the vignetting, and the slightly-enlarged image may be displayed and/or outputted outside.

According to the device in the embodiment illustrated herein, the characteristic correction unit **36** corrects both of the chromatic aberration of magnification and the distortion aberration by way of the preferable mode, however, the present invention is not limited to this mode. The characteristics of any one of the chromatic aberration of magnification and the distortion aberration are stored as the lens characteristics, and any one of these aberrations may be corrected by use of the lens characteristics and the image position.

Furthermore, there are stored the information (data) about not only at least one of the chromatic aberration of magnification and the distortion aberration but also the defocusing (PSF: Point Spread Function), the decrease in the marginal lumination, etc. attributed to the lens characteristics, and at least one of the chromatic aberration of magnification and the distortion aberration is corrected. In addition to or instead of this correction, the decrease in the marginal lumination and the defocusing may also be corrected.

Another option is that whether or not the correction pertaining to those lens characteristics should be conducted is set selectable, and the correction to be carried out may also be set selectable.

The image data processed by the interpolation processing unit **36***b* of the data processing unit **16** are supplied to the compression unit **18** and/or the display unit **22**.

The compression unit **18** compresses the image data and supplies the image memory **20** and the I/F unit **24** with the compressed image data. The image data are thus stored in the image memory **20**, and outputted from the I/F unit **24** to an outside personal computer, a TV, and outside recording mediums (a drive thereof) such as a floppy disk and an MO (magneto-optical) disk, etc. A method and a form of compressing the image data in the compression unit **18** are not particularly restricted, and the data compression may be executed by any methods and in any forms. The conventionally known methods and forms may be adopted. There may be adopted typical image data compression forms such as, e.g., JPEG, GIF and FlashFix. A selection of which form is adopted among those typical image data compression forms may be properly made corresponding to an image quality (a data quantity per frame) requested of the target image and a capacity of the image memory **20**.

Note that the compression unit **18** is not limited to what compresses the image data supplied from the data process-

ing unit **16**, and may also be what rereads the compressed image data from the image memory **20** and decompresses the image data in order to display on the display unit **22** the compressed image data stored in the image memory **20**.

It is also to be noted that the image data compression may preferably be done after the lens characteristic correction unit **36** in the data processing unit **16** has corrected the aberrations originating in the lens. This is because the compression forms such as JPEG and FlashPix which are normally frequently used are classified as an irreversible compression form, wherein if the aberration is corrected after the compression, the correction of the aberration must be done in such a state that some pieces of the image data are missed, and the proper aberration correction is unable to be implemented.

The image memory **20** is not particularly restricted and any kinds of image recording mediums are usable but the image recording medium is capable of recording the digital image data of the subject image photographed. The recording medium may be a built-in memory so implemented in the digital camera **10** as not to be removable therefrom such as, for example, a non-volatile memory such as a flash memory, an EPROM and an EEPROM, and a RAM, or may be a removable memory such as a smart media and a card memory like a PCMCIA (PC card), an ATA card and a compact flash card, or may also be an image recording medium such as a floppy disk and an MO (magneto-optical) disk. Incidentally, it is required in the case of the built-in memory that the image data will be transmitted serially or in parallel via a cable in order for the image recording device such as a personal computer and a digital photo printer to take in the image data. In the case of the removable memory, however, the memory itself may simply be set in a slot of the image recording device such as the personal computer and the digital photo printer, which is preferable because of no necessity for transferring the image data and the handling being simple.

Note that the number of photographic frames in the digital camera **10** is determined by a compression rate of the image data in the compression unit **18** and by a recording capacity of the image memory **20**. In the digital camera **10**, it is preferable that the recording capacity of the image memory **20** is larger because of a greater number of photographic frames. If the recording capacity is large, however, a physical size of the image memory **20** becomes large, and hence it is preferable to properly select the recording capacity of the image memory **20** in accordance with the physical size and the required number of photographic frames.

The display unit **22** displays as a visible image the image data (image) processed by the data processing unit **16**, and as described above, it is used as the viewfinder when in the photographing.

The display unit **22** has no limit, there are a variety of usable known display devices such as a liquid crystal display utilized in the digital camera **10**.

Herein, in the digital camera **10** of the present invention, the image displayed on the display unit **22** may be an image processed by both of the characteristic correction unit **36** and the image processing unit **34** of the data processing unit **16**, or may be an image processed by only the image processing unit **34** without the correction of the aberrations. These settings may be properly made corresponding to a photographing speed requested to the digital camera **10**, or may preferably be selectable.

It is, however, preferable that the image stored in the image memory **20** and the image outputted outside from the I/F unit **24** are performed the correction of the aberrations in the characteristic correction unit **36**, and the image performing no correction of the aberrations or the like may be combined with the data required for the correction of the lens characteristics and then stored in the image memory **20** or outputted outside from the I/F unit **24**.

In the thus constructed digital camera **10** according to the present invention, after the one frame image has been photographed, the data processing unit **16** may process the image data of this frame and stores the image data in the image memory **20** then the next frame image may be photographed, or the data processing unit **16** may perform the image data processing during the photographing of the next frame onward.

The mode of performing the process during the photographing of the next frame image onward has an advantage of being capable of quick photographing (consecutive photographing) on one hand, and is disadvantageous in terms of costs because of requiring the memory for storing the frame images photographed during the image processing on the other hand.

Further, in the digital camera **10**, the image photographed is displayed on the display unit **22**, then stored in the image memory **20** and outputted from the I/F unit **24**. Besides, the image data temporarily stored in the image memory **20** may be decompressed by the compression unit **18** and then displayed on the display unit **22**, or alternatively the image data may be received from the I/F unit **24** and displayed on the display unit **22** or stored in the image memory **20**.

In the above example, the digital camera have been explained as a representative example of the digital image shooting device of the present invention. However, the present invention is not limited to the above mentioned example, as the digital image shooting device of the present invention, for instance, products in the form of the camera such as a digital video camera, and, in addition, a digital image shooting device which includes an image forming lens and an image sensor element in part is not the form of camera itself such as a computer which includes a function of a camera partially and various kinds of image forming devices and image pickup devices.

One embodiment of the digital image shooting device of the present invention has been discussed so far, however, the present invention is not limited to the above embodiment but may be changed and modified in a variety of forms without deviating from the scope of the present invention.

As discussed above in details, according to the present invention, it is feasible to attain the digital image shooting device capable of obtaining the quality which is high enough for the utilization even by using the comparatively low-price lens which does not exhibit a high performance.

What is claimed is:

1. A digital image shooting device comprising:

an image forming lens;

an image sensor element;

a data processing unit for processing an output signal from said image sensor element into digital image data;

an image memory for storing the digital image data and a lens characteristic relating to the image forming lens; and

a lens characteristic correction unit for performing, by using the stored lens characteristic of said image forming lens and a position of a frame image photographed, a process of correcting a deterioration of an image quality derived from said image forming lens upon the digital image data, to obtain processed image data, before a shooting of a next frame of an image, in which the processed image data is stored in said image

memory prior to the shooting of the next frame, or during the shooting of the next frame onward, in which the processed image data is stored in said image memory during or after the shooting of the next frame,

wherein the digital image data comprises three primary color-based image data; and wherein the lens characteristic correction unit calculates a first deviation quantity of a first color-based image data due to the deterioration of the image quality, the first color-based image data selected among the three primary color-based image data, and calculates second deviation quantities of two color-based image data other than the first color-based image data on a basis of the calculated first deviation quantity, the second deviation quantities representing relative quantities to the first deviation quantities, and performs the process of correcting the deterioration of the image quality using the first deviation quantity and the second deviation quantities.

2. The digital image shooting device according to claim **1** wherein said image quality deterioration further includes a distortion aberration.

3. A digital image shooting device according to claim **1**, wherein said lens characteristic correction unit corrects the deterioration of the image quality before a process of compressing the digital image data.

4. A digital image shooting device according to claim **1**, wherein said lens characteristic correction unit performs the process of correcting a deterioration of an image quality before the shooting of the next frame or during the shooting of the next frame onward, wherein the digital image data of the frame on which the correction process is performed, and the processed image data obtained by the correction process of the lens characteristic correction unit are stored in said image memory.

5. A digital image shooting device according to claim **1**, wherein said image memory is a built-in image recording medium or a removable image recording medium.

6. A digital image shooting device according to claim **1**, further comprising an image display unit for displaying the photographed image,

wherein an image based on the digital image data which is or is not performed the correction process in said lens characteristic correction unit, is displayed on said image display unit, and the digital image data performed the correction process in said lens characteristic correction unit, is stored in a memory.

7. A digital image shooting device according to claim **1**, wherein an image of a region larger than a photographic region confirmed by a photographer is formed on said image sensor element in accordance with missing of pixels which is caused as a result of the correction by said lens characteristic correction unit.

8. The digital image shooting device according to claim **1**, wherein said image forming lens comprises a plurality of lens and said image memory stores a plurality of lens characteristics pertaining thereto.

9. The digital image shooting device of claim **1**, wherein the lens is a zoom lens and the lens characteristic relates to a plurality of focal lengths of the zoom lens,

wherein the lens characteristic is converted at the plurality of focal lengths to the focal length when the image is photographed.

10. The digital image shooting device of claim **1**, wherein said image quality deterioration corrected by said lens characteristic correction unit is at least one of a chromatic aberration of magnification, defocusing and a decrease in marginal rumination.

11. The digital image shooting device according to claim **1**, wherein the deterioration of the image quality comprises a distortion aberration and a chromatic aberration and,

the first deviation quantity due to the distortion aberration and the second deviation quantities are deviation quantities due to both the distortion aberration and the chromatic aberration.

12. A digital image shooting device comprising:

an image forming lens;

an image sensor element optically coupled to said lens;

a data processing unit connected to said image sensor and receiving an output signal from said image sensor element and converting the output signal into digital image data;

an image memory connected to said data processing unit, the digital image data and a lens characteristic relating to the image forming lens being stored in said image memory; and

a lens characteristic correction unit connected to said image memory, said lens characteristic correction unit correcting a deterioration of an image quality derived from said image forming lens upon the digital image data, to obtain processed image data, by using the stored lens characteristic of said image forming lens and a position of a frame image photographed before a shooting of a next frame of an image, in which the processed image data is stored in said image memory prior to the shooting of the next frame, or during the shooting of the next frame onward, in which the processed image data is stored in said image memory during or after the shooting of the next frame,

wherein the image quality deterioration corrected by the lens characteristic correction unit is a distortion aberration and a chromatic aberration of magnification,

wherein the digital image data comprises three primary color-based image data; and wherein the lens characteristic correction unit calculates a first deviation quantity of a first color-based image data due to the deterioration of the image quality, the first color-based image data selected among the three primary color-based image data, and calculates second deviation quantities of two color-based image data other than the first color-based image data on a basis of the calculated first deviation quantity, the second deviation quantities representing relative quantities to the first deviation quantities, and performs the process of correcting the deterioration of the image quality using the first deviation quantity and the second deviation quantities.

* * * * *

US 20070080280A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2007/0080280 A1**

Havens (43) **Pub. Date: Apr. 12, 2007**

(54) **CONTROL SYSTEMS FOR ADAPTIVE LENS**

(76) Inventor: **William H. Havens**, Syracuse, NY (US)

Correspondence Address:
HAND HELD PRODUCTS, INC.
700 VISIONS DRIVE
P.O. BOX 208
SKANEATELES FALLS, NY 13153-0208 (US)

(21) Appl. No.: **11/546,531**

(22) Filed: **Oct. 11, 2006**

Related U.S. Application Data

(60) Provisional application No. 60/725,531, filed on Oct. 11, 2005. Provisional application No. 60/778,569, filed on Mar. 2, 2006.

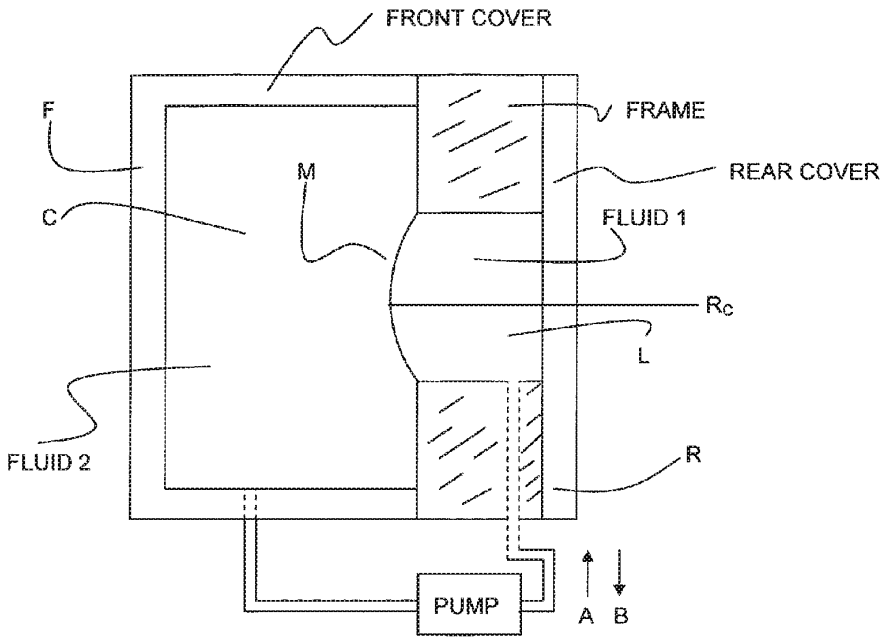
Publication Classification

(51) **Int. Cl.**
G01J 1/20 (2006.01)

(52) **U.S. Cl.** **250/201.1**

(57) **ABSTRACT**

Systems and methods for controlling a fluid lens in a data collection device. One or more micropump control systems are used to control one or more fluid lenses. The micropump control systems are used to change volume and/or pressure within the fluid lens system, changing the radius of curvature of the lens.



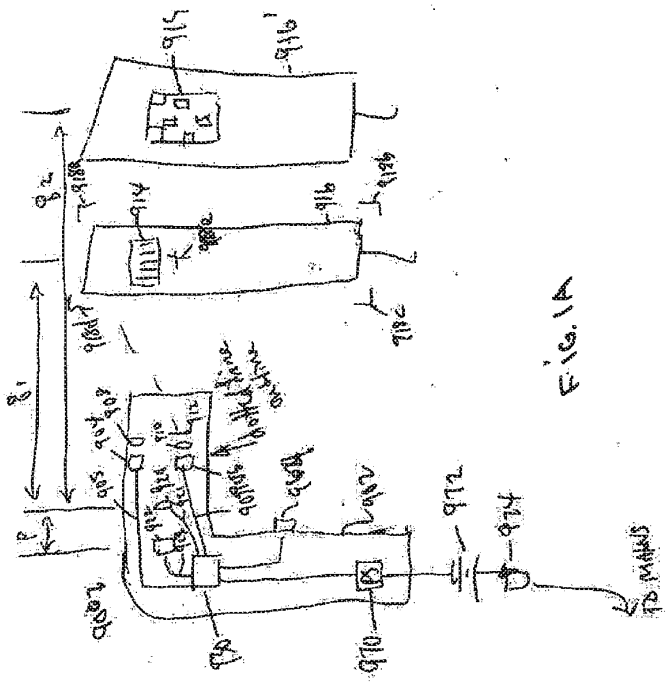


FIG. 14

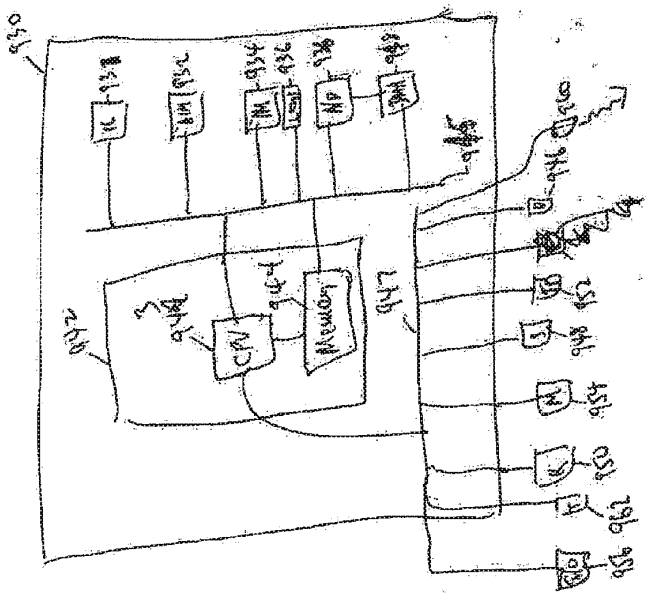


FIG. 13

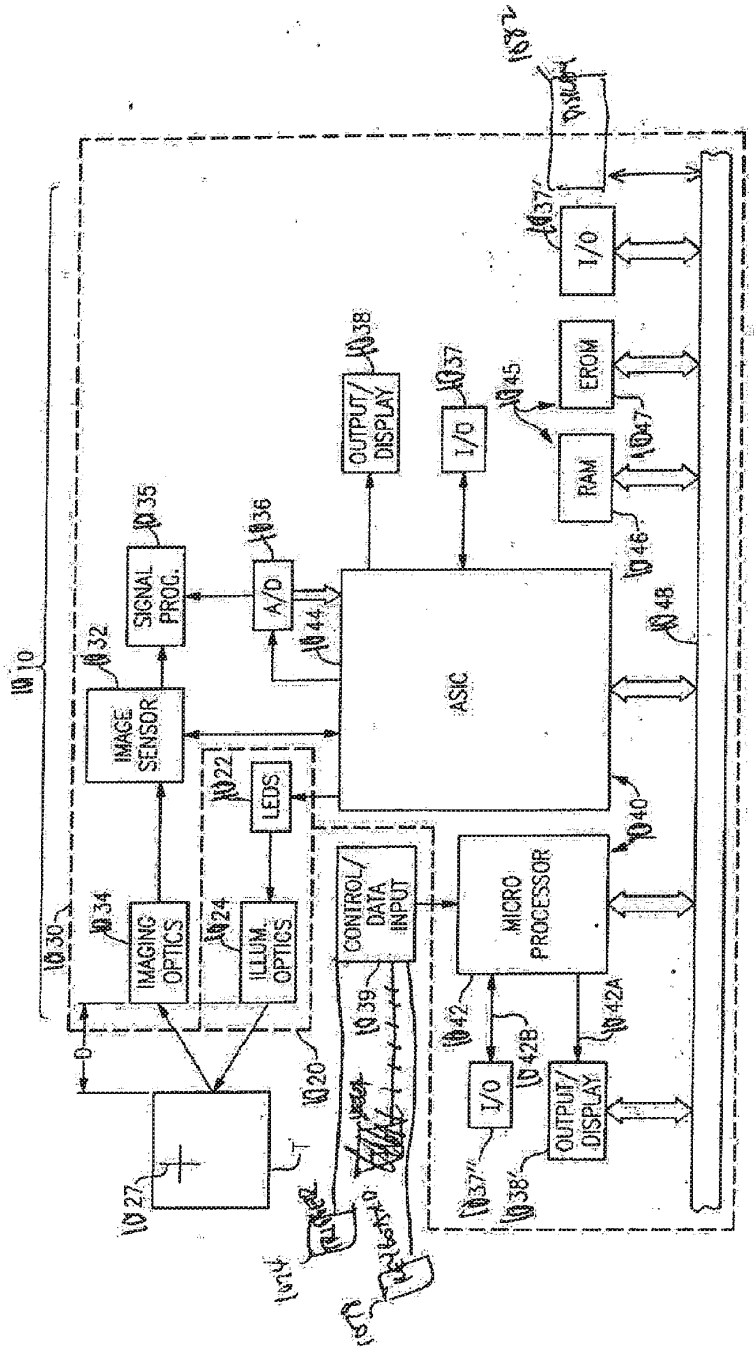


IMAGE SENSOR
SIGNAL PROC.
A/D
OUTPUT/ DISPLAY
I/O
EROM
RAM
ASIC
LEDS
IMAGING OPTICS
ILLUM. OPTICS
CONTROL/ DATA INPUT
MICRO PROCESSOR
I/O
OUTPUT/ DISPLAY

FIG. 2

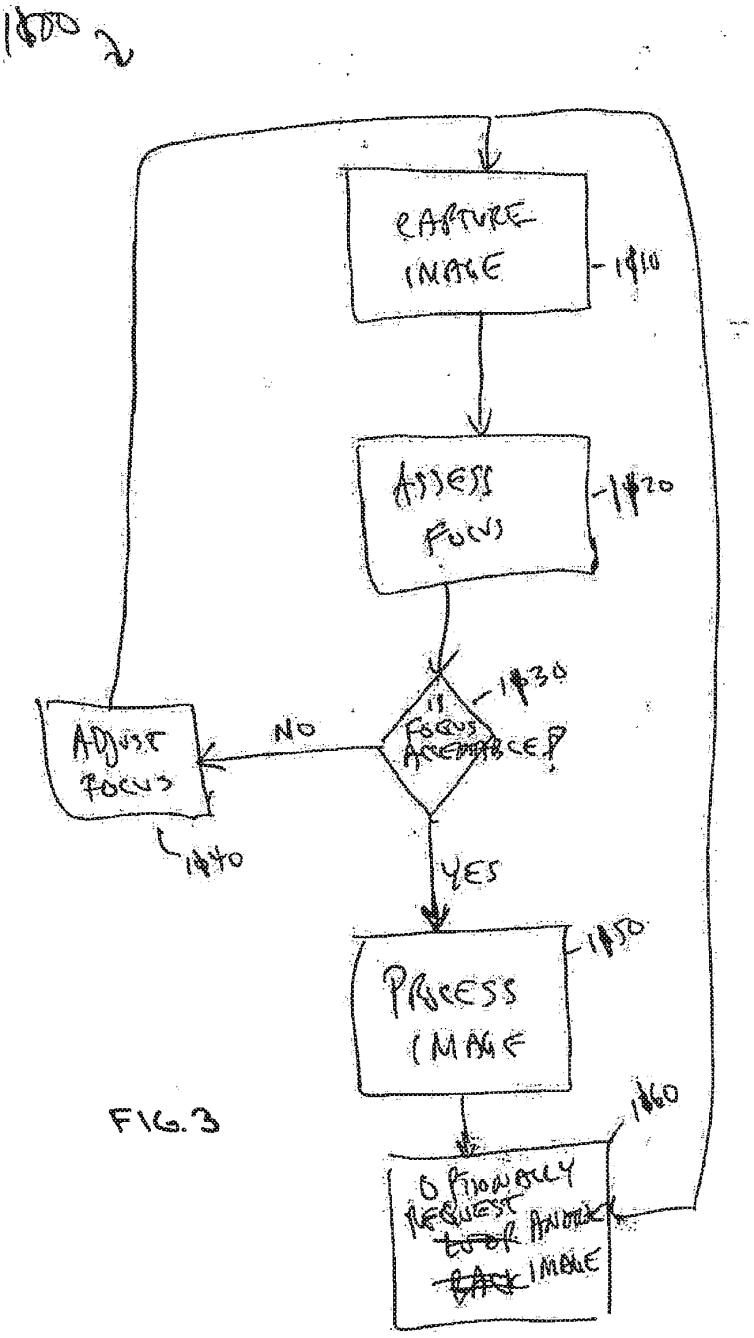

1600
CAPTURE IMAGE
1610
ASSESS FOCUS
1620
IS FOCUS ACCEPTABLE?
1630
NO
ADJUST FOCUS
1640
YES
PROCESS IMAGE
1650
OPTIONALLY REQUEST TOOK ANOTHER IMAGE
1660

FIG. 3

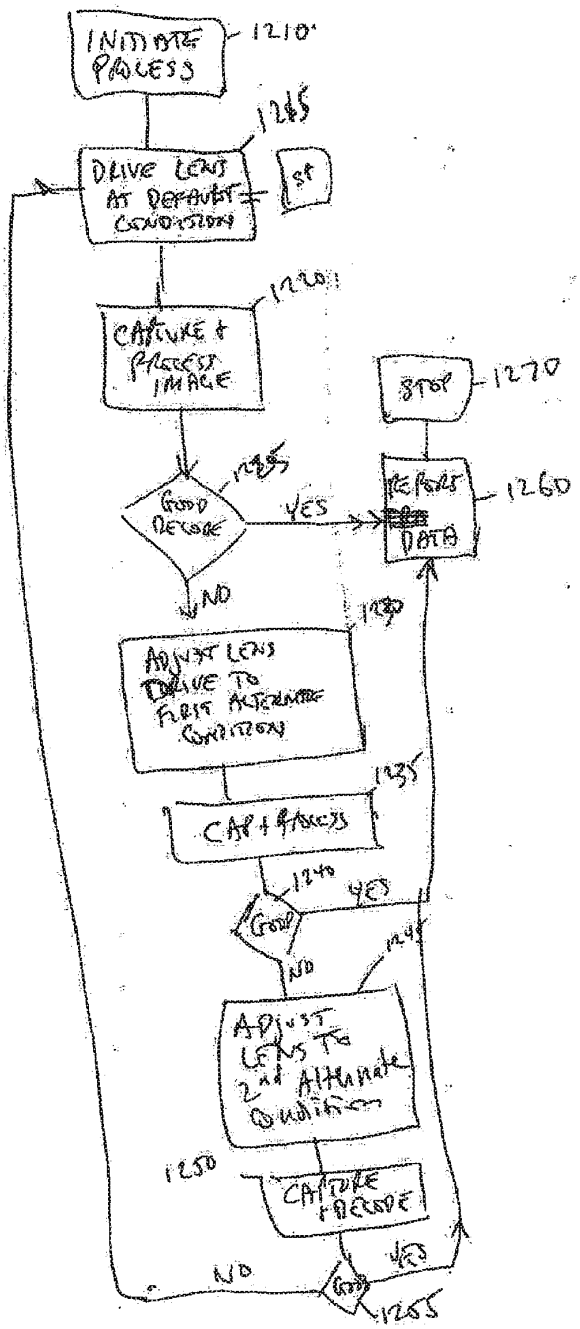

INITIATE PROCESS
1210'
1215
DRIVE LENS AT DEFAULT CONDITION
SET
1220
CAPTURE & PROCESS IMAGE
1225
GOOD DECODE
YES
NO
STOP
1270
REPORT DATA
1260
ADJUST LENS DRIVE TO FIRST ALTERNATE CONDITION
1230
CAPTURE & PROCESS
1235
GOOD
1240
YES
NO
ADJUST LENS TO 2nd ALTERNATE CONDITION
1245
CAPTURE & DECODE
1250
GOOD
YES
NO
1255

FIG.4

FIG.5A

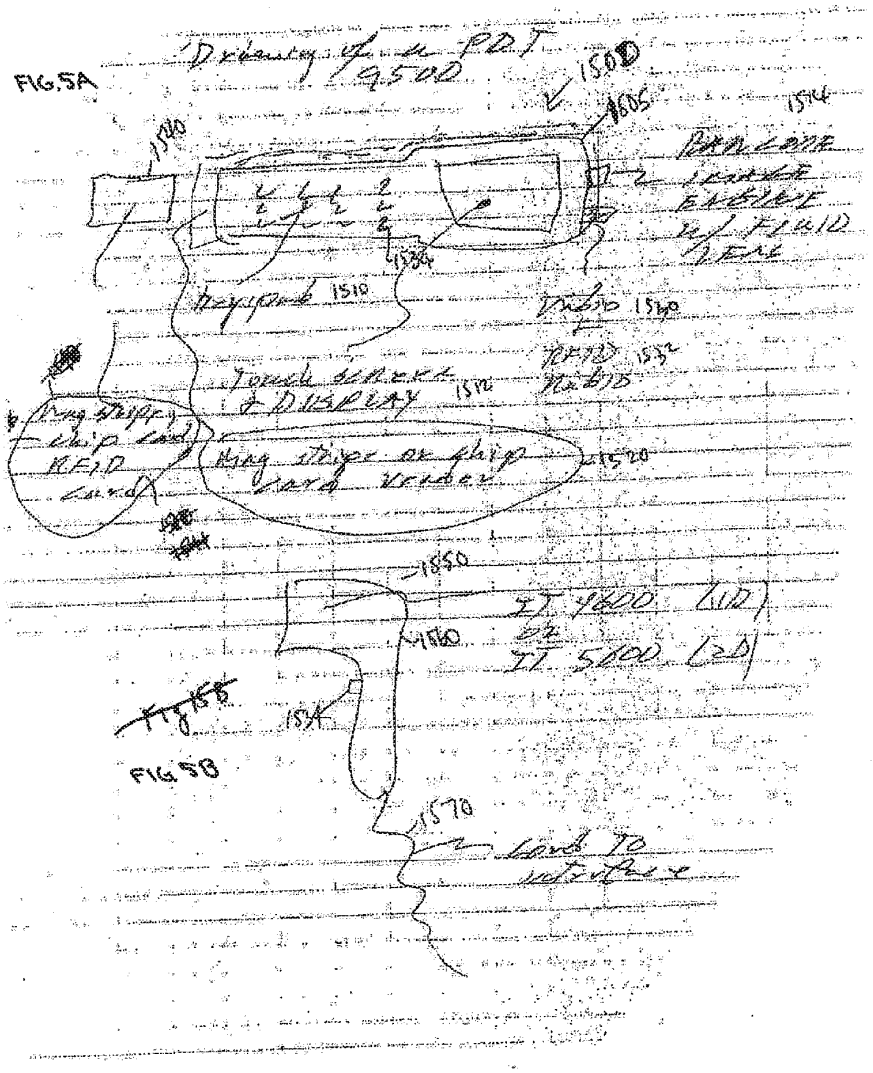

Drawing of a PDT
9500
1500
1605
1514
1540
1534
1510
1540
RFID 1532
Touch screen
& DISPLAY 1512
Mag stripe or chip card vendor
1520
1550
1560
1534
1570
Cord to
interface

FIG.5B

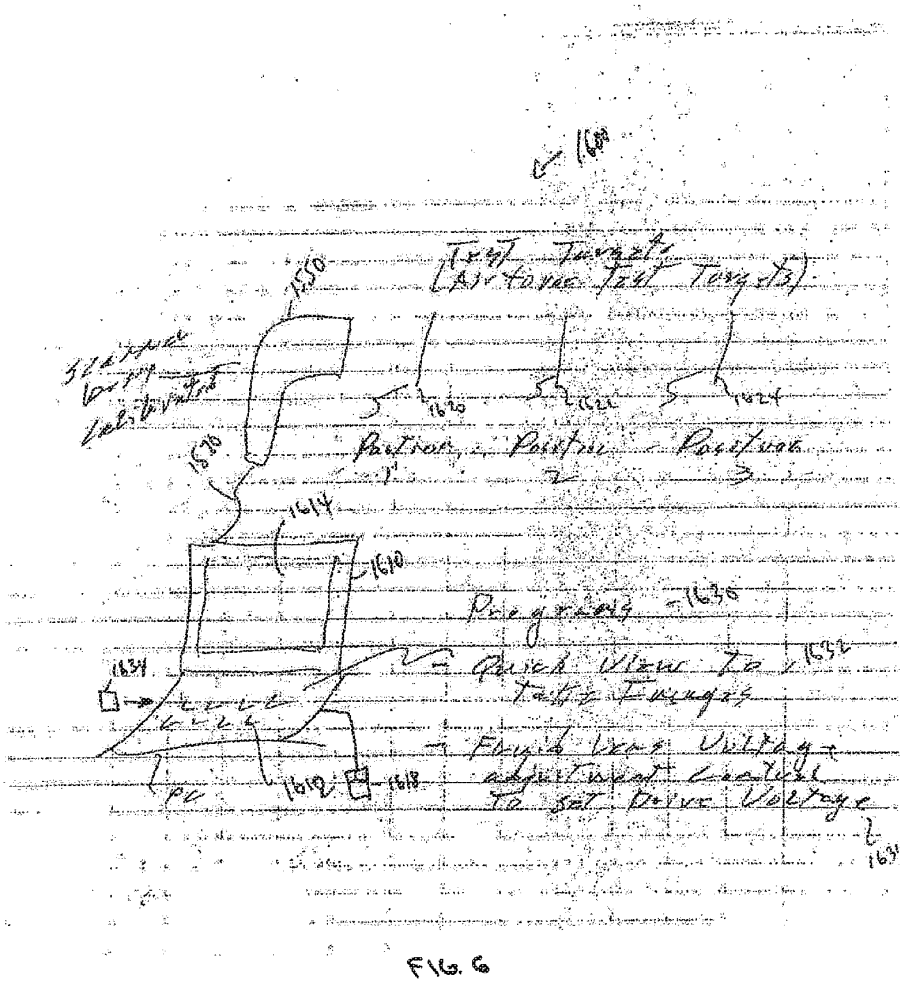

1600
Test Targets
(Airforce Test Targets)
1550
1620
1622
1624
Position 1
Position 2
Position 3
1530
1614
1610
Programs 1630
Quick View To Take Images 1632
1634
Fluid Lens Voltage adjustment Control To set Drive Voltage
1631
PC
1612
1618

FIG. 6

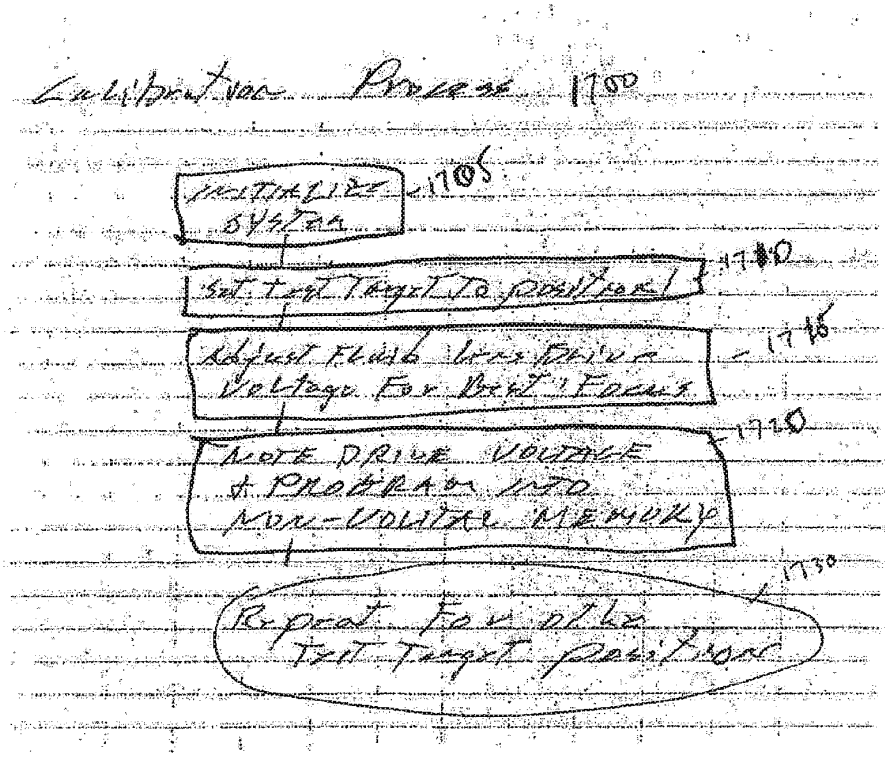

Calibration Process 1700
INITIALIZE SYSTEM
1705
Set Test Target To Position
1710
Adjust Fluid Lens Drive Voltage For Best Focus
1715
STORE DRIVE VOLTAGE & POSITION INTO NON-VOLATILE MEMORY
1720
Repeat For Other Test Target Positions
1730

FIG. 7

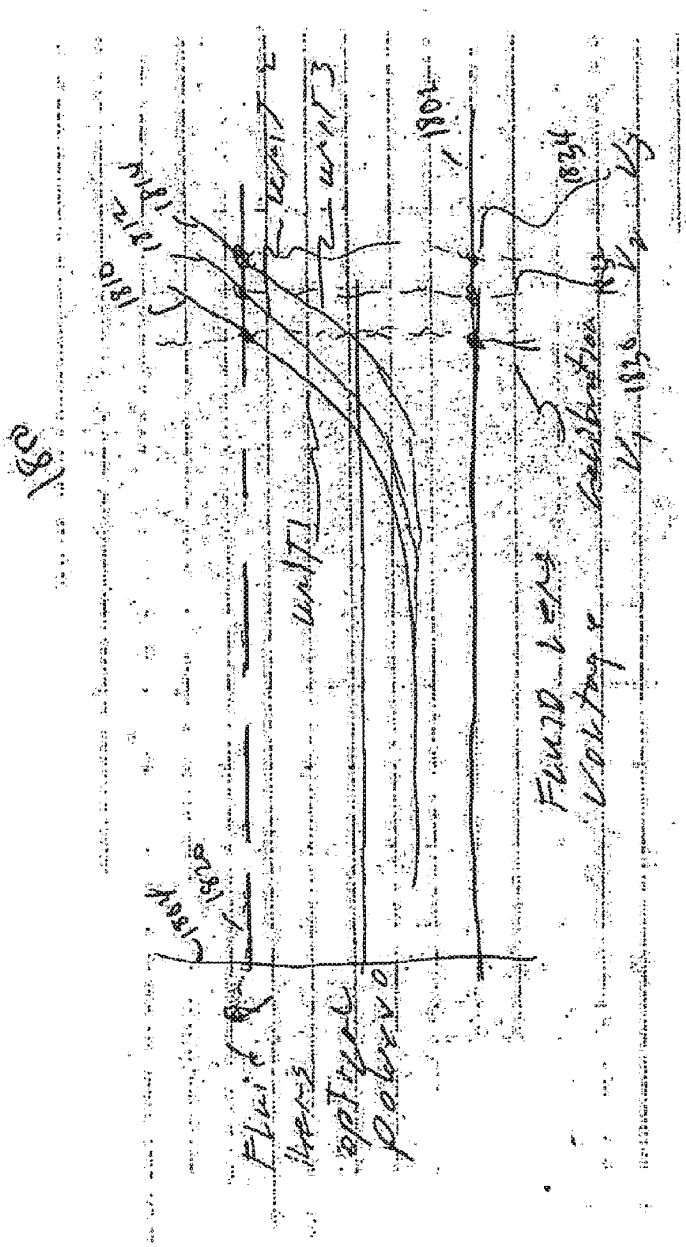
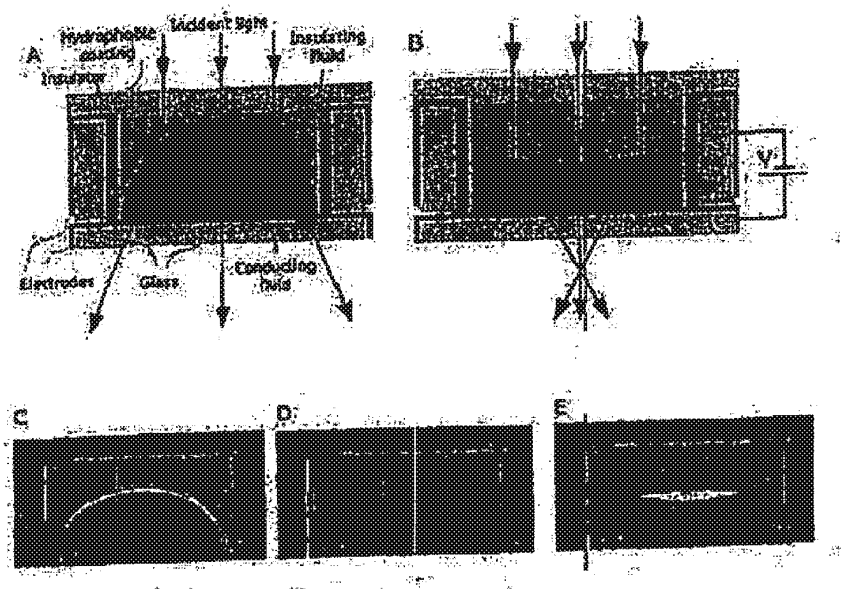
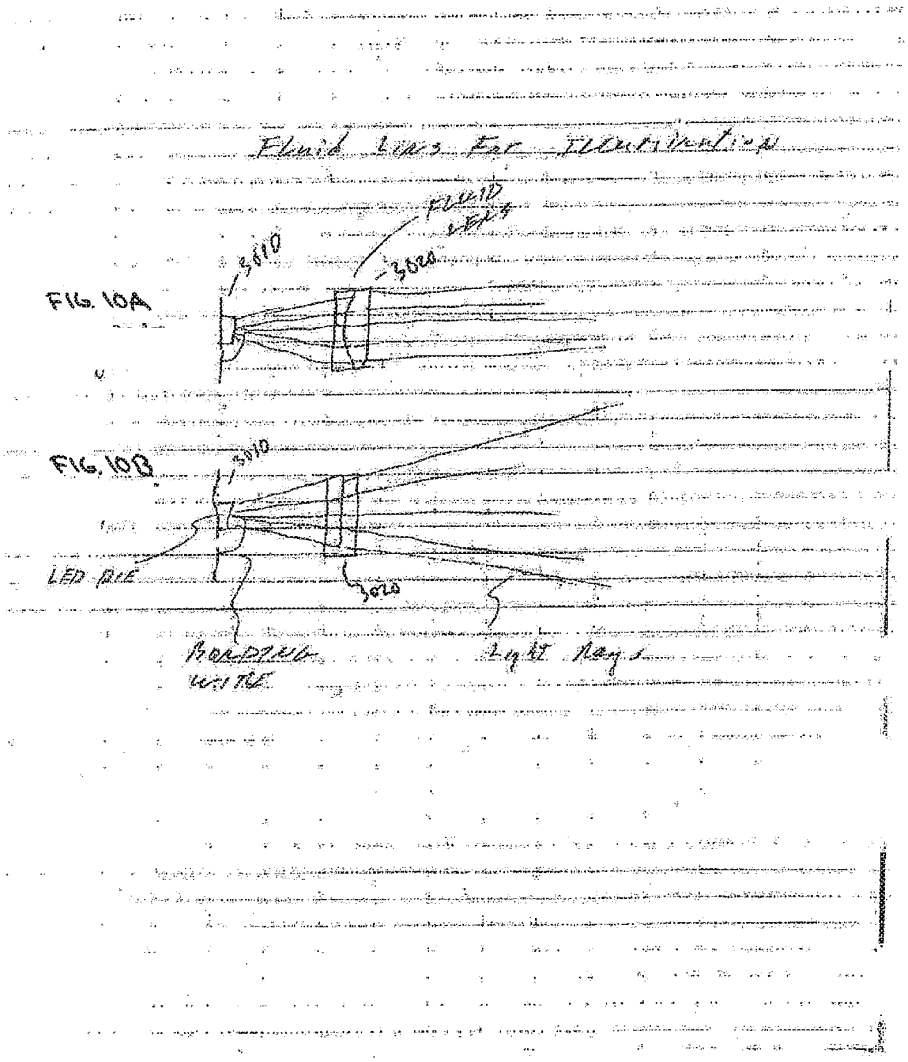


FIG. 8



(Prior Art)

FIGS. 9A-9E


Fluid Lens For Illumination
FIG. 10A
FIG. 10B
LED die
Light Rays

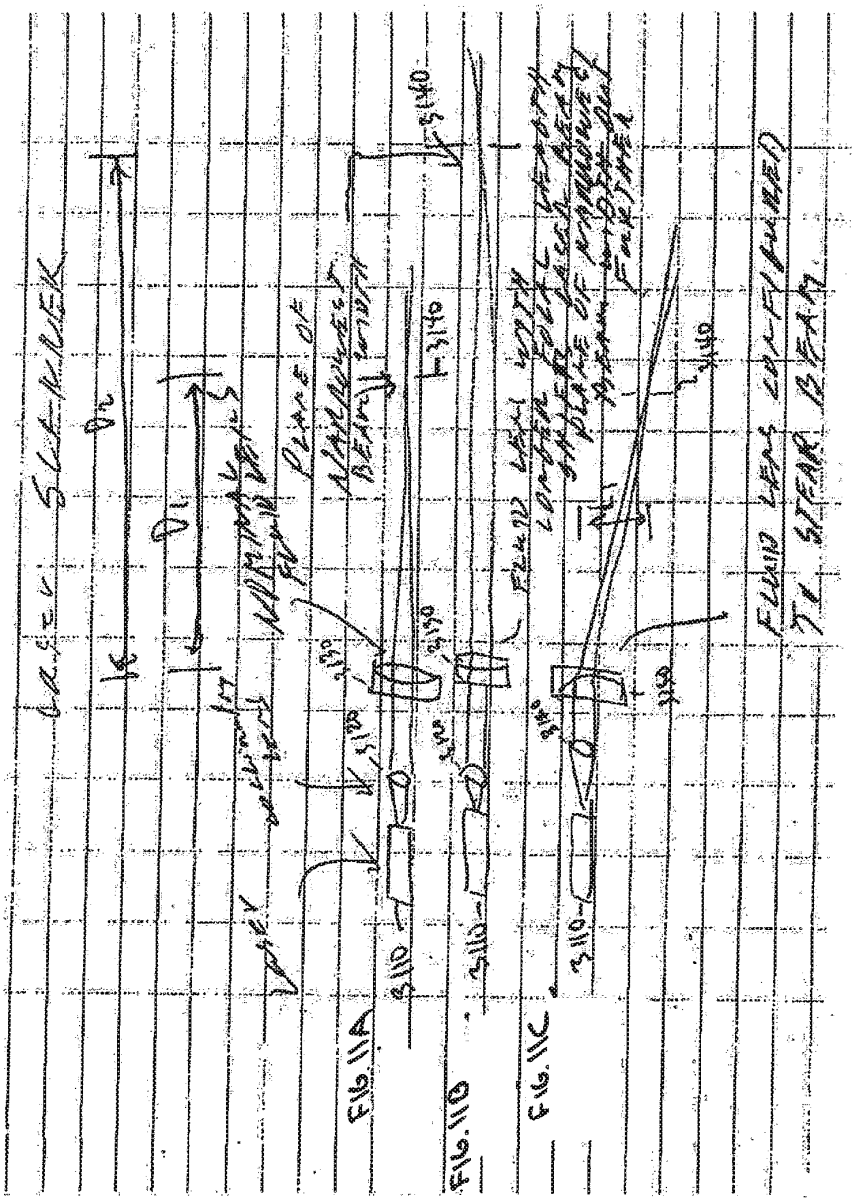


FIG. 11A
FIG. 11B
FIG. 11C

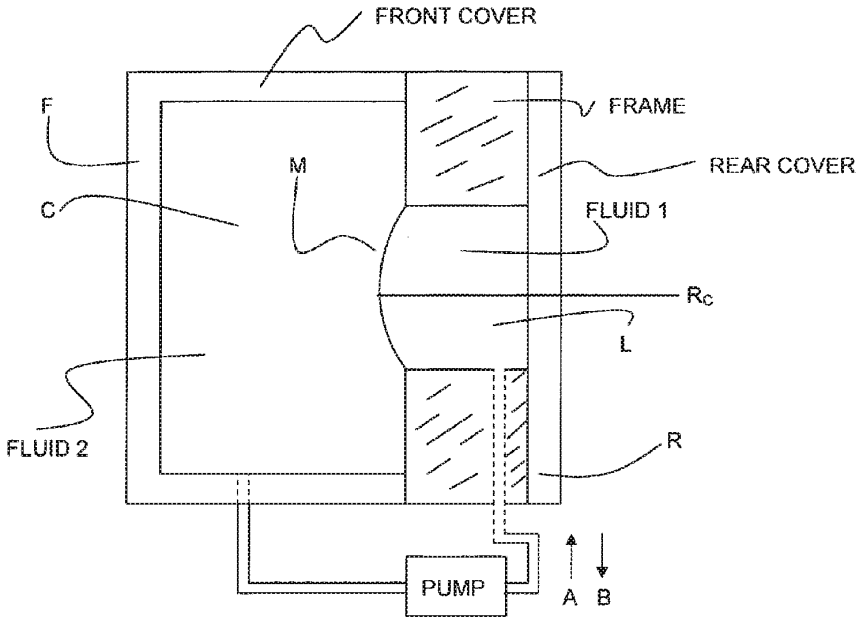

FRONT COVER
F
FRAME
M
REAR COVER
C
FLUID 1
Rc
L
FLUID 2
R
PUMP
A
B

FIG. 12

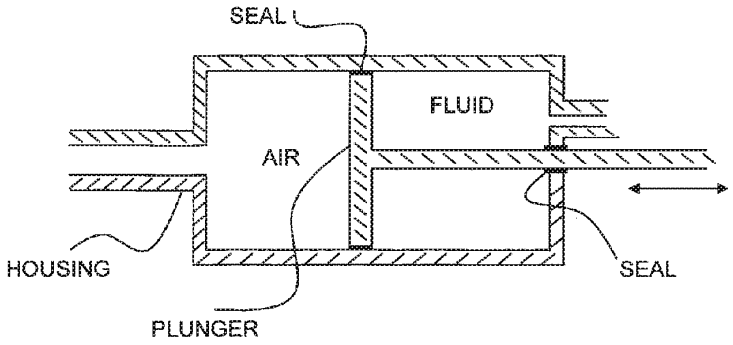

SEAL
FLUID
AIR
HOUSING
SEAL
PLUNGER

FIG. 13

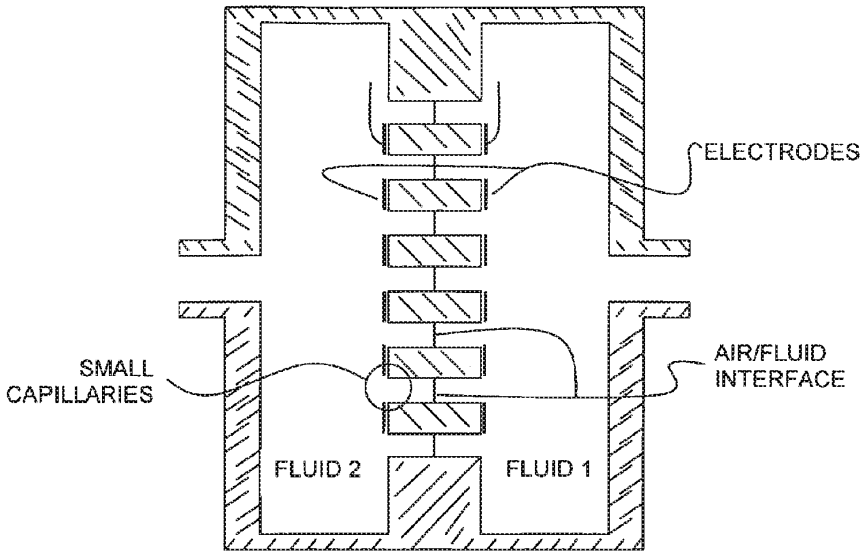

ELECTRODES
SMALL CAPILLARIES
AIR/FLUID INTERFACE
FLUID 2
FLUID 1

FIG. 14

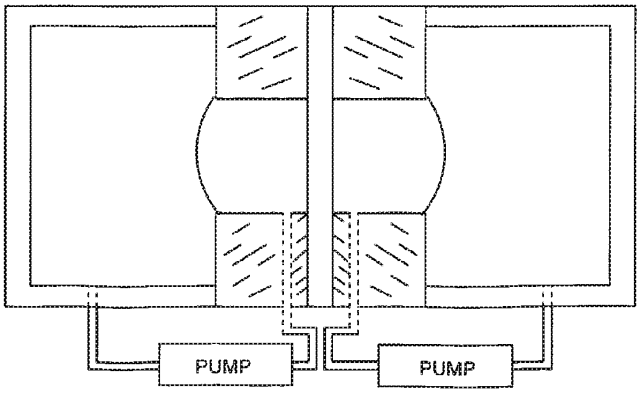

PUMP
PUMP

FIG. 15

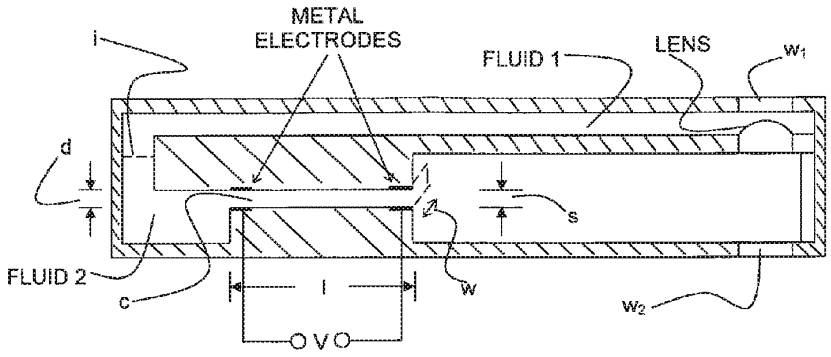

METAL
ELECTRODES
i
FLUID 1
LENS
w_1
d
s
FLUID 2
c
l
w
w_2
V

FIG. 16

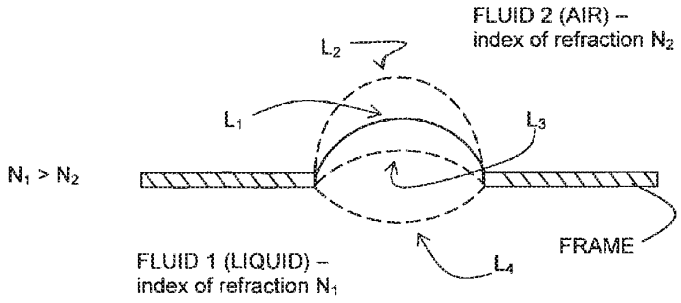

FLUID 2 (AIR) –
index of refraction N_2
L_2
L_1
L_3
$N_1 > N_2$
FRAME
L_4
FLUID 1 (LIQUID) –
index of refraction N_1

FIG. 17

FIG. 18A

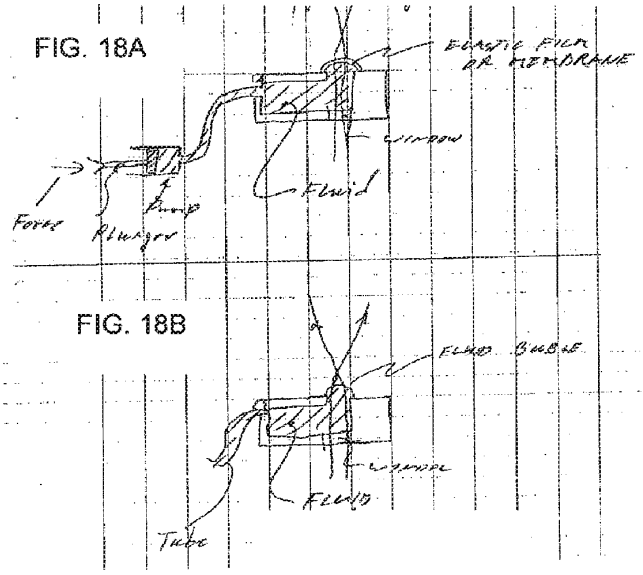


FIG. 18B

FIG. 18C

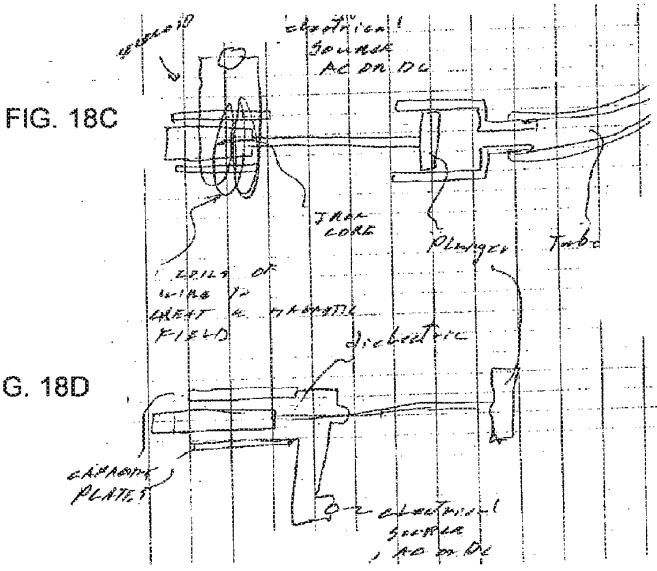


FIG. 18D

FIG. 18

CONTROL SYSTEMS FOR ADAPTIVE LENS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to co-pending U.S. patent application Ser. No. 60/717,583, filed Sep. 14, 2005, entitled "Apparatus Comprising a Variable Lens"; co-pending U.S. patent application Ser. No. 60/725,531, filed Oct. 11, 2005, entitled "Data Reader Apparatus Having an Adaptive Lens"; co-pending U.S. patent application Ser. No. 11/521,142, filed Sep. 14, 2006, entitled "Apparatus Comprising a Variable Lens"; and co-pending U.S. patent application Ser. No. 60/778,569, filed Mar. 2, 2006, entitled "Control systems for adaptive lens", the disclosures of which are hereby incorporated in their entireties by reference thereto.

FIELD OF THE INVENTION

[0002] The invention relates to adaptive lenses in general, adaptive lenses having auto-calibration and auto-adjustment features, and devices that use such adaptive lenses.

[0003] More particularly, the present invention is directed to control systems for the control of adaptive lenses.

BACKGROUND OF THE INVENTION

[0004] In brief, a fluid lens comprises an interface between two fluids having dissimilar optical indices. The shape of the interface can be changed by the application of external forces so that light passing across the interface can be directed to propagate in desired directions. As a result, the optical characteristics of a fluid lens, such as whether the lens operates as a diverging lens or as a converging lens, and its focal length, can be changed in response to the applied forces.

[0005] Fluid lens technology that employs electrical signals to control the operation of the fluid lens has been described variously in U.S. Pat. No. 2,062,468 to Matz, U.S. Pat. No. 6,399,954 to Berge et al., U.S. Pat. No. 6,449,081 to Onuki et al., U.S. Pat. No. 6,702,483 to Tsuboi et al., and U.S. Pat. No. 6,806,988 to Onuki et al., in U.S. Patent Application Publication Nos. 2004/0218283 by Nagaoka et al., 2004/0228003 by Takeyama et al., and 2005/0002113 by Berge, as well as in several international patent documents including WO 99/18456, WO 00/58763 and WO 03/069380.

[0006] Additional methods of controlling the operation of fluid lenses include the use of liquid crystal material (U.S. Pat. No. 6,437,925 to Nishioka), the application of pressure (U.S. Pat. No. 6,081,388 to Widl), the use of elastomeric materials in reconfigurable lenses (U.S. Pat. No. 4,514,048 to Rogers), the uses of micro-electromechanical systems (also known by the acronym "MEMS") (U.S. Pat. No. 6,747,806 to Gelbart), the use of stack-type piezoelectric actuators to vary the focus of the lens member to compensate for temperature fluctuations (U.S. Pat. 6,188,526 to Sasaya et al.), the use of piezoelectric material to deform a variable focus lens (Japanese Patent No. JP2002243918), and the use of piezoelectric element in contact with a fluid such that the element changes dimensions in response to changes in voltage, changing the fluid pressure and altering the radius of curvature of an associated transparent membrane (GB Patent 1,327,503); the disclosures of the foregoing are hereby incorporated in their entireties herein.

[0007] There is a need for improved systems and methods for using fluid lenses in present day systems.

[0008] In the drawings, while every effort has been made to use like numerals to indicate like parts throughout the various views, the right is reserved to make corrections should errors become apparent.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The objects and features of the invention can be better understood with reference to the drawings described below, and the claims. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

[0010] FIG.1A is a diagram showing a reader embodying features of the invention;

[0011] FIG.1B is a diagram showing the control circuitry of the reader of FIG.1A in greater detail, according to principles of the invention;

[0012] FIG. **2** is a block diagram of an optical reader showing a general purpose microprocessor system that is useful with various embodiments of the invention;

[0013] FIG. **3** is a flow chart showing a process for operating a system having an adjustable focus system comprising feedback, according to principles of the invention;

[0014] FIG. **4** is a flow chart showing a process for operating a system having an adjustable focus system that does not comprise feedback, according to principles of the invention,

[0015] FIGS. **5***a* and **1***b* are drawings of hand held readers that embody features of the invention;

[0016] FIG. **6** is a diagram of a handheld reader of the invention in communication with a computer;

[0017] FIG. **7** is a flow chart of a calibration process useful for calibrating apparatus embodying features of the invention;

[0018] FIG. **8** is a diagram showing calibration curves for a plurality of exemplary hand held readers embodying features of the invention;

[0019] FIGS. **9***a*-**9***e* are cross-sectional diagrams of another prior art fluid lens that can be adapted for use according to the principles of the invention;

[0020] FIGS. **10**A and **10**B are diagrams that show an LED die emitting energy in a forward direction through a fluid lens, according to principles of the invention; and

[0021] FIGS. **11**A and **11**B show diagrams of a laser scanner comprising a laser **3110**, a collimating lens **3120**, and a fluid lens **3130** in various configurations, according to principles of the invention.

[0022] FIG. **12** shows a closed lens embodiment in which a fluid lens pump is used to maintain and change the curvature of the lens.

[0023] FIG. **13** presents one embodiment of a pump system that may be used in the closed lens configuration.

[0024] FIG. **14** presents another embodiment of a pump system that may be used in the closed lens configuration.

[0025] FIG. **15** presents an embodiment involving two closed lens configurations operating in series.

[0026] FIG. **16** presents an embodiment in which the lens and pump control system are highly integrated.

[0027] FIG. **17** presents a detail of the lens structure showing changes in radius of curvature.

[0028] FIGS. **18**A-**18**D present further lens control configurations.

DETAILED DESCRIPTION OF THE INVENTION

[0029] The present application is directed to apparatus and methods useful for imaging, capturing, decoding and utilizing information represented by encoded indicia such as bar codes (for example, 1D bar codes, 2D bar codes, and stacked bar codes), optically recognizable characters (for example printed, typed, or handwritten alphanumeric symbols, punctuation, and other OCR symbols having a predefined meaning), as well as selected graphical images such as icons, logos, and pictographs. The apparatus and methods involve the use of one or more fluid lens components with data collection devices, which include corded and cordless bar code scanners, portable data terminals, transaction terminals (including price checkers), and bar code verifiers, to accomplish such tasks as imaging barcodes and other optically readable information, including focusing on images of interest, and improving image quality by removing artifacts such as jitter introduced by a user who is manually operating a reader of the invention.

[0030] U.S. Pat. No. 2,062,468 to Matz, U.S. Pat. No. 4,514,048 to Rogers, U.S. Pat. No. 6,081,388 to Widl, U.S. Pat. No. 6,369,954 to Berge et al., U.S. Pat. No. 6,437,925 to Nishioka, U.S. Pat. No. 6,449,081 to Onuki et al., U.S. Pat. No. 6,702,483 to Tsuboi et al., U.S. Pat. No. 6,747,806 to Gelbart, and U.S. Pat. No. 6,806,988 to Onuki et al., U.S. Patent Application Publication Nos. 2004/0218283 by Nagaoka et al., 2004/0228003 by Takeyama et al., and 2005/0002113 by Berge, and international patent publications WO 99/18546, WO 00/58763 and WO 03/069380 are each individually incorporated by reference herein in its entirety. The aforementioned published patent documents describe various embodiments and applications relating generally to fluid lens technology.

[0031] While the operation of the device has been described as adaptable primarily to an alteration in the surface curvature of the liquid lens, it is to be understood that there are other associated effects which may contribute largely to the successful operation of the system, and may be important in the modulation of some frequencies. The electrocapillary rise and fall of the fluid in the slot where the device is employed, for example, may be employed to augment the modulating effect of the alteration in the lenticular structure of the fluid. This capillary rise and fall is, however, probably relatively slow, and where the device is used as a light valve with high frequencies, it probably has little effect.

[0032] Where a liquid is employed in the device which absorbs certain wave lengths of the transmitted beam, the device may be effective to alter the intensity of the beam because of the alteration in the effective thickness of the film of liquid interposed in the path of the beam at the center of the slot with the impressment of the electric potential.

[0033] The fluids employed in the lens are light-transmitting. A wide variety of liquids may be usable, such as for example as methyl alcohol, ethyl alcohol, ether, carbon tetrachloride, methyl acetate, distilled water, glycerine, nitrobenzene, and some oils.

[0034] The device which has been described and which has been termed a liquid lens of variable focal length has many other applications. It may be employed, for example, as an electrostatic voltmeter, as the alteration in the divergence or convergence of a translated beam is a function of the intensity of the impressed field. The device may be employed in connection with suitable apparatus for the transmission of audible or other signals over a beam of light. When the device is employed in connection with transmission of audible signs it may be said to modulate the beam of light at audible frequencies, and where such an expression is used in the claims it should be so interpreted. It is admirably adapted for use in sound-recording on motion picture film.

[0035] Although Matz describes his fluid lens as being responsive to "an electric potential," it is clear that different fluid lens technologies can be used that respond to signals that are voltages (electric potentials, or electric potential differences), as well as signals that can be characterized by other electrical parameters, such as electric current or electric charge (the time integral of electric current). One can also design lenses that have adjustable behavior based on the interaction of light with two or more fluids (or a fluid and vacuum) having differing optical indices that operate in response to other applied signals, such as signals representing mechanical forces such as pressure (for example hydrodynamic pressure), signals representing mechanical forces such as tensile stress (such as may be used to drive elastomeric materials in reconfigurable lenses), and signals representing a combination of electrical and mechanical forces (such as may be used to drive micro-electromechanical systems). For the purposes of the present disclosure, the general term "fluid lens control signal" without more description will be used to denote an applied signal for driving any type of fluid (or reconfigurable) lens that responds to the applied signal by exhibiting adjustable behavior based on the interaction of light with two or more fluids (or a fluid and vacuum) having differing optical indices.

[0036] We now describe apparatus and methods of operation that embody various features and aspects of the invention, in the form of readers having the capability to obtain images, and to detect, analyze, and decode such images. In particular, the readers of the invention can in some embodiments be hand held, portable, apparatus that can image encoded indicia, such as bar codes of a variety of types (1D, 2D, matrix, stacked 1D, and other bar codes), and encoded symbols such as handwritten, printed, and typed characters (for example using optical character recognition methods), as well as imaging surfaces or objects that are amenable to being identified using optical illumination.

[0037] FIG. **1**A is a diagram showing a reader **900**, such as a bar code scanner, embodying features of the invention. The reader **900** comprises various optical components and components of hardware and software for controlling the operation of the reader **900** and for analyzing an image acquired

by the reader **900**. FIG. **1**B is a diagram showing the control circuitry of the reader of FIG. **1**A in greater detail. In FIG. **1**A, a case **902** is shown which in principle can be any convenient enclosure or frame for supporting the various components in suitable mutual orientation, and in some embodiments is a case adapted to be held in a hand of a user, as described in greater detail hereinbelow in conjunction with FIGS. **5***a* and **5***b*. The reader **900** comprises sources of illumination **904**, **906** that can be operated in various circumstances to illuminate a target and to provide an aiming signal. The illumination source **904** is in general a source comprising one or more light sources such as lamps or LEDs that provide illumination at a convenient wavelength, such as red or green illumination, for illuminating a target whose image is to be acquired. The aimer source **906** in some embodiments is a second LED with appropriate imaging optics to image a slit, or alternately is a laser diode operating at a different wavelength from the illumination source **904** (for example, red illumination), so that it is easily distinguished therefrom. The aimer source **906** is used by an operator of the reader **900** to ascertain what the reader is aimed at. Optics **908** are provided for distributing the illumination from illumination source **904** in a pattern calculated to illuminate a target. In a preferred embodiment the target is illuminated optimally. A collimation lens **910** and a diffractive element **912** are optionally provided to collimate the light from the aimer source **906**, and to spread or diffract the light from the aimer source **906** in a predefined pattern, respectively. As can be seen in FIG. **1**A, an object **914** to be imaged is situated on an object plane **916** located at a distance q_1 from the reader **900**. The object **914** is for example a bar code affixed to a surface, namely the object plane **916**. For purposes of discussion, there is also shown in FIG. **1**A a second object plane **916'** located at a greater distance q_2 from the reader **900**, and having thereon an object **914'** (which can also be a bar code). The surface **916**, **916'** is preferably illuminated, either by light from the illumination source **904**, or by ambient light, or a combination thereof. As can be seen in FIG. **1**A, the aimer **906**, the collimation lens **910** and the diffractive element **912** in combination provide a locator pattern **918**, comprising **5** elements **918***a*-**918***e* in FIG. **1**A, that identify for a user where the reader **900** is aimed, so that a desired target can be made to fall within the aiming area of the reader **900**. Light reflected from the target (or alternatively, light generated at the target) is captured by the reader using a lens **920**, which in some embodiments comprises a fluid lens and possibly one or more fixed lenses, and is conveyed via the fluid lens to an imager **922**. The imager **922** in various embodiments is a 1D or 2D semiconductor array sensor, constructed using any convenient processing technology, such as a CMOS sensor, a CCD sensor, or the like. The imager **922** converts the optical signals that it receives into electrical signals that represent individual pixels of the total image, or frame, or a portion thereof. In various embodiments, the imager can be any of a color CCD imager and a color CMOS imager.

[**0038**] The reader **900** also includes various hardware components, shown in a single control element **930** for controlling and for acquiring signals from the reader **900** in FIG. **1**A. The details of control element **930** are shown in FIG. **1**B. An illumination control **931** is provided to control the intensity and timing of illumination provided by the illumination source **904**. The illumination control **931** is in electrical communication with illumination source **904** by way of a cable **905**. An aimer control **932** is provided to control the intensity and timing of illumination provided by the aimer source **906**. The aimer control **932** is in electrical communication with aimer source **906** by way of a cable **907**. An imager control **934** is provided to control the timing and operation of the imager **922**, for example by providing clocking signals to operate the imager, reset signals, start and stop signals for capturing illumination, and synchronization signals for providing electrical output as data indicative of the intensity of illumination received at any pixel of the imager array **922**, which data may be provided as analog or as digital data. The imager control **934** is in electrical communication with imager **922** by way of a cable **923**. A lens controller **936** is provided to control the behavior of the fluid lens **920**. The lens controller **938** and the fluid lens **920** are in electrical communication by way of a cable **921**.

[**0039**] An analog-to-digital converter **938** is provided for converting analog signals output by the imager **922** to digital signals. In some embodiments, a DMA controller **940** is provided to allow direct transfer of digital data to a memory for storage. In general, any and all of illumination control **930**, aimer control **932**, imager control **934**, A/D **938** and DMA **940** are connected to a general purpose programmable computer **942** by way of one or more buses **945**, which buses **945** may be serial buses or parallel buses as is considered most convenient and advantageous. The general purpose programmable computer **942** comprises the usual components, including a CPU **943** which can in some embodiments be a microprocessor, and memory **944** (for example semiconductor memory such as RAM, ROM, magnetic memory such as disks, or optical memory such as CD-ROM). The general purpose computer can also communicate via one or more buses **947** with a wide variety of input and output devices. For example, there can be provided any or all of an output device **946** such as a display, a speaker **948** or other enunciator, devices for inputting commands or data to the computer such as a keyboard **950**, a touchpad **952**, a microphone **954**, and bidirectional devices such as one or more I/O ports **956** which can be hardwired (i.e., serial, parallel, USB, firewire and the like) or can be wireless (i.e., radio, WiFi, infra-red, and the like). The general purpose programmable computer **942** can also comprise, or can control, indicators **960** such as LEDs for indicating status or other information to a user.

[**0040**] As shown in FIG. **1**A, the reader **900** and/or the general purpose computer **942** (as shown in FIG. **1**B) can comprise one or more trigger switches **964** that allow a user to indicate a command or a status to the reader **900**. In addition, the entire system is provided with electrical power by the use of one or more of a power supply **970**, batteries **972** and a charger **974**. Any convenient source of electrical power that can be used to operate the reader **900** and its associated general purpose programmable computer **942** (as shown in FIG. **1**B) is contemplated, including the conventional electrical grid (which can be accessed by connection to a conventional wall plug), and alternative power sources such as emergency generators, solar cells, wind turbines, hydroelectric power, and the like.

[**0041**] As may be seen from FIG. **1**A, the distance at which the reader of the invention can operate, or equivalently, a focal length of the optical system of the reader, can vary as the distance q from the lens to the object to be

imaged varies. The focal length for a specific geometrical situation can be determined from the formula

$$1/f=1/p+1/q$$

in which f is the focal length of a lens, p is the distance from the lens to a surface at which a desired image is observed (such as an imaging sensor or a photographic film), and q is a distance between the lens and the object being observed.

[0042] Consider the two objects situated at a nearer distance q_1, and a farther distance q_2 from the reader lens (e.g., $q_2>q_1$). In a system that is less expensive and more convenient to construct, the distance p (from the lens **920** to the imaging sensor **922**) is fixed. One can image objects lying at the distance q_1, from the lens with a focal length given by $1/f_1=1/p+1/q_1$, and one can image objects lying at the distance q_2 from the lens with a focal length given by $1/f_2=1/p+1/q_2$. Since $q_2>q_1$, and p is constant, we have $f_1<f_2$. In particular, for a reader comprising a fluid lens that can provide a minimum focal length of f_1 and a maximum focal length of f_2, for a fixed value of p, one would have the ability to observe in proper focus objects at distances ranging at least from q_1 to q_2, without consideration for issues such as depth of field at a particular focal length setting of the lens. By way of example, q_1 might be a short distance such as 4 inches (approximately 10 cm) so that one can image a target object having much detail (such as a high density bar code) with recovery or decoding of all of the detail present in the object. On the other hand, q_2 might be a longer distance, such as 12 inches (approximately 30 cm) or more, whereby a reader can image an object at longer distance with lesser density (e.g., fewer pixels of resolution per unit of length or area observed at the target object). Accordingly, a reader of the invention comprising a particular imaging sensor can be configured to perform at either extreme of high density/short distance or of low density/long distance (or any variant intermediate to the two limits) by the simple expedient of controlling the focal length of the fluid lens such that an object at the intended distance d in the range $q_2 \cong d \cong q_1$ will be imaged correctly.

[0043] FIG. **2** is a block diagram of an optical reader showing a general purpose microprocessor system that is useful with various embodiments of the invention. Optical reader **1010** includes an illumination assembly **1020** for illuminating a target object T, such as a 1D or 2D bar code symbol, and an imaging assembly **1030** for receiving an image of object T and generating an electrical output signal indicative of the data optically encoded therein. Illumination assembly **1020** may, for example, include an illumination source assembly **1022**, together with an illuminating optics assembly **1024**, such as one or more lenses, diffusers, wedges, reflectors or a combination of such elements, for directing light from light source **1022** in the direction of a target object T. Illumination assembly **1020** may comprise, for example, laser or light emitting diodes (LEDs) such as white LEDs or red LEDs. Illumination assembly **1020** may include target illumination and optics for projecting an aiming pattern **1027** on target T. Illumination assembly **1020** may be eliminated if ambient light levels are certain to be high enough to allow high quality images of object T to be taken. Imaging assembly **1030** may include an image sensor **1032**, such as a 1D or 2D CCD, CMOS, NMOS, PMOS, CID OR CMD solid state image sensor, either black-and-white or color, together with an imaging optics assembly **1034** for receiving and focusing an image of object T onto image sensor **1032**. The array-based imaging assembly shown in FIG. **2** may be replaced by a laser array based scanning assembly comprising at least one laser source, a scanning mechanism, emit and receive optics, at least one photodetector and accompanying signal processing circuitry.

[0044] A partial frame clock out mode is readily implemented utilizing an image sensor which can be commanded by a control module to clock out partial frames of image data or which is configured with pixels that can be individually addressed. Using CMOS fabrication techniques, image sensors are readily made so that electrical signals corresponding to certain pixels of a sensor can be selectively clocked out without clocking out electrical signals corresponding to remaining pixels of the sensor, thereby allowing analysis of only a partial frame of data associated with only a portion of the full imager field of view. CMOS image sensors are available from such manufacturers as Symagery, Omni Vision, Sharp, Micron, STMicroelectronics, Kodak, Toshiba, and Mitsubishi. A partial frame clock out mode can also be carried out by selectively activating a frame discharge signal during the course of clocking out a frame of image data from a CCD image sensor. A/D **1036** and signal processor **1035** may individually or both optionally be integrated with the image sensor **1032** onto a single substrate.

[0045] Optical reader **1010** of FIG. **2** also includes programmable control circuit (or control module) **1040** which preferably comprises an integrated circuit microprocessor **1042** and an application specific integrated circuit (ASIC **1044**). The function of ASIC **1044** could also be provided by a field programmable gate array (FPGA). Processor **1042** and ASIC **1044** are both programmable control devices which are able to receive, to output and to process data in accordance with a stored program stored in memory unit **1045** which may comprise such memory elements as a read/write random access memory or RAM **1046** and an erasable read only memory or EROM **1047**. Other memory units that can be used include EPROMs and EEPROMs. RAM **1046** typically includes at least one volatile memory device but may include one or more long term non-volatile memory devices. Processor **1042** and ASIC **1044** are also both connected to a common bus **1048** through which program data and working data, including address data, may be received and transmitted in either direction to any circuitry that is also connected thereto. Processor **1042** and ASIC **1044** differ from one another, however, in how they are made and how they are used. The processing module that is configured to extract information encoded by the encoded indicium employs some or all of the capabilities of processor **1042** and ASIC **1044**, and comprises the hardware and as necessary, software and or firmware, required to accomplish the extraction task, including as necessary decoding tasks to convert the raw data of the image to the information encoded in the encoded indicium.

[0046] More particularly, processor **1042** is preferably a general purpose, off-the-shelf VLSI integrated circuit microprocessor which has overall control of the circuitry of FIG. **2**, but which devotes most of its time to decoding image data stored in RAM **1046** in accordance with program data stored in EROM **1047**. ASIC **1044**, on the other hand, is preferably a special purpose VLSI integrated circuit, such as a programmable logic array or gate array that is programmed to

devote its time to functions other than decoding image data, and thereby relieves processor **1042** from the burden of performing these functions.

[**0047**] The actual division of labor between processors **1042** and **1044** will naturally depend on the type of off-the-shelf microprocessors that are available, the type of image sensor which is used, the rate at which image data is output by imaging assembly **1030**, etc. There is nothing in principle, however, that requires that any particular division of labor be made between processors **1042** and **1044**, or even that such a division be made at all. This is because special purpose processor **1044** may be eliminated entirely if general purpose processor **1042** is fast enough and powerful enough to perform all of the functions contemplated by the present invention. It will, therefore, be understood that neither the number of processors used, nor the division of labor there between, is of any fundamental significance for purposes of the present invention.

[**0048**] With processor architectures of the type shown in FIG. **2**, a typical division of labor between processors **1042** and **1044** will be as follows. Processor **1042** is preferably devoted primarily to such tasks as decoding image data, once such data has been stored in RAM **1046**, recognizing characters represented in stored image data according to an optical character recognition (OCR) scheme, handling menuing options and reprogramming functions, processing commands and data received from control/data input unit **1039** which may comprise such elements as a trigger **1074** and a keyboard **1078** and providing overall system level coordination.

[**0049**] Processor **1044** is preferably devoted primarily to controlling the image acquisition process, the A/D conversion process and the storage of image data, including the ability to access memories **1046** and **1047** via a DMA channel. The A/D conversion process can include converting analog signals to digital signals represented as 8-bit (or gray scale) quantities. As A/D converter technology improves, digital signals may be represented using more that 8 bits. Processor **1044** may also perform many timing and communication operations. Processor **1044** may, for example, control the illumination of LEDs **1022**, the timing of image sensor **1032** and an analog-to-digital (A/D) converter **1036**, the transmission and reception of data to and from a processor external to reader **1010**, through an RS-232, a network such as an Ethernet or other packet-based communication technology, a serial bus such as USB, and/or a wireless communication link (or other) compatible I/O interface **1037**. Processor **1044** may also control the outputting of user perceptible data via an output device **1038**, such as a beeper, a good read LED and/or a display monitor which may be provided by a liquid crystal display such as display **1082**. Control of output, display and I/O functions may also be shared between processors **1042** and **1044**, as suggested by bus driver I/O and output/display devices **1037'** and **1038'** or may be duplicated, as suggested by microprocessor serial I/O ports **1042**A and **1042**B and I/O and display devices **1037"** and **1038"**. As explained earlier, the specifics of this division of labor is of no significance to the present invention.

[**0050**] FIG. **3** is a flow chart **1100** showing a process for operating a system having an adjustable focus system comprising feedback, for example a system having components as described in FIG. **1**A. The process begins at step **1110**, where a command to capture an image is generated, for example by a user depressing a trigger, or by an automated system issuing a capture image command in response to a specified condition, such as an object being sensed as coming into position for imaging. Once an image is captured at step **1110**, the image focus is assessed, as indicated at step **1120**. Focus assessment can comprise comparison of the image quality with a specified standard or condition, such as the sharpness of contrast at a perceived edge of a feature in the image, or other standards.

[**0051**] Another procedure for performing an autofocus operation using a flatness metric includes the following steps:

[**0052**] 1. capturing a gray scale image (i.e., capture an image with the hand held reader and digitize the image using at least two bit resolution, or at least 4 discrete values);

[**0053**] 2. optionally sampling the gray scale image (i.e., extract from the image a line or a series of points, or alternatively, the sampled image can be the captured image if it is a windowed frame comprising image data corresponding to selectively addressed pixels);

[**0054**] 3. creating a histogram by plotting number of occurrences of data points having a particular gray scale value, for example using the X axis to represent gray scale values and the Y axis to represent frequency of occurrence;

[**0055**] 4. processing the histogram to provide a flatness measurement as output;

[**0056**] 5. determining a focus level (or quality of focus) based on the flatness measurement; and

[**0057**] 6. in the event that the quality of focus as determined from the flatness metric is less than desired, changing the focus and repeating steps 1 through 5.

[**0058**] The flatness of an image refers to the uniformity of the distribution of different gray scale values in the histogram. A flat distribution is one with little variation in numbers of observations at different gray scale values. In general, poorly focused images will be "flatter" than better focused images, i.e. there will be a relatively even incidence of gray scale values over the range of gray scale values. Generally, a histogram for a well focused image has many pixels with high gray scale values, many pixels with low gray scale values, and few pixels in the middle. The use of historical information for various types of images, such as bar codes, including information encoded in look up tables, or information provided using the principles of fuzzy logic, are contemplated

[**0059**] At step **1130**, the outcome of the focus assessment is compared to an acceptable criterion, such as sharpness (or contrast change) of a specified amount over a specified number of pixels. Images that are digitized to higher digital resolutions (e.g., using a range defined by a larger number of bits) may support more precise determinations of acceptable focus. If the result of the assessment of focus is negative, the process proceeds to step **1140**, where the focus of the lens **920** of FIG. **1**A, is modified. After adjusting the focus, the operation of the process returns to step **1110**, and a new image is captured, and is assessed. When an image is

captured that is found to have suitable focus, the process moves from step **1130** to step **1150**, wherein the image with suitable focal properties is processed, and a result is made available to a user or to the instrumentality that commanded the capturing of the image, and/or the result is stored in a memory. Optionally, as indicated at step **1160**, the system can be commanded to obtain another image, that is to loop back to the step **1110**, and to repeat the process again.

[**0060**] FIG. **4** is a flow chart showing a process for operating a system having an adjustable focus system that does not comprise feedback. At step **1210** a command to capture an image is generated, for example by a user depressing a trigger, or by an automated system issuing a capture image command in response to a specified condition, such as an object being sensed as coming into position for imaging. At step **1215**, the lens **920** is driven with a first fluid lens control signal corresponding to a first condition, such as a default condition, for example causing the lens **920** to operate by approximation with a focus position q_1 of 10 cm. Using this focus condition, an image is captured and processed at step **1220**. At step **1225**, the information retrieved from the captured image is examined to determine if a valid decoding of a bar code has been achieved. If the decoding is valid, the information or data represented by the decoded image is reported as indicated at step **1260**, and the process stops, as indicated at step **1270**. A later command to repeat the process can be given as may be necessary or advantageous.

[**0061**] If at step **1225** it is determined that a good decode has not been achieved, the process continues to step **1230**, at which time the fluid lens control signal applied to the lens **920** is adjusted to a first alternative value, for example causing the lens **920** to focus by approximation at a distance q_2 of 30 cm. Using this focus condition, an image is captured and processed at step **1235**. At step **1240**, the information retrieved from the captured image is examined to determine if a valid decoding of a bar code has been achieved. If the decoding is valid, the information or data represented by the decoded image is reported as indicated at step **1260**, and the process stops, as indicated at step **1270**.

[**0062**] If at step **1240** it is determined that a good decode has not been achieved, the process continues to step **1245**, at which time the fluid lens control signal applied to the lens **920** is adjusted to a second alternative value, for example causing the lens **920** to focus by approximation at a distance q_3 of 100 cm. Using this focus condition, an image is captured and processed at step **1250**. At step **1255**, the information retrieved from the captured image is examined to determine if a valid decoding of a bar code has been achieved. If the decoding is valid, the information or data represented by the decoded image is reported as indicated at step **1260**, and the process stops, as indicated at step **1270**. If a valid decoding of a bar code is still not achieved, the process returns to step **1215**, and the process is repeated to try to identify a valid bar code value. In other embodiments, after a specified or predetermined number of iterative loops have occurred without a successful outcome, or after a specified or predetermined time elapses, the process can be aborted by a supervisory control device, which in some embodiments can operate according to a computer program. Although the process depicted in FIG. **4** uses three discrete conditions to drive the lens **920** in the search for a suitable focus condition, it is possible to use more or fewer than three predefined drive conditions as components of such a process. For example, one can define a process in which the focal distance changes by a predefined distance, or a predefined percentage. Alternatively, one can define a process in which the adjustment is based upon a quantity determined from the information obtained in assessing whether the captured image is in focus (as described hereinabove) or from the quality of the decoded information (e.g., whether the information is completely garbled or incorrectly formatted, or is close to being valid). In general, the distances specified may not be attained to absolute precision (for example, a distance of 30 cm may not be measured to a precision of 30.000 cm but merely to 30 cm to within one tenth of a centimeter), but rather the test is that the lens operates adequately at the distance that is identified. In the laboratory, precise distances may be set up for experiments, but in actual use in the field, distances are measured less accurately than in the laboratory.

[**0063**] As discussed hereinbefore, fluid lenses may have aberrations, such as spherical aberration and/or color aberration. In the reader of the invention, additional lenses, such as positive or negative lenses, can be used in conjunction with a fluid lens such as lens **920** to correct one or more of spherical, color, or higher order aberrations. In some embodiments, the materials of construction of the additional lenses can be chosen so as to compensate for optical imperfections and aberrations introduced by the fluid lens.

[**0064**] It is expensive to manufacture devices that require high levels of mechanical precision, with regard to making the components of the device, assembling the components with the required precision, and testing the assemble product to assure compliance with the intended design specifications. There are cost and manufacturability advantages that accrue if one is not required to assemble a device with high precision, and can reduce or omit the testing of the assembled device. Accordingly, using the systems and methods of the invention, the incorporation of a fluid lens **920** in the reader **900** can in some embodiments permit one or more of relaxed design tolerances, relaxed assembly tolerances, and substitution of a calibration step for a testing step. In some instances, devices that would otherwise have been rejected as being outside of design specifications can be appropriately operated by the simple expedient of operating the fluid lens so as to provide an acceptable level of performance. In particular, one way to assure such a condition is to deliberately design a reader in which the baseline operation of the optical system of the reader is set for a condition of operation of the fluid lens at an operating point intermediate in the range of operation of the fluid lens. In such an instance, the fluid lens is first driven at the default (or design) condition, and upon calibration, an "adjusted operating condition" different from the default condition can be identified that causes the specific reader being calibrated to most closely match the design condition. This "adjusted operating condition" is then recorded as the condition that the reader should use as its initial operating state in general operation, and information identifying the "adjusted operating condition" can be save for future reference, for example in a non-volatile memory. By the application of these design principles (e.g., baseline operation at an intermediate point in the range of operation of the fluid lens), and the associated calibration procedure, readers that might have been rejected as failing a quality assurance test if the design criterion were tighter, and/or if the fluid lens was designed

to operate at an extremum of its operating range, can be used satisfactorily by adjusting the base operating condition of the fluid lens in a required direction within the range. Examples of readers in which such fluid lens systems can be employed are the IT 4000, the IT 4600, the IT 5600, and the PDT 9500, all available from Hand Held Products, Inc. of Skaneateles Falls, N.Y. Similar functionality could also be implemented in the smaller form factors as one associates with the PDA products. An example of such a product would be the Zire 72 with imager, sold by PalmOne.

[0065] FIGS. 5*a* and 5*b* are drawings of hand held readers that embody features of the invention. FIG. 5*a* shows a hand held reader **1500** comprising a case having a substantially linear shape. The handheld reader **1500** comprises circuitry as has been described with regard to FIG. **2**, including data processing capability and memory. The hand held reader **1500** comprises an input device **1510**, such as a key pad, for use by a user, one or more buttons of which may also be used as a trigger **1534** to allow a user to provide a trigger signal. The hand held reader **1500** comprises an output device **1512**, such as a display, for providing information to a user. In some embodiments, the display **1512** comprises a touch screen to allow a user to respond to prompts that are displayed on the display **1512**, or to input information or commands using any of icons or graphical symbols, a simulated keypad or keyboard, or through recognition of handwritten information. Hand held reader **1500** can also comprise a touch pad or touch screen that can display information as an output and accept information as an input, for example displaying one or more icons to a user, and accepting activation of one of the icons by the user touching the touch pad or touch screen with a finger or with a stylus **1508**. The hand held reader **1500** also comprises a bar code image engine **1514** that includes a fluid lens. The image engine **1514** acquires images of objects of interest that the hand held reader **1500** is employed to read. The fluid lens provides the ability to adjust a focal distance, as is described in more detail herein. The hand held reader **1500** also comprises a card reader **1520** that is configured in various embodiments to read cards bearing information encoded on a magnetic strip, such as is found on credit cards, and information encoded in a semiconductor memory, such as found in PC, PCMCIA or smart cards. The hand held reader **1500** also comprises a wireless communication device **1530** such as a radio transceiver and/or an infrared transceiver for communication with a remote base station, a computer-based data processing system, a second hand held reader **1500'**, or a device such as a PDA. The hand held reader **1500** also comprises an RFID transceiver **1532** for communicating with an RFID tag. As used herein, the term "RFID tag" is intended to denote a radio-frequency identification tag, whether active or passive, and whether operating according to a standard communication protocol or a proprietary communication protocol. An RFID transceiver can be programmed to operate according to a wide variety of communication protocols. FIG. 5*a* also depicts a card **1540** that in different embodiments includes information encoded on at least one of a magnetic stripe, a semiconductor memory, smart card, and in RFID tag. An example of a hand held reader **1500** in which such fluid lens systems can be employed is the PDT 9500, available from HandHeld Products, Inc. of Skaneateles Falls, N.Y. In one embodiment, the CMOS image array can be implemented with a Micron image sensor such as the Wide VGA MT9V022 image sensor from Micron Technology, Inc., 8000 South Federal Way, Post Office Box 6, Boise, Id. 83707-0006. The MT9V022 image sensor with full frame shutter is described in more detail in the product MT9V099 product flyer available from Micron Technology (www.micron.com), for example at http://download.micron.com/pdf/flyers/mt9v022_(mi-0350)_flyer.pdf. The ICM105T CMOS progressive imager available from IC Media, 5201 Great America Pkwy, Suite 422, Santa Clara, Calif. 95054. The imager is shown at website http://www.ic-media.com/products/view.cfm?product=ICM%2D105T. This imager uses a rolling shutter. Although both imagers cited are progressive imagers, as is well known in the art, interleaved imagers will also function properly in these systems.

[0066] FIG. 5*b* shows another embodiment of a hand held reader **1550** which comprises components as enumerated with respect to hand held reader **1500**, including specifically input **1510**, output **1512**, image engine and fluid lens **1514**, card reader **1520**, radio **1530**, and RFID transceiver **1532**. The handheld reader **1550** comprises circuitry as has been described with regard to FIG. **2**, including data processing capability and memory. For hand held reader **1550**, the case **1560** comprises a "pistol grip" or a portion disposed at an angle, generally approaching **90** degrees, to an optical axis of the imaging engine and fluid lens of the reader **1550**. Hand held reader **1550** also comprises a trigger **1534**, for example situated on the pistol grip portion of the reader **1550**, and located so as to be conveniently operated by a finger of a user. Hand held reader **1550** also comprises a cable or cord **1570** for connection by wire to a base station, a computer-based data processing system, or a point of sale apparatus. Examples of readers **1550** in which such fluid lens systems can be employed are the IT 4600 comprising a 2D image sensor array, and the IT 5600 comprising a ID image sensor array, all available from Hand Held Products, Inc. of Skaneateles Falls, N.Y.

[0067] In some embodiments, the hand held readers **1500** and **1550** are deployed at a fixed location, for example by being removably secured in a mount having an orientation that is controlled, which may be a stationary mount or a mount that can be reoriented. Examples of such uses are in a commercial setting, for example at a point of sale, at the entrance or exit to a building such as an office building or a warehouse, or in a government building such as a school or a courthouse. The hand held readers of the invention can be used to identify any object that bears an identifier comprising one or more of a bar code, a magnetic stripe, an RFID tag, and a semiconductor memory.

[0068] In some embodiments, the hand held reader **1500**, **1550** can be configured to operate in either a "decode mode" or a "picture taking" mode. The hand held reader **1500**, **1550** can be configured so that the decode mode and picture taking mode are user-selectable. For example, the reader can be configured to include a graphical user interface (GUI) for example on a touch pad or key pad that is both an input and an output device as depicted in FIG. 5*a* or a trigger as depicted in FIG. 5*b* enabling a user to select between the decode mode and the picture taking mode. In one embodiment, the decode mode is selected by clicking on an icon displayed on a display such as display **1512** of FIG. 5*a* whereby the reader is configured with a decode mode as a default. Alternatively, the mode of operation (either "decode mode" or "picture taking mode") can be set by a commu-

nication from a remote device, or by default upon initial activation of the reader, as part of a power-up sequence. Thus, the reader is configured to operate in the decode mode on the next (and subsequent) activation of trigger **1534** to generate a trigger signal. In the decode mode, the hand held reader **1500**, **1550** in response to the generation of the trigger signal captures an image, decodes the image utilizing one or more bar code decoding algorithms and outputs a decoded out message. The decoded out message may be output, e.g., to one or more of a memory, a display **1512** or to a remote device, for example by radio communication or by a hard-wired communication.

[0069] In one embodiment, the "picture taking mode" is selected is selected by clicking on icon (which can be a toggle switch), and hand held reader **1500**, **1550** is configured in a "picture taking mode" as the default mode. Thus, the hand held reader **1500**, **1550** is configured to operate in the "picture taking mode" on the next (and subsequent) activation of trigger **1534** to generate a trigger signal. The hand held reader **1500**, **1550** in response to the generation of the trigger signal captures an image and outputs an image to one or more of a memory, to a display **1512**, or to a remote device.

[0070] The hand held reader **1500**, **1550** can be configured so that when the image capture mode is selected, the hand held reader **1500**, **1550** avoids attempting to decode captured images. It is understood that in the process of capturing an image for decoding responsively to receipt of a trigger signal, the hand held reader **1500**, **1550** may capture a plurality "test" frames, these may be full frames or only partial frames as discussed above, for use in establishing imaging parameters (e.g., exposure, gain, focus, zoom) and may discard frames determined after decode attempts to not contain decodable symbol representations. Likewise in the process of capturing an image for image output responsively to receipt of a trigger signal in a picture taking mode, the hand held reader **1500**, **1550** may capture test frames, these may be full frames or only partial frames as discussed above, for use in establishing imaging parameters and may also discard images that are determined to be unsuitable for output. It is also understood that in the "picture taking mode" the images captured may be archived for later analysis, including decoding of bar codes or other encoded indicia that may be present in the images, for example for use in providing evidence of the condition of a package at the time of shipment from a vendor for insurance purposes (which image may never be decoded if the package arrives safely). Other examples of similar kind can be a photograph of a loaded truck, for example with a license plate, an identifying number or similar indication of which of many possible trucks is the subject of the photograph, optionally including a date and time, and possibly other information that can be stored with the image, such as the identity of the photographer (e.g., a name, an employee number, or other personal identifier).

[0071] In an alternative embodiment, the hand held reader **1500**, **1550** displays a plurality of icons (at least one for decode mode and one for picture taking mode) whereby activation of an icon both configures the hand held reader **1500**, **1550** to operate in the selected operating mode (decoding or picture taking) and results in a trigger signal automatically being generated to commence an image capture/decode (decode mode) or image capture/output image process (picture taking mode). Thus, in the alternative embodiment, the trigger **1534** need not be actuated to commence image capture after an icon is actuated.

[0072] FIG. **6** is a diagram **1600** of a handheld reader of the invention in communication with a computer. In FIG. **6**, a hand held reader **1550** of the type described hereinabove is connected by way of a cable **1570** to a computer **1610**, which in the embodiment depicted is a laptop or portable computer. The computer **1610** comprises the customary computer components, including an input **1612**, which may include a keyboard, a keypad and a pointing device such as a mouse **1608**, an output **1614** for use by a user, such as a display screen, and software **1630** recorded on one or more machine-readable media. Examples of software that operate on the computer **1610** are a QuickView program 1632 (available from Hand Held Products of Skaneateles Falls, N.Y.) that provides a display of the image as "seen" by the image engine and fluids lens in the hand held reader **1550** on the display **1614** of the computer **1610**, and a interactive program **1634**, for example provided on a machine readable medium, (not shown) that allows a user to control the signal applied to the fluid lens and to observe that response of the fluid lens thereto, for example as a representation in a graph or as a representation of one or more images read by the reader as the fluid lens control signal is varied. As used herein, "signal" refers to an input, controlled by a user, the signal operating in turn on a control system or element such as a solenoid, voice coil, electrostatic motor or MEMs pump, artificial muscle or polymer [CHECK THIS PARA AT THE END!]. In FIG. **6**, there are also shown a plurality of test targets **1620**, **1622**, **1624**, which in some embodiments are optical test targets conforming to a test target known as the United States Air Force ("USAF") 1951 Target (or 1951 USAF Resolution Target) as shown and described at the web site http://www.sinepatterns.com/USAF_labels.htm, and provided commercially in a variety of forms by SINE PATTERNS LLC, 1653 East Main Street, Rochester, N.Y. 14609, a manufacturer of the 1951 USAF Target and many other types of targets and visual patterns, as further indicated at the web site http://www.sinepatterns.com/i_Stdrds.htm.

[0073] The example depicted in FIG. **6** shows a target at each of three distances or positions relative to the hand held reader **1550**. In one embodiment, the three targets lie along a single optical axis at discrete, different distances. Each target **1620**, **1622**, **1624** presents an object, such as a known test pattern of defined geometry, that the hand held reader **1550** can image. By controlling the behavior of the fluid lens in the hand held reader **1550**, it is possible to calibrate the operation of the fluid lens by recording the observed control signal (such as a voltage or impressed electric potential) that is required to obtain an acceptable (e.g., an image within an acceptable range of image quality or one that can be correctly decoded to retrieve information encoded therein), and preferably optimal, image of the target at each location or position.

[0074] FIG. **7** is a flow chart **1700** of a calibration process useful for calibrating an apparatus embodying features of the invention. In FIG. **7**, the calibration is initiated, as shown at step **1705**, by initializing the system, including performing all power-on-sequence tests to assure that the system components are operating properly. At step **1710**, a test target bearing a pattern or encoded symbol is positioned at a first test position. When in the first test position, the target will

in general be a defined distance and orientation relative to the hand held reader comprising a fluid lens. At step **1715**, the fluid lens control signal (which in some embodiments is a voltage) is adjusted to obtain an acceptable, and preferably an optimal, focus condition for the target. At step **1720**, the distance and orientation of the target and the fluid lens control signal parameters are recorded for future use in a non-volatile memory, for example in a table.

[**0075**] One can iteratively repeat the process steps of locating the target at a new location and orientation, controlling the fluid lens control signal applied to the fluid lens to obtain a satisfactory, and preferably optimal, focus, and recording in a memory the information about the target location and the fluid lens control signal parameters, so as to provide a more complete and detailed set of calibration parameters. The number of iterations is limited only by the amount of time and effort one wishes to expend performing calibration steps, and the amount of memory available for recording the calibration parameters observed. In the example presented in FIG. **6**, a calibration according to the flow diagram of FIG. **7** would include performing calibration steps as described by steps **1710**, **1715** and **1720** at three distinct positions for the target. The information obtained in calibration tests can be used when operating the corresponding imager (or in some instances, another imager of similar type) either by using the calibration information as an initial setting for operation in a closed loop mode as explained in connection with FIG. **3**, or as fixed operating conditions for discrete points in an open loop operating mode as explained in connection with FIG. **4**.

[**0076**] FIG. **8** is a diagram **1800** showing calibration curves for a plurality of exemplary hand held readers. In FIG. **8**, the horizontal axis **1802** represents a fluid lens control signal parameter, such as voltage, and the vertical axis **1804** represents an optical property of the fluid lens, such as optical power. One can also represent other optical properties of a fluid lens that are relevant for its operation, such as focal length and f-number. In FIG. **8**, three curves **1810**, **1812**, **1814** are shown, each curve representing a response (e.g., optical power) of a specific fluid lens to an applied fluid lens control signal (e.g., voltage). As seen in FIG. **8**, the curve **1810**, representing the behavior of a first fluid lens, reaches an optical power P **1820** at an applied voltage V_1 **1830**. However, other fluid lenses may behave slightly differently, such that a second fluid lens, represented by curve **1812**, attains optical power P at an somewhat larger voltage V_2 **1832**, and a third fluid lens, represented by curve **1814**, attains optical power P at yet a larger voltage V_3 **1834**. Accordingly, one can extract from the information in FIG. **8** a relation between the fluid lens control signal that is to be applied to the first fluid lens and the second fluid lens to attain the same optical power P, for example for operating two hand held readers under substantially similar conditions, or for operating a binocular reader or other device that uses two fluid lenses simultaneously, for example to generate a stereoscopic view of a target. At power P, there exists a difference in drive voltage between the first lens and the second lens given by V_2-V_1, where the difference has a magnitude given by the absolute value of V_2-V_1 and a sign which is positive if V_2 exceeds V_1 in magnitude, negative if V_1 exceeds V_2 in magnitude, and zero if $V_2=V_1$. In operation, in order to attain optical power P in both of the first and second fluid lenses, one can provide a fluid lens control signal equal to V_1 to both the first and second fluid lenses, and a differential signal equal to the signed difference of V_2-V_1 to the second fluid lens. Alternatively, one could use two power supplies that provide signals V_1 and V_2 to the first and second fluid lenses, respectively. As the optical power required for operation of a fluid lens changes, the fluid lens control signal changes, and can be deduced or read from the appropriate curve of FIG. **8**. Since one in general does not measure the parameters of a fluid lens or other device at all possible values within a range, a curve such as **1810** can also be obtained by measuring a discrete number of pairs of optical parameter and associated fluid lens control signal, and fitting a curve to the data, or interpolating values between adjacent data points, as may be most convenient to prepare a suitable calibration curve. In some instances, only a single calibration point per fluid lens module may be required. Rather than creating curves for different fluid lenses, one can measure the same fluid lens at different temperatures. Then the appropriate operating point can be determined at the various temperatures. Other operating points may be determined by either extrapolation or interpolation, by suitable curve fitting relationships, or by deducing a representation of the behavior in the form of an equation.

[**0077**] FIGS. **9***a*-**9***e* are cross-sectional diagrams of another prior art fluid lens that can be adapted for use according to the principles of the invention. FIG. **9***a* is a cross-sectional view of a prior art fluid lens having no control signal applied thereto and exhibiting divergence of transmitted light. FIG. **9***b* is a cross-sectional view of a prior art fluid lens having a control signal applied thereto and exhibiting convergence of transmitted light. FIGS. **9***c*, **9***b*, and **9***e* are cross-sectional images of fluid lenses having convex, flat and concave interface surfaces as viewed from a position above each lens, respectively.

[**0078**] Using a device comprising a fluid lens, an image sensor, and a suitable memory, it is possible to record a plurality of frames that are observed using the fluid lens under one or more operating conditions. The device can further comprise a computation engine, such as a CPU and an associated memory adapted to record instructions and data, for example for processing data in one or more frames. The device can additionally comprise one or more control circuits or control units, for example for controlling the operation of the fluid lens, for operating the image sensor, and for controlling sources of illumination. In some embodiments, there is a DMA channel for communicating data among the image sensor, the CPU, and one or more memories. The data to be communicated can be in raw or processed form. In some embodiments, the device further one or more comprises communication ports adapted to one or more of hard-wired communication, wireless communication, communication using visible or infra-red radiation, and communication employing networks, such as the commercial telephone system, the Internet, a LAN, or a WAN.

[**0079**] In this embodiment, by applying suitable selection criteria, one can use or display only a good frame or alternatively a most suitable frame of the plurality for further data manipulation, image processing, or for display. According to this aspect of the invention, the device can obtain a plurality of frames of data, a frame being an amount of data contained within the signals that can be extracted from the imager in a single exposure cycle. The device can assess the quality of each of the frames against a selection criterion,

which can be a relative criterion or an absolute criterion. Examples of selection criteria are an average exposure level, an extremum exposure level, a contrast level, a color or chroma level, a sharpness, a decodability of a symbol within a frame, and a level of compliance of an image or a portion thereof with a standard. Based on the selection criterion, the device can be programmed to select a best or a closest to optimal frame from the plurality of frames, and to make that frame available for display, for image processing, and/or for data manipulation. In addition, the operating conditions for the device can be monitored by the control circuit, so that the conditions under which the optimal frame was observed can be used again for additional frame or image acquisition.

[0080] In alternative embodiments, it is possible to use the plurality of frames as a range finding system by identifying which frame is closest to being in focus, and observing the corresponding focal length of the fluid lens. In such an embodiment, the fluid lens can be operated so as to change its plane of optimum focus from infinity to an appropriate near position. The device can obtain one or more frames of data for each focus position that is selected, with the information relating to each focus position being recorded, or being computable from a defined algorithm or relationship, so that the focal length used for each image can be determined. Upon a determination of an object of interest within a frame (or of an entire frame) that is deemed to be in best focus from the plurality of frames, the distance from the device to the object of interest in the frame can be determined from the information about the focal length setting of the fluid lens corresponding to that frame. In some instances, if two adjacent frames are deemed to be in suitable focus, the distance may be taken as the average of the two focal lengths corresponding to the two frames, or alternatively, additional frames can be observed using focal lengths selected to lie between the two adjacent frames, so as to improve the accuracy of the measurement of distance.

[0081] In a second embodiment, apparatus and methods are provided to counteract changes in the environment that surrounds an apparatus comprising a fluid lens. In one embodiment, the apparatus additionally comprises a temperature sensor with a feed back (or feed forward) control circuit, to provide correction to the fluid lens operating signal as the temperature of the fluid lens (or of its environment) is observed to change.

[0082] Feedback systems rely on the principle of providing a reference signal (such as a set point) or a plurality of signals (such as a minimum value and a maximum value for a temperature range) that define a suitable or a desired operating parameter (such as a temperature or a pressure), and comparing a measured value of the parameter to the desired value. When a deviation between the observed (or actual) parameter value and the desired parameter value is measured, corrective action is taken to bring the observed or actual value into agreement with the desired parameter value. In the example of temperature, a heater (such as a resistance heater) or a cooling device (such as a cooling coil carrying a coolant such as water) can be operated to adjust an actual temperature. Using a feedback loop, the apparatus is made to operate at the desired set point, or within the desired range. Feedback loops can be provided using either or both of digital and analog signal processing, and using one or more of derivative, integral and proportional ("D-I-P") controllers.

[0083] In some embodiments, a feed-forward system can be used, in which a change (or a rate of change) of a parameter such as actual or observed temperature is measured. Corrective action is taken when it is perceived that a condition outside of acceptable operating conditions likely would be attained if no corrective action were to be applied and the observed change (or rate of change) of the parameter were allowed to continue unabated for a further amount of time. Feed-forward systems can be implemented using either or both of digital and analog signal processing. In some systems, combinations of feedback and feed-forward systems can be applied. In some embodiments, multiple feedback and feed-forward controls can be implemented.

[0084] In the embodiment contemplated, the operating parameter, such as temperature, of the apparatus comprising a fluid lens, or of the environment in which it is situated, is monitored, and the observed parameter is compared to one or more pre-defined values. The one or more predefined values may fixed (such as a maximum tolerable temperature above which a substance begins to degrade at one atmosphere of pressure) or the one or more predefined values may depend on more than one parameter, such as the combination of pressure and temperature, for example using relationships in a pressure-temperature-composition phase diagram (for example, that a substance or chemical composition in the fluid lens apparatus undergoes a phase change if the pressure and temperature vary such that a phase boundary is crossed, or undergoes a change from covalent to ionic character, or the reverse).

[0085] In another embodiment, a system comprising a fluid lens additionally comprises a non-adjustable lens component configured to correct one or more specific limitations or imperfections of the fluid lens, such as correcting for color, spherical, coma, or other aberrations of the fluid lens itself or of the fluid lens in conjunction with one or more other optical components. By way of example, a fluid lens may exhibit dispersive behavior or color error. In one embodiment, a second optical element is added that provides dispersion of the sign opposite to that exhibited by the fluid lens, so as to correct the dispersive error introduced by the fluid lens. In one embodiment, the dispersive element is a diffraction element, such as an embossed grating or an embossed diffractive element. As will be understood, different optical materials have different dispersive characteristics, for example, two glass compositions can have different dispersion, or a composition of glass and a plastic material can have different dispersion. In the present invention, a material having a suitable dispersive characteristic, or one made to have suitable dispersive characteristics by controlling the geometry of the material, such as in a grating or other diffractive element, can be used to correct the errors attributable to the fluid lens and/or the other components in an optical train.

[0086] The aberrations that are possible in a fluid lens can in principle be of any order, much as the aberrations that are possible in the lens or the cornea of a human eye. Both a human eye and a fluid lens operate using interfaces between two or more dissimilar fluids. In the human eye, there are membranes that are used to apply forces to the fluids adjacent the membranes, by application of muscle power controlled by signals cried by the nervous system. In a fluid lens, there are forces that are applied, in some instances to the fluid or fluids directly by electromagnetic signals, and in

some instances by forces applied to transparent membranes that are adjacent the fluids. Both kinds of systems can be affected by external forces, such as the force of gravity and other accelerative forces, changes in ambient or applied pressure, and changes in ambient or applied temperature.

[0087] In another embodiment, there is provided a calibration tool, process, or method for calibrating a fluid lens. As one example, a system comprising a fluid lens is operated at one or more known conditions, such as one or more magnifications or one or more focal lengths. For each known operating condition, an operating parameter, such as a value of the driving voltage, is observed or measured. The observed or measured data is stored in a memory. The data in memory is then used to provide calibration data for application to the operation of the fluid lens.

[0088] Even if two or more nominally identical fluid lenses are provided, there can be differences that exist in the two fluid lenses themselves, as has been explained hereinbefore. When intrinsic differences between two nominally identical fluid lenses exist, application of a substantially identical fluid lens control signal to the two lenses can result in different operative behavior for each lens. A default calibration can be provided, for example based on a calibration performed under controlled or defined conditions. The default calibration data can be recorded and used at a later time to operate the fluid lens for which the calibration was obtained. Using such calibrations is an effective and efficient way to operate a given fluid lens over a defined operating range. For many purposes, such information is well worth having and helps to provide a fluid lens that is conveniently operated in a predictable manner. Between calibration points, interpolation can be used to achieve an improved resolution. Similarly extrapolation may be used to estimate the attributes of a feature beyond the range of measured calibration data.

[0089] In addition, as has been indicated, differences may be externally imposed, such as applied voltage, ambient or applied pressure, ambient or applied temperature, and accelerative forces. These forces may, individually and in combination, cause one fluid lens to operate somewhat differently that a nominally identical fluid lens. When such differences in operating conditions exist, application of a substantially identical fluid lens control signal to the two lenses can result in different operative behavior for each lens. Accordingly, it can be helpful to provide a simple and readily applied calibration method for a fluid lens, so that each lens can be calibrated and provided with suitable fluid lens control signals to operate in a desired fashion under the particular conditions obtaining for that fluid lens.

[0090] Yet a third reason for providing calibration capabilities relates to changes in operation of a given fluid lens over time. The operation of an individual fluid lens relies on one or more of the chemical, mechanical, and electrical properties of the components of the fluid lens, which properties may change with time and with use. For example, as indicated hereinabove, a fluid lens operating in response to electrical signals may undergo electrochemically driven reactions in one or more fluids. In addition, a fluid may change properties over time as a result thermal history, such as of repeated heating and cooling cycles or exposure to extremes of temperature. As will be understood, as a property of one or more components of a fluid lens changes with time, it may be advantageous to calibrate the operating conditions of interest.

[0091] In another embodiment, an inertial device such as an accelerometer is provided to determine an orientation of a fluid lens, which orientation information is used to self-calibrate the fluid lens. Gravitational and other accelerative forces can cause fluids to move and change shape at a free boundary, or a boundary where two fluids come into mutual contact. By way of example, consider a fluid lens that comprises two fluids having slightly different densities. Different density implies that equal volumes of the two fluids will have proportionately different masses, because density=mass/volume. Therefore, since Force (F)=mass× acceleration, the equal volumes of the two fluids will experience slightly different forces under equal acceleration, such as the acceleration of gravity, or of an external accelerative force applied to a container holding the two fluids. One consequence of such an applied acceleration can be a change in the relative locations of the fluids, and as a result, a change in the shape of the interface defined by the surface of contact between the two fluids. In addition, the direction of application of the acceleration will also have a bearing on the response of the fluids. For example, an acceleration applied normal to a flat interface between the two fluids may have much less of an effect than an acceleration parallel to, or tangent to, a surface component of the interface between the two fluids. Since the accelerative force in general can be applied at any angle with regard to an interface between the two fluids, there will in general be differences in response depending on the precise orientation of the applied accelerative force. Inertial sensors such as accelerometers and gyroscopes can be useful in determining and in tracking the position of an object over time. Through the use of such inertial sensors, it is possible to discern an orientation of an object, and to measure the magnitudes and directions of applied accelerative forces. It is possible to calculate or to model how the fluids present in the lens will respond to the forces operating on the lens with knowledge of the orientation of a fluid lens and of the external forces, including that of gravity. While the description presented hereinabove may be understood to describe linear accelerative forces such as gravity, it is also possible to perform both the tracking and the calculation of the responses of fluids to forces having non-linear components, forces having rotational components, or time-varying forces. In some embodiments, using appropriate sensors for various forces, one can determine the relative orientation of the applied force and the interface between two fluids, and compute what response would be expected. As a result of the computation, information is provided for the timely application of a restorativesignal. In one embodiment, solid state accelerometer sensors are provided that operate at sufficiently high rates as to determine the magnitude and orientation of an external force. Accelerometers having response rates of at least 10,000 Hz are available from Crossbow Technology, Inc. located at 4145 N. First Street, San Jose, Calif. 95134.

[0092] In another embodiment, in an apparatus comprising a fluid lens, the fluid lens is operated to provide corrective properties with regard to such distortions as may be caused by vibration, location or orientation of the lens, chromatic aberration, distortions caused by higher order optical imperfections, and aberrations induced by environmental factors, such as changes in pressure. As has been explained herein-

before, using accelerative forces as an example, the fluid lens may in some instances be subjected to various distorting forces or to forces that cause degradation of the operation of the fluid lens from that which is desired. In other instances, the fluid lens may have inherent imperfections, such as chromatic aberration or higher order optical imperfections. It is possible to analyze such optical imperfections in various ways, such as the use of a calibrated imaging system comprising a source, at least one image sensor, and hardware and/or software configured to analyze optical information to assess whether errors or imperfections exist in an optical component under test. The calibrated imaging system in some instances can be a laboratory setting in which highly sophisticated equipment is employed to perform tests. In other instances, the calibrated test system can comprise a source that provides a known optical signal that is passed through an optical component under test, and the analysis of the resulting signal that emerges from the optical component under test. The calibrated test system in some embodiments is a system or device suitable for use in the field, so that periodic calibration can be performed in a convenient and efficient manner, if necessary by personnel who are not familiar with all of the sophistications of optical testing in a laboratory setting.

[0093] In one embodiment, the optical component can be modeled in the frequency domain as a transfer function, wherein a known applied input signal I(s) is provided and an observed output signal O(s) is measured. An observed transfer function $H_{obs}(s)=O(s)/I(s)$ is determined. $H_{obs}(s)$ can then be compared to a desired transfer function H(s), to determine a corrective factor or relation C(s) that should be applied to the system under test to cause it to perform as desired. where $C(s)H_{obs}(s)=H(s)$, or $C(s)=H(s)/H_{obs}(s)$. Once the corrective factor or relation C(s) has been determined, it (or its time domain equivalent) can be applied to drive the fluid lens so as to reduce the observed imperfection or imperfections. Transfer function concepts, discrete time mathematical procedures, digital filters and filtering methods, and circuitry (including hardware and software) that can handle the required detection, analysis and computation, and can be used to apply corrective action are described in many texts on real time digital signal processing. Hardware such as digital signal processors are commercially available from multiple vendors.

[0094] FIGS. **10**A and **10**B are diagrams that show an LED die **3010** emitting energy in a forward direction through a fluid lens **3020**. The divergence of the emitted light is modified with the fluid lens. In FIG. **10**A the divergence of the emitted light is modified because of the optical power of the fluid lens. In the example shown the light exiting the fluid lens could be considered to approximate collimated light even though the light exiting the LED is diverging. In a situation where the curvature of the fluid lens is more extreme than is shown in FIG. **10**A, the light may be focused on a small region, or even down to a point of light. In FIG. **10**B the power of the fluid lens has been reduced to approximately zero so that the divergence of the light emitted by the LED is substantially unchanged. The comparison of the light patterns in FIGS. **10**A and **10**B indicates that such systems can be used to control the coverage (in area) and intensity of illumination at a target of interest, for example a bar code that one is interested in reading with a hand held reader or imager. In some embodiments, one or more windows on a reader or scanner may also be used to protect the optical system including the fluid lens from adverse environmental conditions.

[0095] It should be appreciated that although the details may change, this concept also applies to encapsulated LEDs, as well as to fluid lens assemblies that may contain additional optical elements such as spherical, aspherical and cylindrical lens elements.

[0096] In one embodiment, such a system is expected to more efficiently utilize a higher fraction of light emitted by the LEDs. For example when viewing bar code patterns near the imager, a more diverging illumination pattern is desirable in order to be assured that larger bar code patterns are illuminated over their entire extent and when viewing bar code patterns at a larger distance from the imager, a more converging illumination pattern is desirable so that illumination is not wasted by falling outside the optical field of interest.

[0097] FIGS. **11**A and **11**B show diagrams of a laser scanner comprising a laser **3110**, a collimating lens **3120**, and a fluid lens **3130** in various configurations. In FIG. **11**A the fluid lens is configured to have a first optical power and a first focal length. The light beam emanating from the fluid lens **3130** is focused to have a narrowest beam width at a plane **3140** situated at a first distance D1 from the fluid lens **3130**. In FIG. **11**B the fluid lens is configured to have a second optical power and a second focal length. In FIG. **11**B, the light beam emanating from the fluid lens **3130** is focused to have a narrowest beam width at a plane **3140** situated at a first distance D2 from the fluid lens **3130**, such that D2 is greater than D1

[0098] Fluid zoom lens configurations can be used in bar code scanners to enable imaging of different bar codes at various distances from the bar code scanner. In bar code scanners manufactured today, often a large working distance is achieved by stopping down the lens aperture to increase the optical depth of field. However this has two disadvantages: First, when the lens stop is smaller, the optical system point spread function increases thereby making it more difficult to scan bar code patterns with narrow bar code elements. Second, when the lens stop is smaller, less light enters the lens thereby reducing the signal-to-noise ratio of the system. The lower SNR requires the operator to hold the reader still for longer period of time. The effect is that the bar code scanner has an increased sensitivity to hand motion. In addition, because longer periods of time are required, the user is more likely to become fatigued.

[0099] These disadvantages can be significantly reduced using a zoom lens to change both the optical power of the lens system and also the plane of optimum focus. This additional control of the operating parameters of the reader or imager would allow the use of a lens system with a larger numerical aperture. In the examples given by Welch Allyn workers, the bar code scanner imager (CCD, CMOS, or color imager) would take the place of the physician's eye (or imager in some systems) and the bar code would replace the patient's eye.

[0100] Object distance measurements can be made if the range of, or the distance to, the object is known. A fluid lens system can be used to implement a range finding system. In one embodiment, the fluid lens would be focused at a number of focus positions and the position with the best

focus, as determined by any of a number of metrics, would be associated with that fluid lens position. By knowing the fluid lens drive signal that caused the fluid lens to have an optimally focused image, and using a table look-up, the associated distance from the system for that specific fluid lens operating signal can be determined. By knowing the range, the magnification can be calculated and thus the object width associated with a given number of pixels at the imager is known or can be deduced. In this way a system such as a bar code reader or imager can calculate the width of a specific object features, such as bar code element widths or the dimensions of a package.

[0101] A fluid lens variable aperture can be added to a bar code system. In some embodiments, the aperture would be used in the portion of the optical system that receives light and would allow the system to optimally trade light efficiency against point spread function width and depth of field. When a small aperture is used, the optical system will have a larger depth of field, but adversely the optical throughput of the system is reduced (i.e., less light gets through the system) and the point spread function (proportional to the minimal element size that can be resolved) is also reduced. In some embodiments, a bar code system is expected to be configured to initially have the optical system set for an optimum light throughput, and if a good read is not achieved then the aperture size could be reduced in order to extend the depth of field in an effort to decode any bar code pattern that may be within the bar code scanner field of view.

[0102] By having more than one lens element configured as a fluid lens, the optical aberrations present in a single element can be reduced for the assemblage of lenses and this would result in a higher quality optical image. The techniques for optimizing a triplet are well known in the lens design art. However, it is typically the case that any given lens is optimized for a given focal length system. Typically, if a lens is optimized for one combination of optical elements, it is not optimally configured when one of the lens surfaces is changed as would happen when a single fluid element is operated to change an optical parameter, such as a focal length. By adding a second fluid lens, the combination of the first lens and the second lens can be optimized to minimize total system aberrations. For different settings of the first lens, corresponding changes in the settings of the second lens can be made to obtain an optimal combination. These optimized relationships between the two fluid lens surfaces curvatures, i.e. surface optical power, and thus also the control voltages, can be contained for example in a table that is recorded in a machine readable memory. Thus for any given setting of desired system optical power, the appropriate drive signals for the two fluid lenses can be developed, and applied in accordance with the recorded values. Where desirable or advantageous, the fineness of the table resolution may be increased through use of linear or higher order interpolation and extrapolation.

[0103] Other prior art fluid lens systems that operate using mechanical forces to control the shape and properties of a fluid lens are described in U.S. Pat. No. 4,514,048 to Rogers, which has already been incorporated herein by reference in its entirety. Additional disclosure relevant to variable focus lenses is presented in the following U.S. Patents: U.S. Pat. No. 2,300,251 issued Oct. 17, 1942 to Flint, U.S. Pat. No. 3,161,718 issued Dec. 15, 1964 to DeLuca, U.S. Pat. No. 3,305,294 issued Feb. 21, 1967 to Alvarez, and U.S. Pat. No. 3,583,790 issued Jun. 8, 1971 to Baker, all of which are hereby incorporated by reference herein in their entirety.

[0104] An approach to controlling the shape of the lens is the use of an electronic fluid lens pump or micropump. This approach may additionally be implemented in such a manner as to close or seal the otherwise exposed face of the fluid lens, thereby preventing fluid loss, as from evaporation or wicking, as well as contamination. This is important because in some fluid lenses, surface tension is used to maintain a given lens curvature, and any contact with the lens surface may cause contamination and/or wicking of the lens material to the contacting material. In addition, the exposed lens surface may lose mass, and hence volume, to evaporation, resulting in unwanted or unintentional changes in lens curvature.

[0105] These problems may be prevented by using a sealed or closed system as described herein. In particular, a closed lens configuration is contemplated having front window F and optional rear window R, which will generally be formed of transparent optical plastic or glass, as shown in FIG. **12**, which depicts the front and rear cavities of the lens structure. Front window F partially bounds a space or chamber volume C between the front window and the surface of the fluid lens. Chamber volume C contains air or a second Fluid **2**, in contrast to a first Fluid **1** comprising the lens itself, that is, comprising lens volume L. Fluid **1** has a refractive index N_1, and Fluid **2** has a refractive index N_2, with $N_1 \neq N_2$. The front and rear windows prevent contamination, evaporation, or wicking away of the lens fluid. This is of particular importance when the lens is formed by surface tension of a hydraulic fluid. In a sealed system, the hydraulic fluid volume in the lens volume L is changed, causing the lens surface curvature to change. This causes the lens power to change; a change in the curvature of meniscus M will cause a change in the radius of curvature R_C, which is the radius of a circle of which meniscus M represents an arc, either increasing the radius or decreasing it up to and including transition to a negative radius of curvature, in which the meniscus inverts from convex to concave. However, if the cavity were sealed without a way for the non-pumped side of the curved surface to accommodate the change in volume, the fluid in this non-pumped volume would have to be compressed. In one embodiment, it may be desirable to develop a pump that is connected to both sides of the lens surface—that is, to both lens volume L and chamber volume C—such that the volumes of both sides of the lens surface are changed by the some amount. Two pump configurations are shown that accomplish this.

[0106] FIG. **13** depicts a plunger pump that may be used with alternate sides of the plunger being connected to alternate sides of the fluid lens cavity. As shown, the left side of the pump is connected to chamber (first) volume C of FIG. **12**, while the right side connects to the lens (second) volume L. The plunger is moved to change the lens curvature. Movement of the plunger to the left as shown in FIG. **13** will pull fluid from the lens volume L while pushing air into the chamber volume C, causing the radius of curvature, R, to increase. Conversely, movement of the plunger to the right will pull air from the chamber volume C while pushing fluid into the lens volume L, thereby causing the radius of curvature, R, to decrease. If chamber C is filled with air

(Fluid **2**), and chamber L is filled with water (Fluid **1**), decreasing the radius of curvature will result in a decrease in the focal length for the lens.

[**0107**] Alternatively, as shown in FIG. **14**, an electrostatic pump may be used to change the location of a fluid-to-fluid interface (where one of the fluids may be a gas such as air) in a parallel group of small capillary tubes by applying a potential difference between the two ends of the capillaries. By changing the relative potential between the two set of electrodes on opposite sides of the pump, the position of the Fluid **1**/Fluid **2** interface can be changed. (Each electrode is wired to a power source, in parallel on each side of the capillary array; in FIG. **14** the wires for the top pair of electrodes only are shown for illustrative purposes only.) When connected to the fluid lens structure of FIG. **12**, a change in the position of this interface results in a fluid lens radius of curvature change for the Fluid **1**/Fluid **2** interface. The diameter of these microchannels are on the order of several micrometers.

[**0108**] In both embodiments the two fluid volumes, namely volume C between the front window and the front surface of the fluid lens, and volume L represented by the material of the fluid lens itself, are operably connected through the pump; that is, movement or actuation of the pump mechanism to cause a change in one volume will thereby cause a corresponding change in the other volume.

[**0109**] Of course, it is not essential that the change in volume of Fluid **1** be offset by a corresponding reduction in the quantity of Fluid **2**. If, for example, Fluid **2** is sufficiently compressible under the force applied to Fluid **1**, lens volume L may be increased at least partially by compressing Fluid **2** rather than by removing a corresponding quantity of Fluid **2** from chamber volume C through the pump system. Depending on the system configuration and choice of materials, it may be possible to increase lens volume L with no removal of Fluid **2** from chamber volume C, that is, lens volume L may be increased solely though compression of Fluid **2**. This applies equally to a reduction of lens volume L; rather than adding a corresponding amount of Fluid **2** to chamber volume C, the decrease in lens volume L may be accompanied by an expansion of Fluid **2**, either in part or in whole. In other words, an increase or decrease of lens volume L may be accompanied by an increase or decrease in the pressure in chamber volume C. For example, chamber volume C and lens volume L may not be operably linked, and instead be separately controlled by separate pump systems, or the two volumes may each be sealed with both, or only one, subject to control by a pump system. Operation of a single pump system on only one volume would change the pressure of that volume, and hence the pressure exerted by that volume on the second volume, changing the radius of curvature of the meniscus in the process.

[**0110**] The above discussion and accompanying figures are primarily directed to a fluid lens system in which there is a single lens having optically clear windows at front and back. This configuration may readily be adapted to systems having plural lenses, preferably independently operable, such as by plural pump systems. One representative embodiment is provided in FIG. **15**, which essentially comprises two lens systems of the type shown in FIG. **12** back-to-back in mirror image. It is contemplated, in this and other plural lens systems, that the respective lenses may have different diameters as well. Changes in the diameter will affect the rate of change to the radius of curvature in response to a given change or rate of change in the pressure/volume of any fluid. Further embodiments will be readily apparent to those of skill in the art.

[**0111**] FIG. **16** presents another embodiment of the pump/lens system of the present invention. In this unitary embodiment, Fluid **1** and Fluid **2** are separated by interface i. The lens is positioned between a first optically clear window w_1 and second optically clear window w_2. A rectangular pump channel c is located within the body of the pump/lens system, the channel having length **1**, separation s, and width w. By way of non-limiting example, channel length **1** may be about 1 mm, separation s may be about 1 μm, and width w may be about 5 mm; however, in any event at least one such dimension of the pump channel should be less than about 10 microns. Metal electrodes disposed at each end and on either side of the pump channel are used to control pressure on the fluid in the channel, moving the interface in either direction and changing the radius of curvature of the lens accordingly. (As in FIG. **14**, wires are shown only for the upper electrodes for illustrative purposes only, the wires/electrodes being used to create a potential difference V therebetween.)

[**0112**] In characterizing how the lens is affected by changes in the fluid volumes, whether of quantity, pressure, or both, reference may be made to the radius of curvature of the lens, the location of the surface of the meniscus, the shape of the meniscus, and the diameter of the lens/meniscus. By way of example, the fluid lens itself may be in the shape of a meniscus, having by approximation a spherical surface, as shown in FIGS. **12** and **16**. The diameter of the lens is fixed in a channel or receptacle, while the meniscus portion may expand or contract in response to changes in the volume/pressures of the fluids forming the lens system, including the fluid forming the lens itself. The edge or perimeter of the meniscus, where the domed portion meets the sidewalls, remains constant, with a fixed diameter. The meniscus is analogous to a flexible membrane whose diameter has been sealed to a closed volume into which air may be added or removed, thereby expanding or deflating the membrane. Inflation causes the membrane to expand, causing the radius of curvature to decrease. Similarly, allowing gas to escape from an expanded membrane causes it to contract with a corresponding increase in the radios of curvature. Any such change causes physical parameters of the membrane to change, including its radius of curvature. Similarly, any change to the fluid lens effected by the control mechanisms of the present invention will result in certain physical changes, such as the radius of curvature of the meniscus.

[**0113**] FIG. **17** provides a closer view of one embodiment of the fluid lens itself, showing possible alternative radii of curvatures that the lens surface, or meniscus, might assume depending on the movements of, and/or pressures on, the fluids brought about by the control systems as described herein. For example, taking the changes in position/shape of the meniscus as shown in FIG. **17**, and effecting those changes to the fluid lens shown in FIG. **12**, operation of the pump causes a first fluid movement in direction A, which will cause a movement of the surface of the meniscus shown in FIG. **12** to the left, while operation in direction B will move it to the right, of the position in which it is presented

in FIG. **12**. Solid line L_1 represents a possible resting or default state of the meniscus that forms the surface of the lens, and whose position relative to the frame and radius of curvature affect the focal length of the lens. Dotted line L_2 shows movement of the meniscus outward or upward relative to the default or resting position. This change in position would result in a decrease in the radius of curvature, and for the case shown in FIG. **17** with $N_1 > N_2$, the focal length of the lens will be decreased. Dotted line L_3 shows movement of the meniscus inward or downward relative to the default or resting position, which still maintaining a convex curvature, while having a larger radius of curvature than L_2. Dotted line L_4 shows further movement of the meniscus inward or downward relative to the default or resting position L_1, in this case resulting in transition of the meniscus from the convex to the concave. This change in shape and position of the meniscus would result in a lens having a negative focal length.

[**0114**] FIGS. **18**A-**18**D represent various lens structures and control systems or mechanisms for control of the fluid lens. In particular, FIG. **18**C represents an electromagnetic solenoid control mechanism that may be used to actuate the plunger, and FIG. **18**D represents an electrostatic plunger control mechanism consisting of a dielectric plunger between two capacitor plates.

[**0115**] It may also be desirable to include, in effect, a safety valve such that, for example, a change in one of the volumes will not produce a change, or at least not a corresponding change, in the other volume. This could be accomplished by providing a safety valve or functionally similar device that will come into play if there is a change in one or both volumes that does not take place in response to deliberate actuation of the pump mechanism. Examples would include thermal expansion or contraction of the fluid, and mechanical shock.

[**0116**] Machine-readable storage media that can be used in the invention include electronic, magnetic and/or optical storage media, such as magnetic floppy disks and hard disks; a DVD drive, a CD drive that in some embodiments can employ DVD disks, any of CD-ROM disks (i.e., read-only optical storage disks), CD-R disks (i.e., write-once, read-many optical storage disks), and CD-RW disks (i.e., rewriteable optical storage disks); and electronic storage media, such as RAM, ROM, EPROM, Compact Flash cards, PCMCIA cards, or alternatively SD or SDIO memory; and the electronic components (e.g., floppy disk drive, DVD drive, CD/CD-R/CD-RW drive, or Compact Flash/PCMCIA/SD adapter) that accommodate and read from and/or write to the storage media. As is known to those of skill in the machine-readable storage media arts, new media and formats for data storage are continually being devised, and any convenient, commercially available storage medium and corresponding read/write device that may become available in the future is likely to be appropriate for use, especially if it provides any of a greater storage capacity, a higher access speed, a smaller size, and a lower cost per bit of stored information. Well known older machine-readable media are also available for use under certain conditions, such as punched paper tape or cards, magnetic recording on tape or wire, optical or magnetic reading of printed characters (e.g., OCR and magnetically encoded symbols) and machine-readable symbols such as one and two dimensional bar codes.

[**0117**] Many functions of electrical and electronic apparatus can be implemented in hardware (for example, hard-wired logic), in software (for example, logic encoded in a program operating on a general purpose processor), and in firmware (for example, logic encoded in a non-volatile memory that is invoked for operation on a processor as required). The present invention contemplates the substitution of one implementation of hardware, firmware and software for another implementation of the equivalent functionality using a different one of hardware, firmware and software. To the extent that an implementation can be represented mathematically by a transfer function, that is, a specified response is generated at an output terminal for a specific excitation applied to an input terminal of a "black box" exhibiting the transfer function, any implementation of the transfer function, including any combination of hardware, firmware and software implementations of portions or segments of the transfer function, is contemplated herein.

[**0118**] While the present invention has been particularly shown and described with reference to the structure and methods disclosed herein and as illustrated in the drawings, it is not confined to the details set forth and this invention is intended to cover any modifications and changes as may come within the scope and spirit of the following claims.

What I/We claim is:

1. An imager for use in a data collection device, said imager comprising a fluid lens system for focusing light received by said data collection device from a target image, said fluid lens system comprising:

a) an optical, clear front window,

b) a fluid lens having a front surface and a rear surface,

c) a first volume bounded by said front window and said front surface of said fluid lens;

d) an optical, clear rear window; and,

e) a second volume bounded by the front surface of said fluid lens and said rear window,

wherein said first volume and said second volume are operably linked through a pump that, in combination with said first volume and said second volume, forms a sealed system.

2. The imager as defined by claim 1, wherein said optical, clear front window is composed of a material selected from the group consisting of optical clear glass and optical clear plastic.

3. The imager as defined by claim 1, wherein said first volume contains a fluid having a diffractive index N_2 and said second volume contains a fluid having a diffractive index N_1, further wherein $N_2 \neq N_1$.

4. The imager as defined by claim 1, wherein said first volume and said second volume are operably linked by a first channel connecting said first volume to said pump and a second channel connecting said second volume to said pump, wherein said pump comprises a plunger, electrostatic electrodes, or piezoelectric material.

5. The imager of claim **4**, said pump comprising a seal separating said first and said second fluids, further wherein operation of said pump to effect a first change in the quantity of fluid in either of said first volume or said second volume results in a corresponding second change in the quantity of fluid in the other of said first volume or said second volume.

6. The imager of claim 5, wherein said corresponding second change in the quantity of fluid in the other of said first volume or said second volume is equal but opposite to said first change in the quantity of fluid in either of said first volume or said second volume.

7. The imager as defined in claim 4, wherein said pump is an electrostatic pump, further wherein said electrostatic pump comprises an interface between said first and second fluids, said interface being located within a capillary channel and being selectively moveable in response to changes in electric potential.

8. The imager as defined by claim 7, wherein said changes in electric potential are created by electrodes positioned adjacent either end of said capillary channel.

9. The imager as defined by claim 7, wherein said capillary channel has one dimension that is less than 10 microns.

10. The imager as defined by claim 8, further comprising a plurality of said capillary channels, each of said capillary channels having electrodes positioned adjacent either end thereof.

11. The imager as defined by claim 10, wherein said plurality of said capillary channels are substantially parallel to each other.

12. The imager of claim 1, further comprising means to prevent a corresponding second change in the quantity of fluid in the other of said first volume or said second volume in response to a first change in the quantity of fluid in either of said first volume or said second volume when said first change is not in response to deliberate actuation of said pump.

13. The imager of claim 12, wherein said means comprises a safety valve.

14. The imager of claim 12, wherein said first change is the result of thermal expansion of at least one of said first volume or said second volume.

15. The imager of claim 12, wherein said first change is the result of thermal contraction of at least one of said first volume or said second volume.

16. The imager of claim 12, wherein said first change is the result of mechanical shock to at least one of said first volume or said second volume.

17. The imager of claim 12 wherein said imager further comprises a fluid lens control module and a temperature sensor for measuring a temperature in a vicinity of said fluid lens, said fluid lens control module being configured to apply to said fluid lens a fluid lens control signal based on information output by said temperature sensor.

18. A data reader for reading an indicium, said data reader comprising a case configured to be held in a hand of a user of the data reader, said case configured to house components of said data reader, said components comprising:

a) a lens system for focusing illumination representing an image of said indicum, said lens system comprising a fluid lens;

b) a fluid lens control module configured to apply a fluid lens control signal to said fluid lens to control an operational parameter thereof;

c) an image sensor configured to receive said focused illumination representing said image of said indicium;

d) an image sensor control module configured to operate said image sensor to capture data comprising at least a portion of a frame of image data from said focused illumination representing said image of said indicium; and

e) a processing module configured to process said at least a portion of said frame of image data to extract therefrom information by the indicium, said lens system further comprising;

f) an optical, transparent front window,

g) a fluid lens having a front surface and a rear surface,

h) a first volume bounded by said front window and said front surface of said fluid lens,

i) an optical, clear rear window, and

j) a second volume bounded by the front surface of said fluid lens and said rear window,

wherein said first volume and said second volume are operably linked through a pump that, in combination with said first volume and said second volume, forms a sealed system.

* * * * *

US 20070171288A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2007/0171288 A1**

Inoue et al. (43) **Pub. Date: Jul. 26, 2007**

(54) **IMAGE CORRECTION APPARATUS AND METHOD, IMAGE CORRECTION DATABASE CREATING METHOD, INFORMATION DATA PROVISION APPARATUS, IMAGE PROCESSING APPARATUS, INFORMATION TERMINAL, AND INFORMATION DATABASE APPARATUS**

(76) Inventors: **Yasuaki Inoue**, Osaka (JP); **Akiomi Kunisa**, Tokyo (JP); **Kenichiro Mitani**, Osaka (JP); **Kousuke Tsujita**, Saitama (JP); **Satoru Takeuchi**, Osaka (JP)

Correspondence Address:
MCDERMOTT WILL & EMERY LLP
600 13TH STREET, N.W.
WASHINGTON, DC 20005-3096 (US)

(21) Appl. No.: **10/594,151**

(22) PCT Filed: **Mar. 1, 2005**

(86) PCT No.: **PCT/JP05/03398**

§ 371(c)(1),
(2), (4) Date: **Sep. 25, 2006**

(30) **Foreign Application Priority Data**

Mar. 25, 2004 (JP) 2004-089684
Jun. 23, 2004 (JP) 2004-185659
Nov. 12, 2004 (JP) 2004-329826

Publication Classification

(51) **Int. Cl.**
H04N 5/217 (2006.01)

(52) **U.S. Cl.** **348/241**

(57) **ABSTRACT**

A capturing unit captures and digitizes a printed image having an electronic watermark embedded therein and a lattice pattern image. A profile creation unit detects position deviations of intersections in the lattice pattern images captured at respective different zoom magnifications, generates correction information on distortion occurring in the images, and registers the correction information into a profile database in association with the zoom magnifications. An image correction unit selects correction information corresponding to a zoom magnification employed at the time of capturing of the printed image from the profile database, and corrects distortion occurring in the captured image of the printed image. An image area determination unit determines an original image area in the distortion-corrected captured image. A watermark extraction unit extracts watermark information from the original image area in the distortion-corrected captured image.

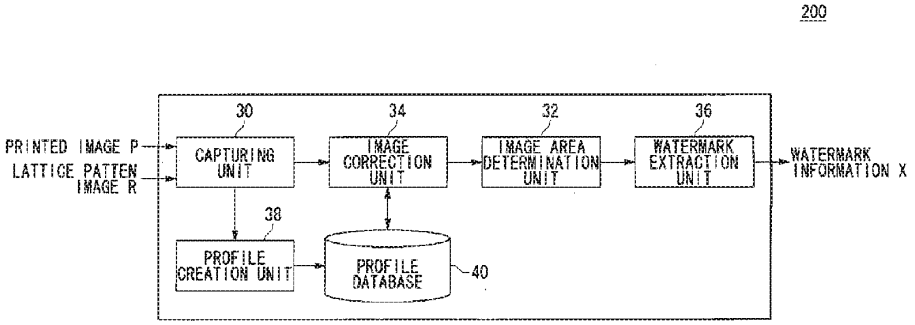


FIG.1

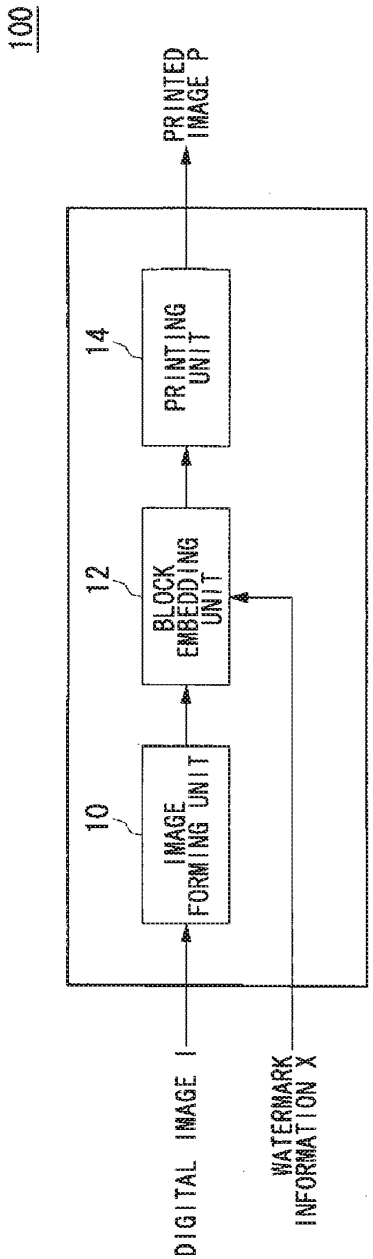

100
PRINTED IMAGE P
14
PRINTING UNIT
12
BLOCK EMBEDDING UNIT
10
IMAGE FORMING UNIT
DIGITAL IMAGE I
WATERMARK INFORMATION X

FIG.2A

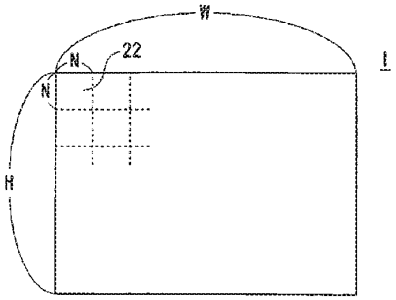


FIG.2B

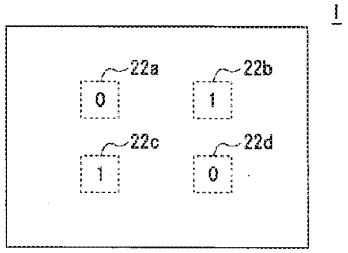


FIG.2C

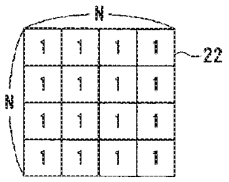


FIG.2D

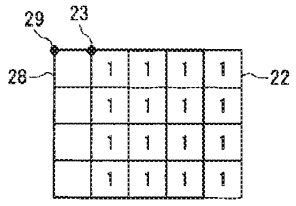


FIG.3

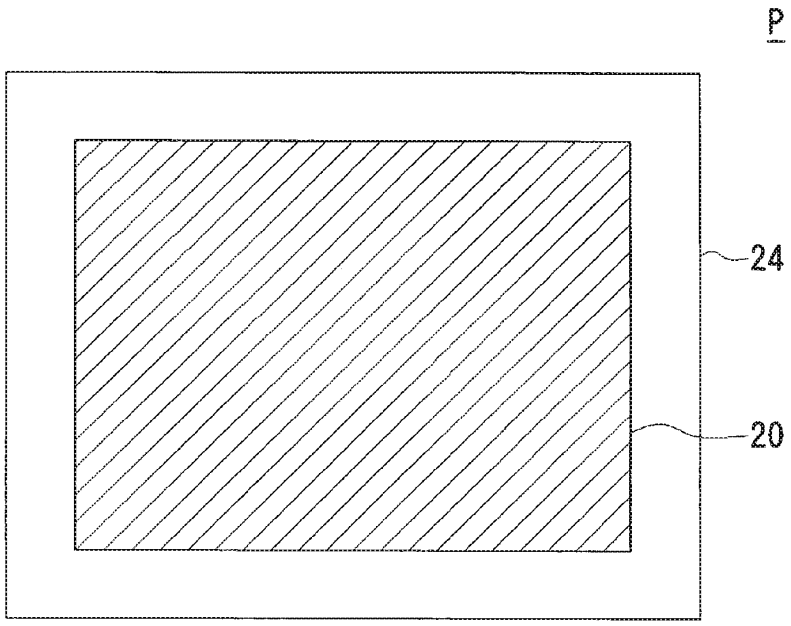


FIG.4

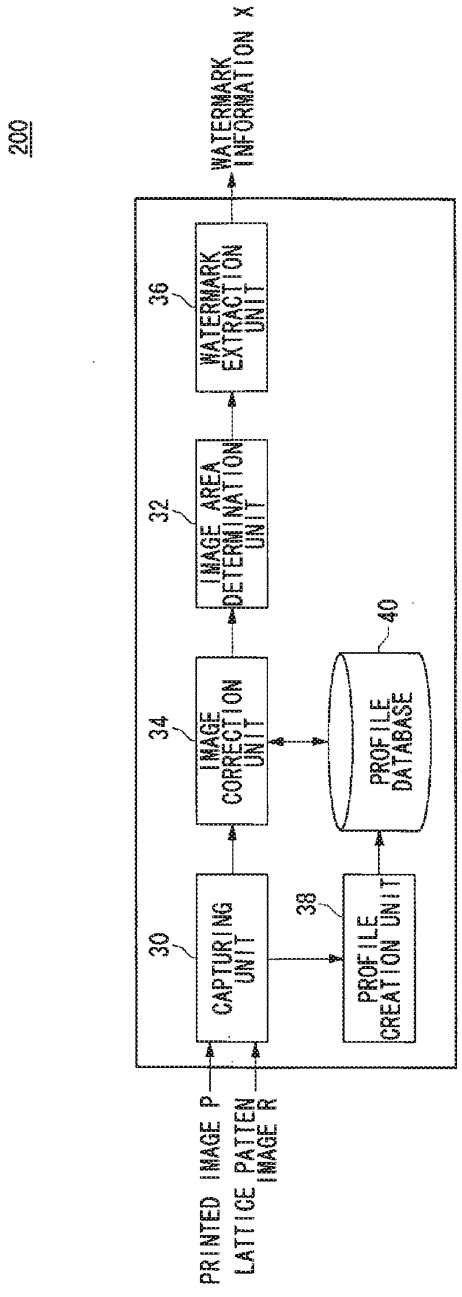

200
WATERMARK INFORMATION X
36
WATERMARK EXTRACTION UNIT
32
IMAGE AREA DETERMINATION UNIT
34
IMAGE CORRECTION UNIT
40
PROFILE DATABASE
30
CAPTURING UNIT
38
PROFILE CREATION UNIT
PRINTED IMAGE P
LATTICE PATTEN IMAGE R

FIG.5

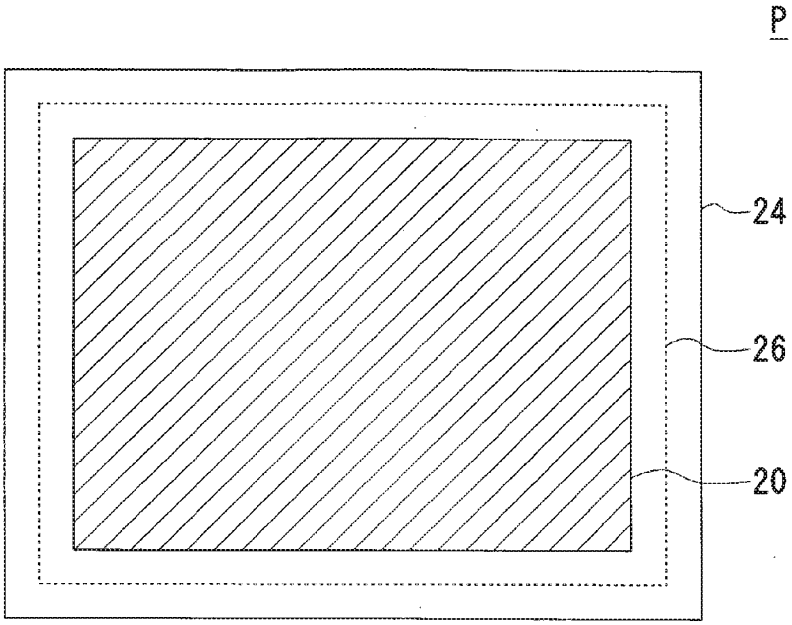


FIG.6

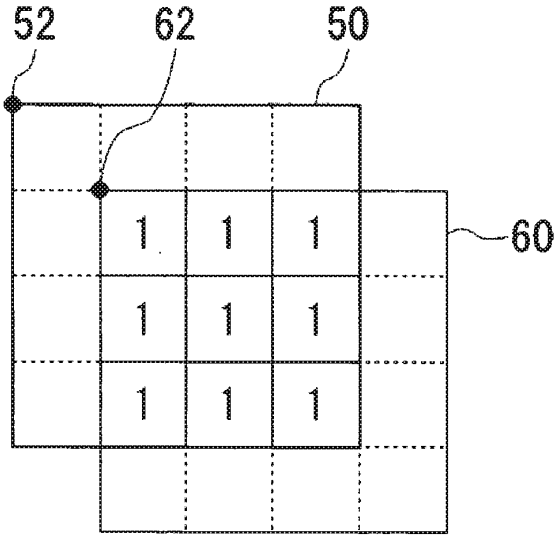
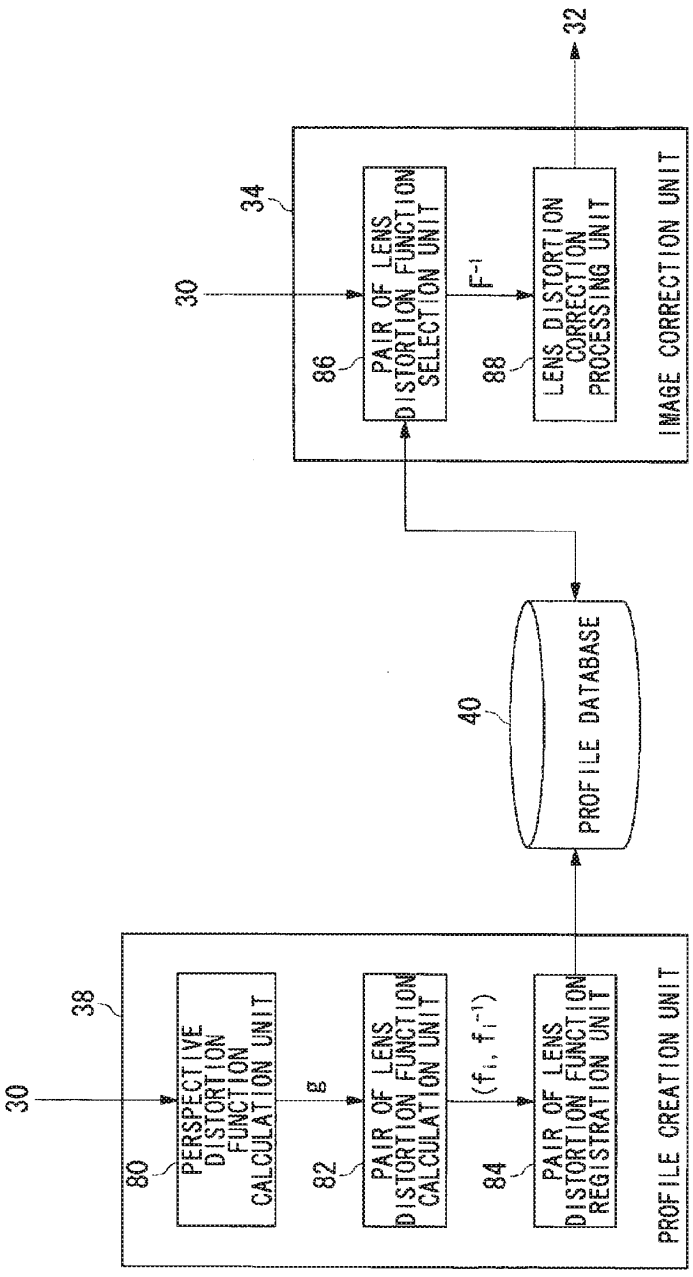


FIG.7


32
34
30
PAIR OF LENS DISTORTION FUNCTION SELECTION UNIT
86
F^{-1}
LENS DISTORTION CORRECTION PROCESSING UNIT
88
IMAGE CORRECTION UNIT
40
PROFILE DATABASE
38
30
PERSPECTIVE DISTORTION FUNCTION CALCULATION UNIT
80
g
PAIR OF LENS DISTORTION FUNCTION CALCULATION UNIT
82
(f_i, f_i^{-1})
PAIR OF LENS DISTORTION FUNCTION REGISTRATION UNIT
84
PROFILE CREATION UNIT

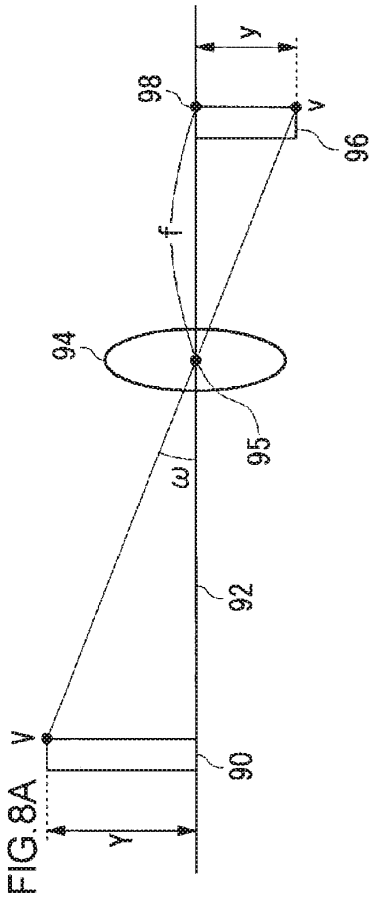


FIG.8A

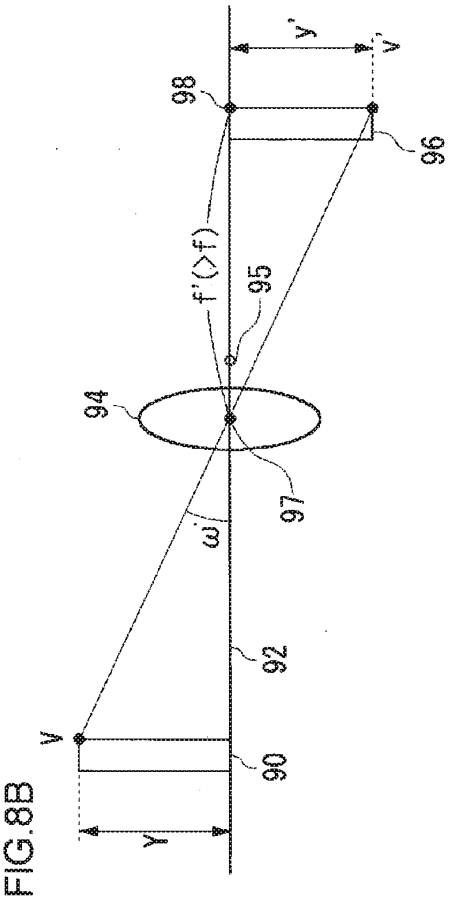


FIG.8B

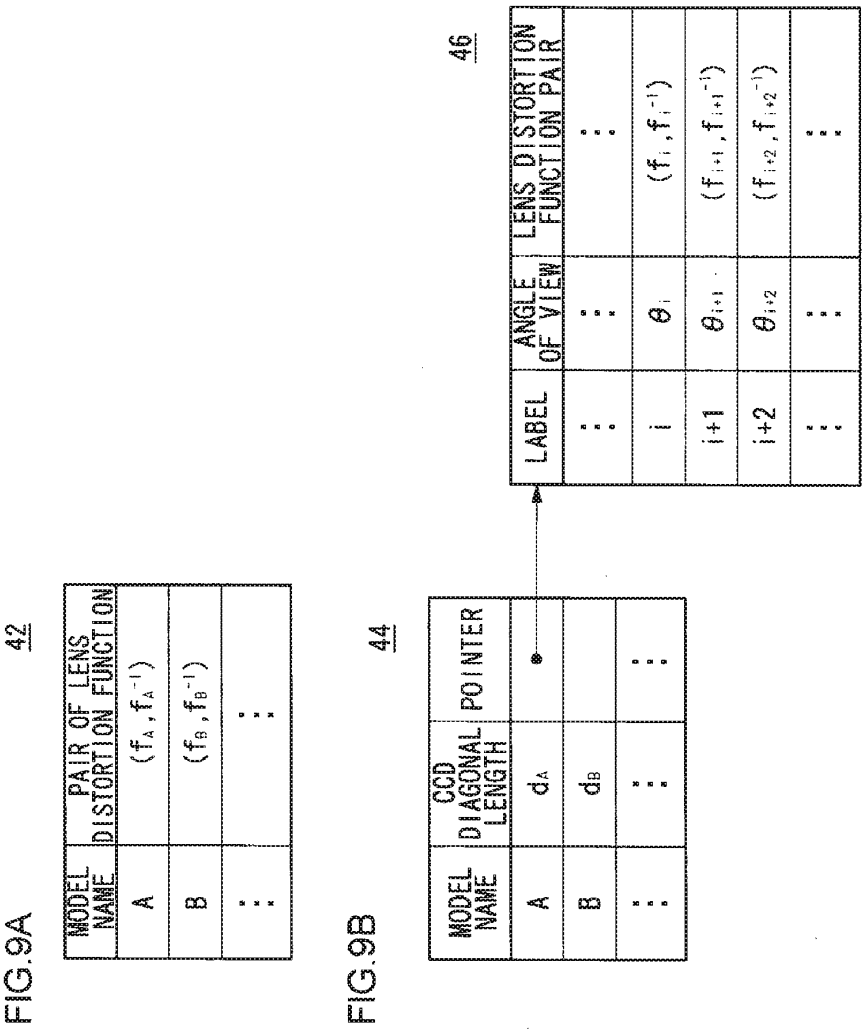

42
MODEL NAME
PAIR OF LENS DISTORTION FUNCTION
A
(f_A, f_A^{-1})
B
(f_B, f_B^{-1})
FIG.9A
44
MODEL NAME
CCD DIAGONAL LENGTH
POINTER
A
d_A
B
d_B
FIG.9B
46
LABEL
ANGLE OF VIEW
LENS DISTORTION FUNCTION PAIR
i
θ_i
(f_i, f_i^{-1})
i+1
θ_{i+1}
(f_{i+1}, f_{i+1}^{-1})
i+2
θ_{i+2}
(f_{i+2}, f_{i+2}^{-1})

FIG.10

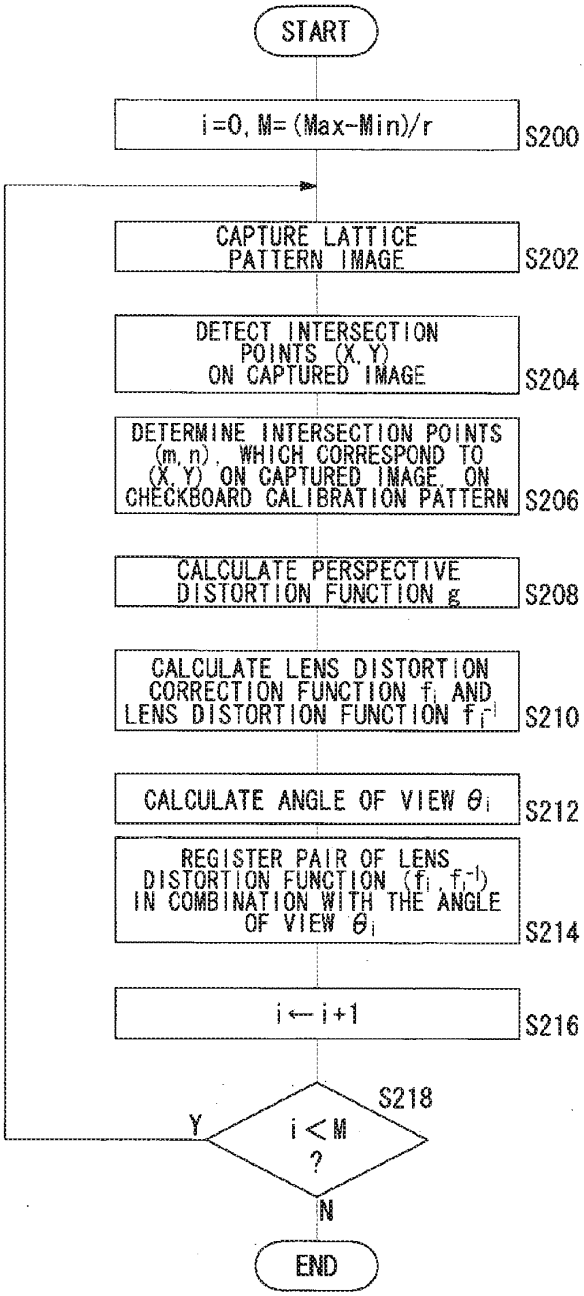

START
i=0, M=(Max-Min)/r
S200
CAPTURE LATTICE PATTERN IMAGE
S202
DETECT INTERSECTION POINTS (X, Y) ON CAPTURED IMAGE
S204
DETERMINE INTERSECTION POINTS (m, n), WHICH CORRESPOND TO (X, Y) ON CAPTURED IMAGE, ON CHECKBOARD CALIBRATION PATTERN
S206
CALCULATE PERSPECTIVE DISTORTION FUNCTION g
S208
CALCULATE LENS DISTORTION CORRECTION FUNCTION f_i AND LENS DISTORTION FUNCTION f_i^{-1}
S210
CALCULATE ANGLE OF VIEW θ_i
S212
REGISTER PAIR OF LENS DISTORTION FUNCTION (f_i, f_i^{-1}) IN COMBINATION WITH THE ANGLE OF VIEW θ_i
S214
i ← i+1
S216
S218
i < M ?
Y
N
END

FIG.11

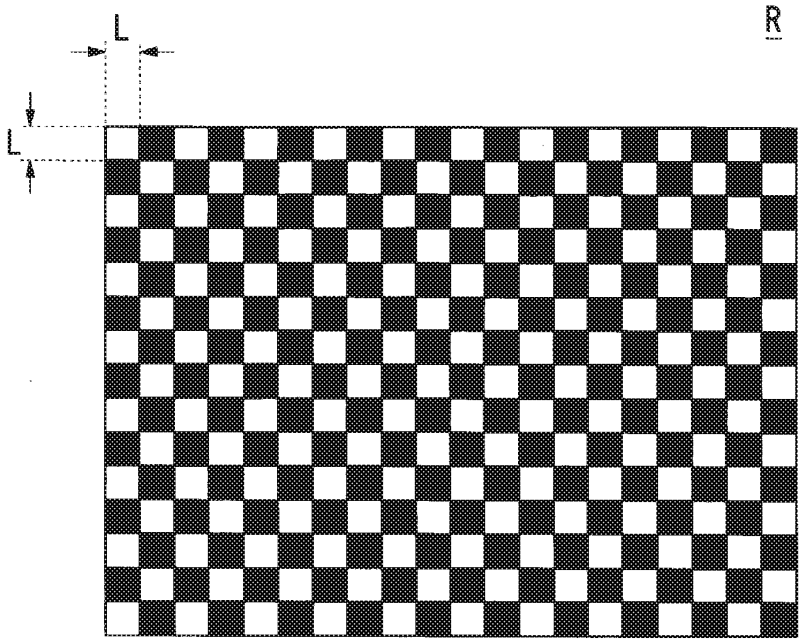


FIG.12

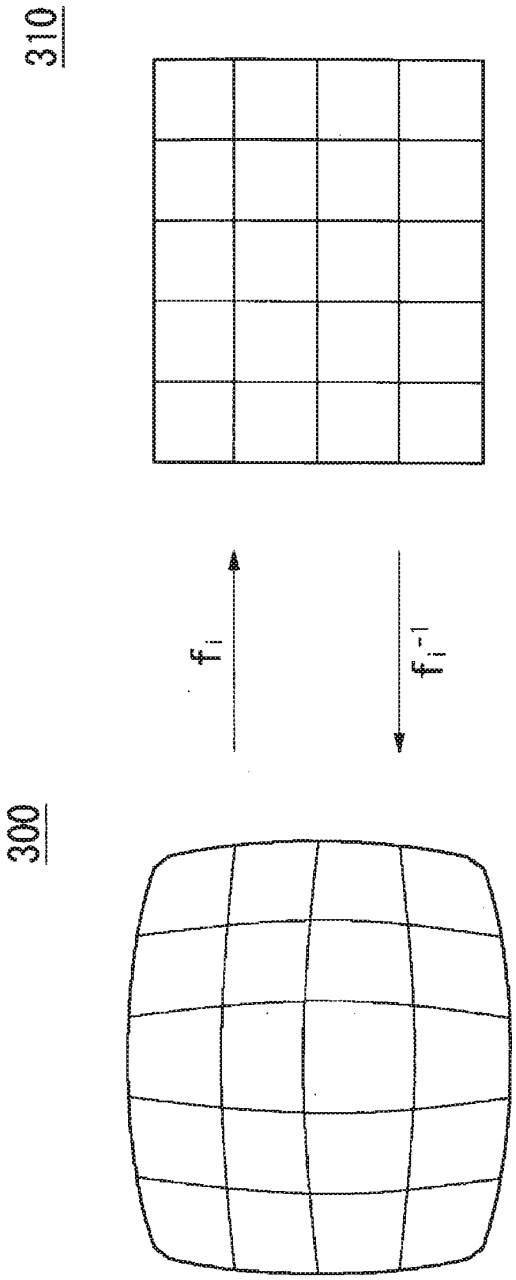


FIG.13

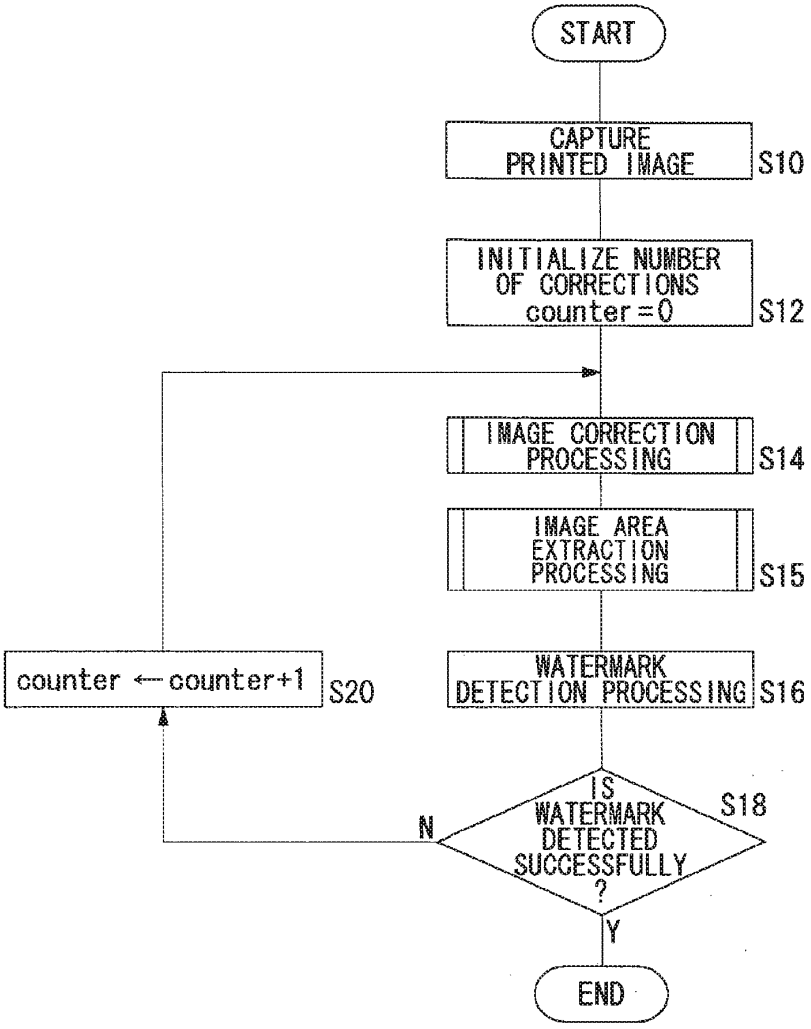

START
CAPTURE PRINTED IMAGE
S10
INITIALIZE NUMBER OF CORRECTIONS counter=0
S12
IMAGE CORRECTION PROCESSING
S14
IMAGE AREA EXTRACTION PROCESSING
S15
WATERMARK DETECTION PROCESSING
S16
IS WATERMARK DETECTED SUCCESSFULLY ?
S18
N
Y
counter ← counter+1
S20
END

FIG.14

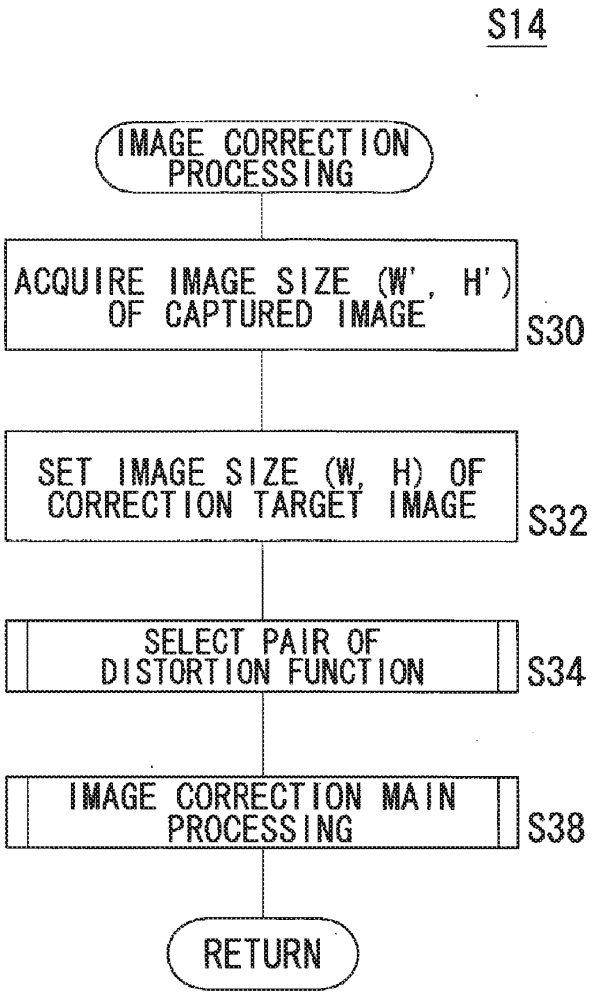

S14
IMAGE CORRECTION PROCESSING
ACQUIRE IMAGE SIZE (W', H') OF CAPTURED IMAGE
S30
SET IMAGE SIZE (W, H) OF CORRECTION TARGET IMAGE
S32
SELECT PAIR OF DISTORTION FUNCTION
S34
IMAGE CORRECTION MAIN PROCESSING
S38
RETURN

FIG.15

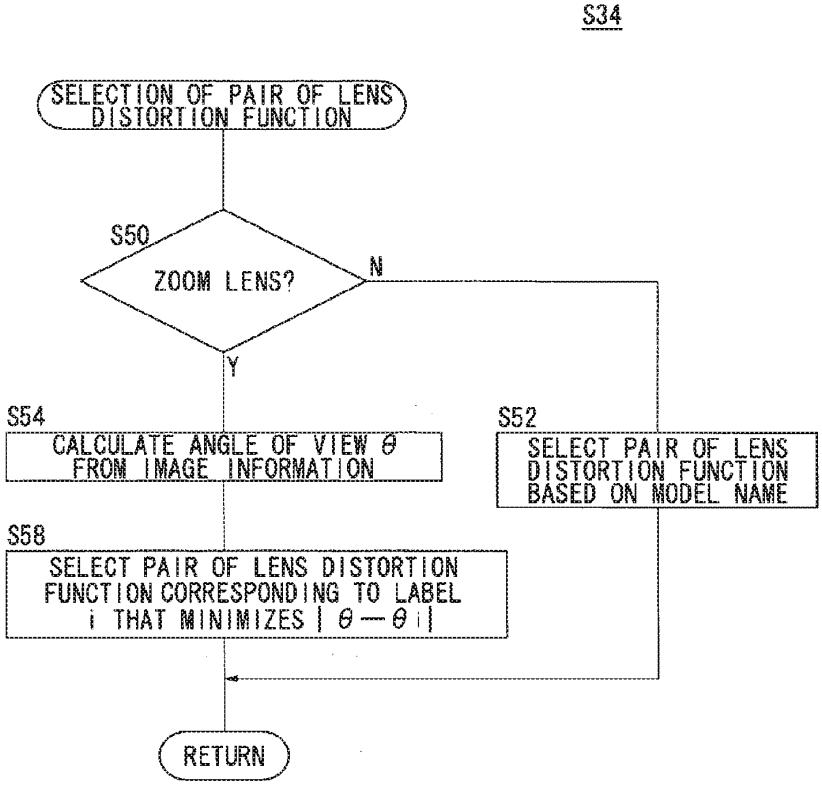

S34
SELECTION OF PAIR OF LENS DISTORTION FUNCTION
S50
ZOOM LENS?
N
Y
S54
CALCULATE ANGLE OF VIEW θ FROM IMAGE INFORMATION
S52
SELECT PAIR OF LENS DISTORTION FUNCTION BASED ON MODEL NAME
S58
SELECT PAIR OF LENS DISTORTION FUNCTION CORRESPONDING TO LABEL i THAT MINIMIZES | θ — θi |
RETURN

FIG.16

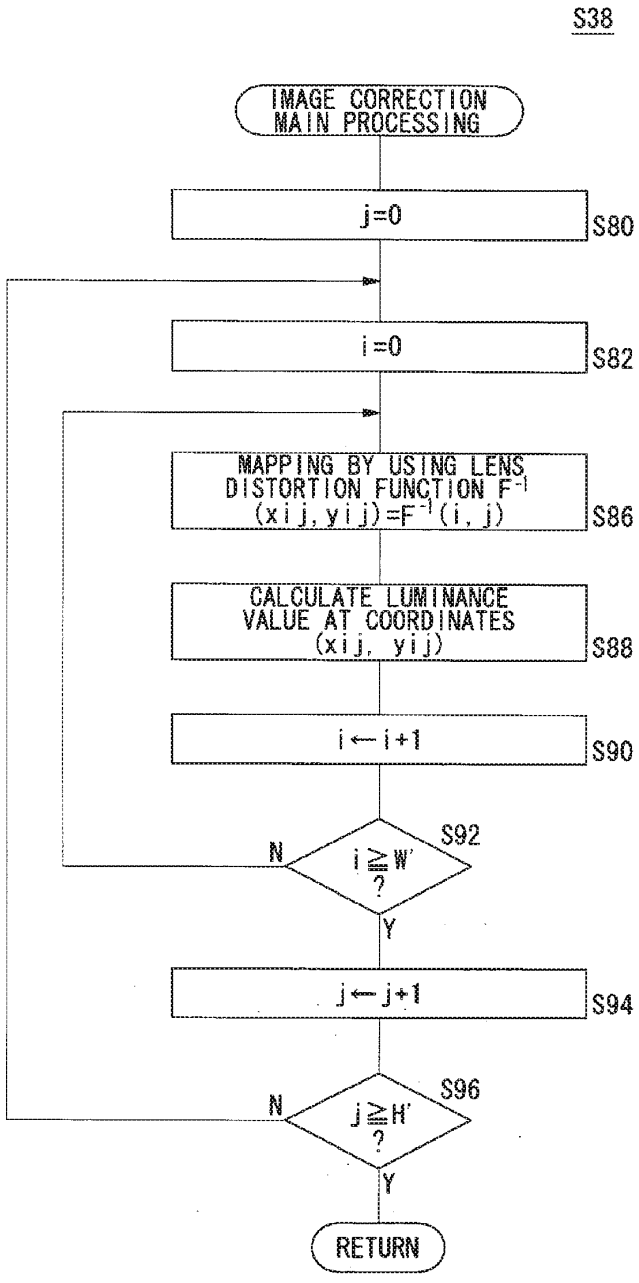

S38
IMAGE CORRECTION MAIN PROCESSING
j=0
S80
i=0
S82
MAPPING BY USING LENS DISTORTION FUNCTION F-1
(xij, yij)=F-1(i, j)
S86
CALCULATE LUMINANCE VALUE AT COORDINATES (xij, yij)
S88
i←i+1
S90
S92
i≧W'
?
N
Y
j←j+1
S94
S96
j≧H'
?
N
Y
RETURN

FIG.17

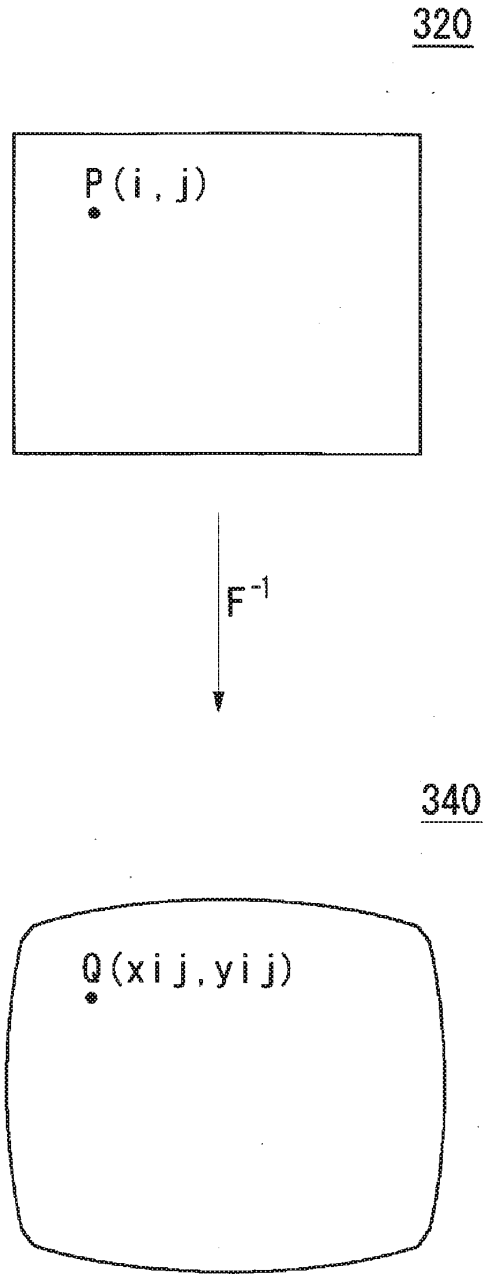


FIG.18

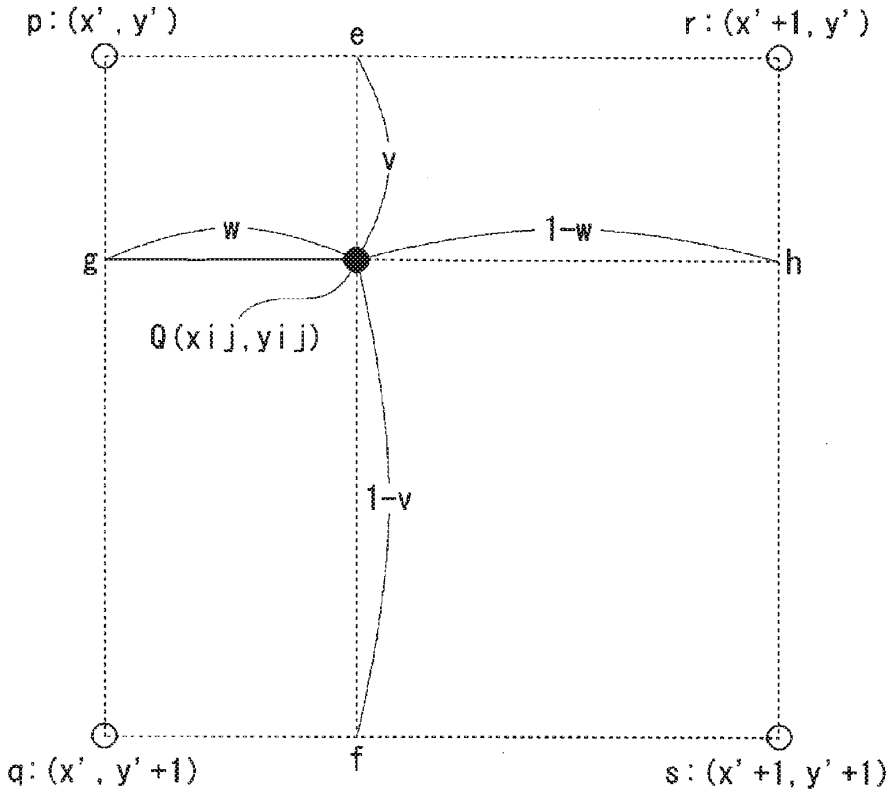


FIG.19

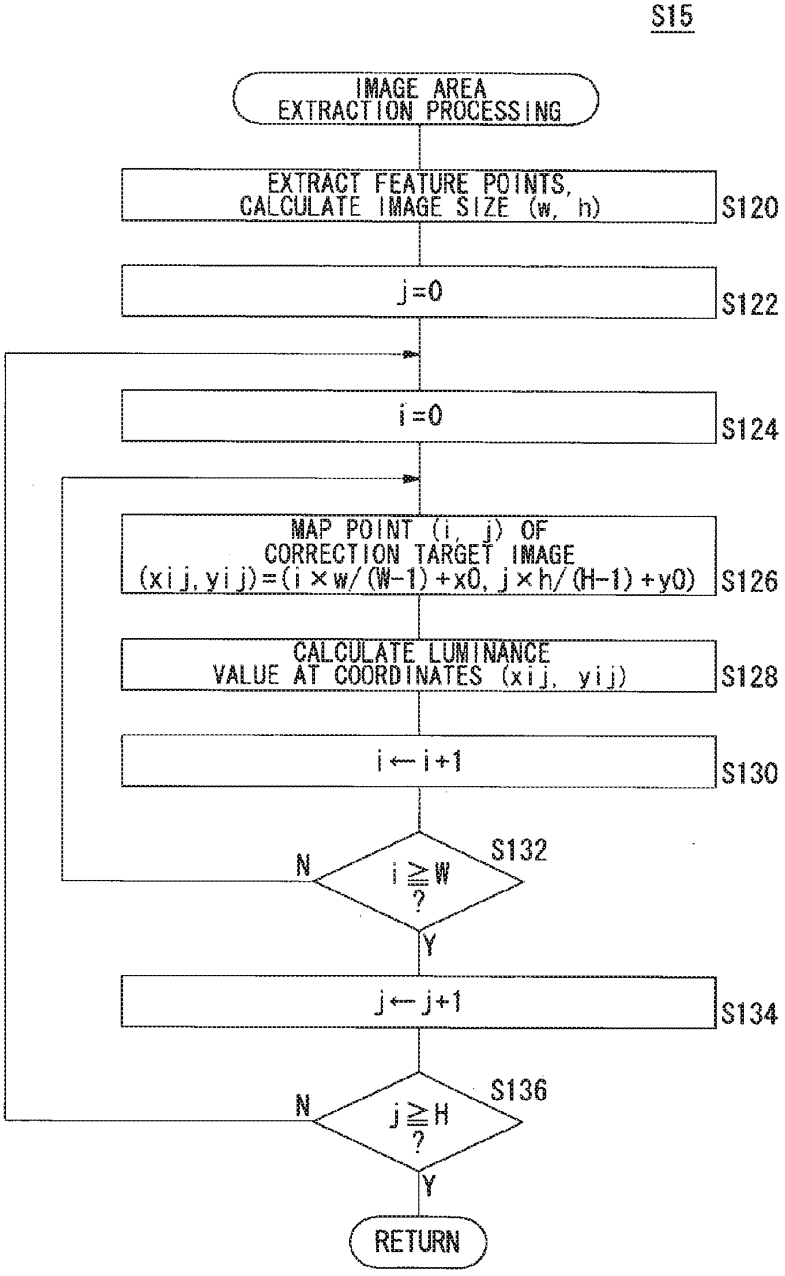

S15
IMAGE AREA EXTRACTION PROCESSING
EXTRACT FEATURE POINTS, CALCULATE IMAGE SIZE (w, h)
S120
j=0
S122
i=0
S124
MAP POINT (i, j) OF CORRECTION TARGET IMAGE (xij, yij)=(i×w/(W-1)+x0, j×h/(H-1)+y0)
S126
CALCULATE LUMINANCE VALUE AT COORDINATES (xij, yij)
S128
i←i+1
S130
i≧W ?
S132
N
Y
j←j+1
S134
j≧H ?
S136
N
Y
RETURN

FIG.20

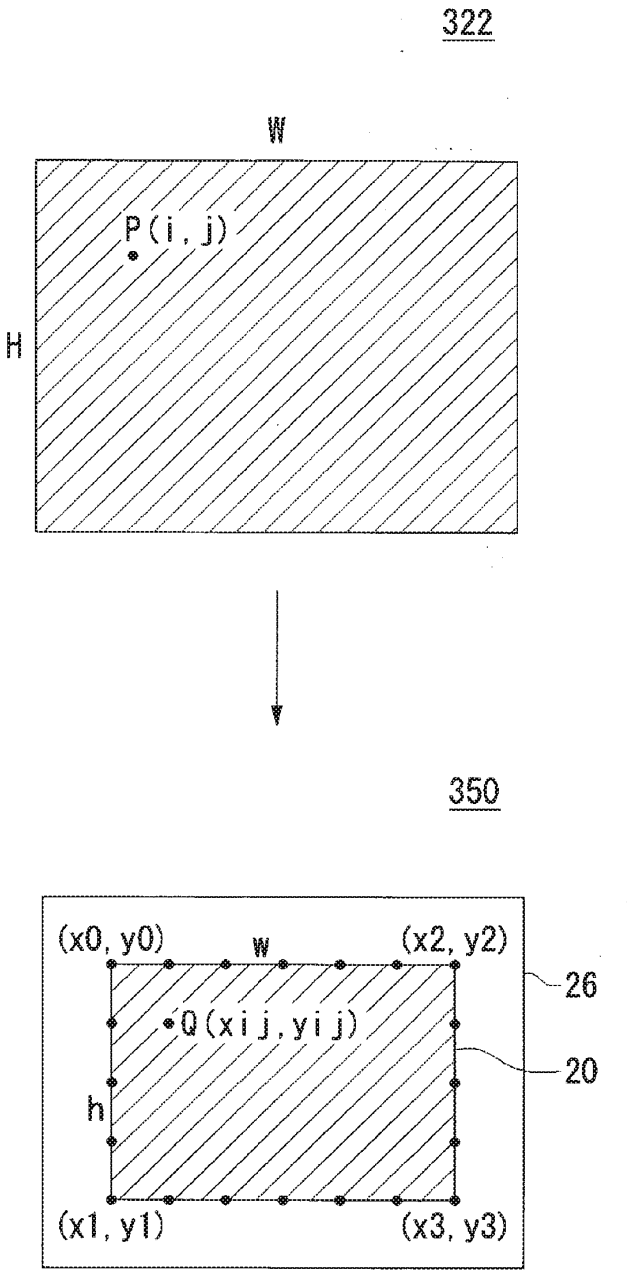


FIG.21

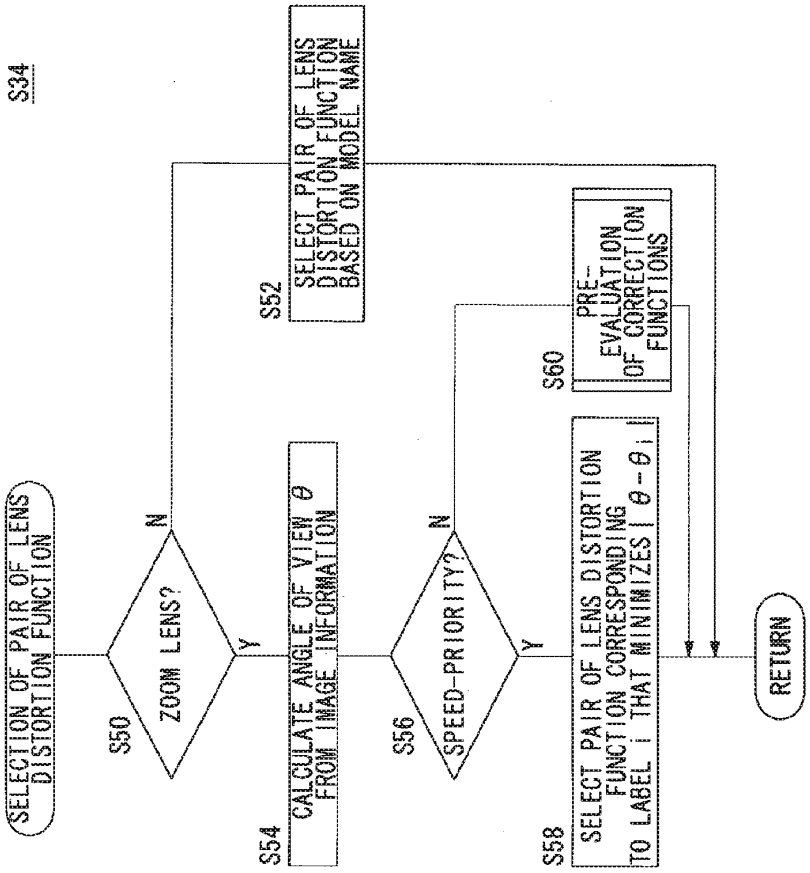

S34
SELECTION OF PAIR OF LENS DISTORTION FUNCTION
S50
ZOOM LENS?
N
Y
S52
SELECT PAIR OF LENS DISTORTION FUNCTION BASED ON MODEL NAME
S54
CALCULATE ANGLE OF VIEW θ FROM IMAGE INFORMATION
S56
SPEED-PRIORITY?
N
Y
S58
SELECT PAIR OF LENS DISTORTION FUNCTION CORRESPONDING TO LABEL i THAT MINIMIZES | θ - θi |
S60
PRE-EVALUATION OF CORRECTION FUNCTIONS
RETURN

FIG.22

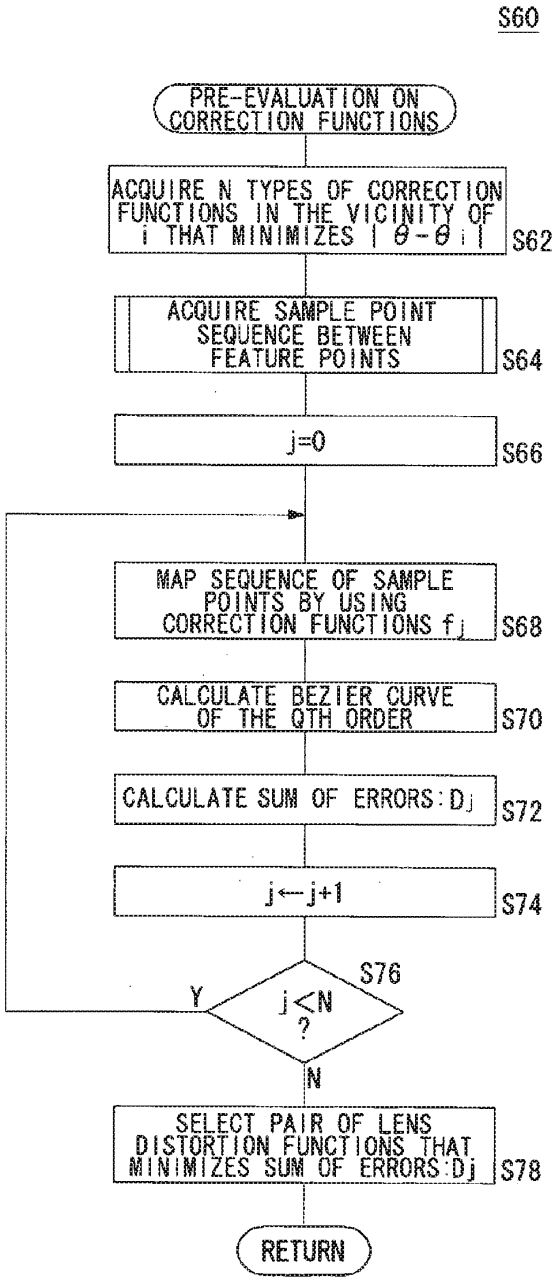

S60
PRE-EVALUATION ON CORRECTION FUNCTIONS
ACQUIRE N TYPES OF CORRECTION FUNCTIONS IN THE VICINITY OF i THAT MINIMIZES | θ-θi |
S62
ACQUIRE SAMPLE POINT SEQUENCE BETWEEN FEATURE POINTS
S64
j=0
S66
MAP SEQUENCE OF SAMPLE POINTS BY USING CORRECTION FUNCTIONS fj
S68
CALCULATE BEZIER CURVE OF THE QTH ORDER
S70
CALCULATE SUM OF ERRORS: Dj
S72
j←j+1
S74
S76
j<N ?
Y
N
SELECT PAIR OF LENS DISTORTION FUNCTIONS THAT MINIMIZES SUM OF ERRORS: Dj
S78
RETURN

FIG.23A

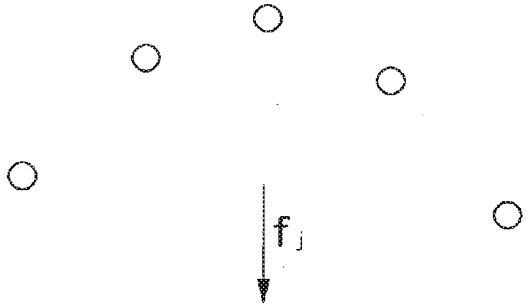


FIG.23B

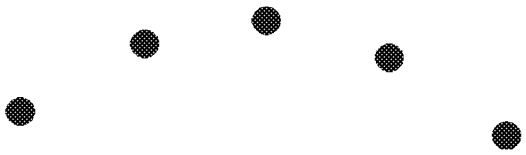


FIG.23C

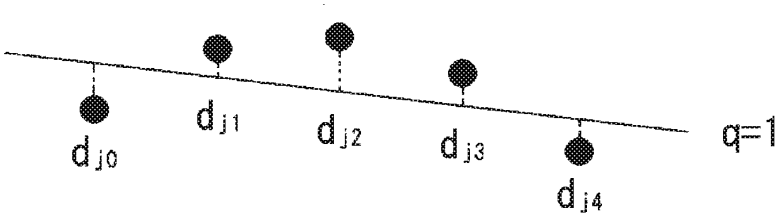


FIG.24

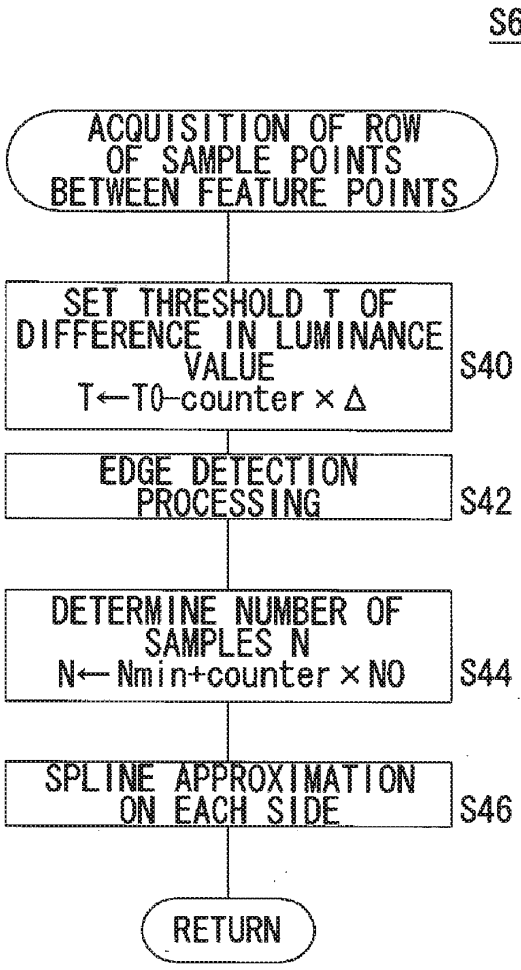

S64
ACQUISITION OF ROW OF SAMPLE POINTS BETWEEN FEATURE POINTS
SET THRESHOLD T OF DIFFERENCE IN LUMINANCE VALUE
T←T0-counter×Δ
S40
EDGE DETECTION PROCESSING
S42
DETERMINE NUMBER OF SAMPLES N
N←Nmin+counter×N0
S44
SPLINE APPROXIMATION ON EACH SIDE
S46
RETURN

FIG.25A

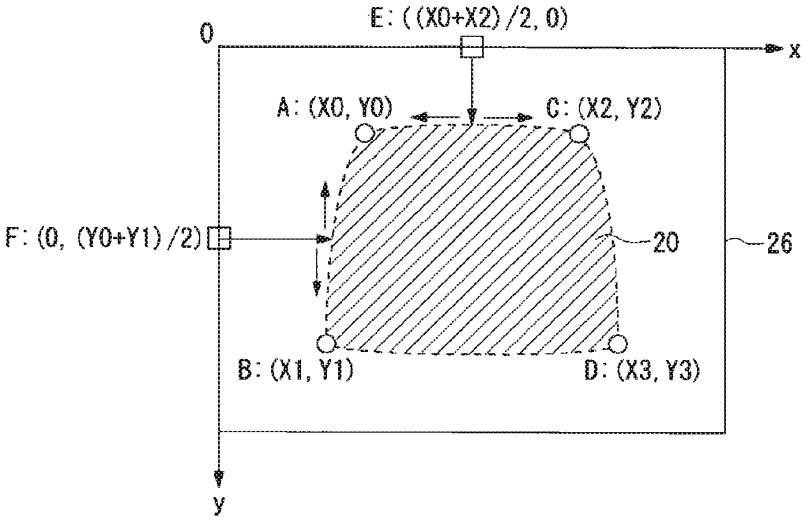


FIG.25B

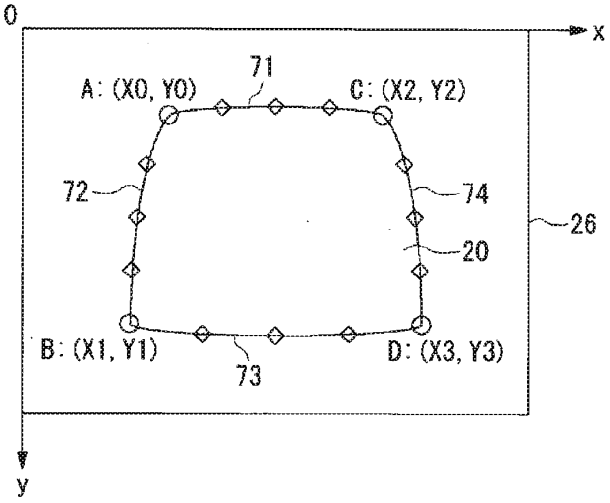


FIG.26

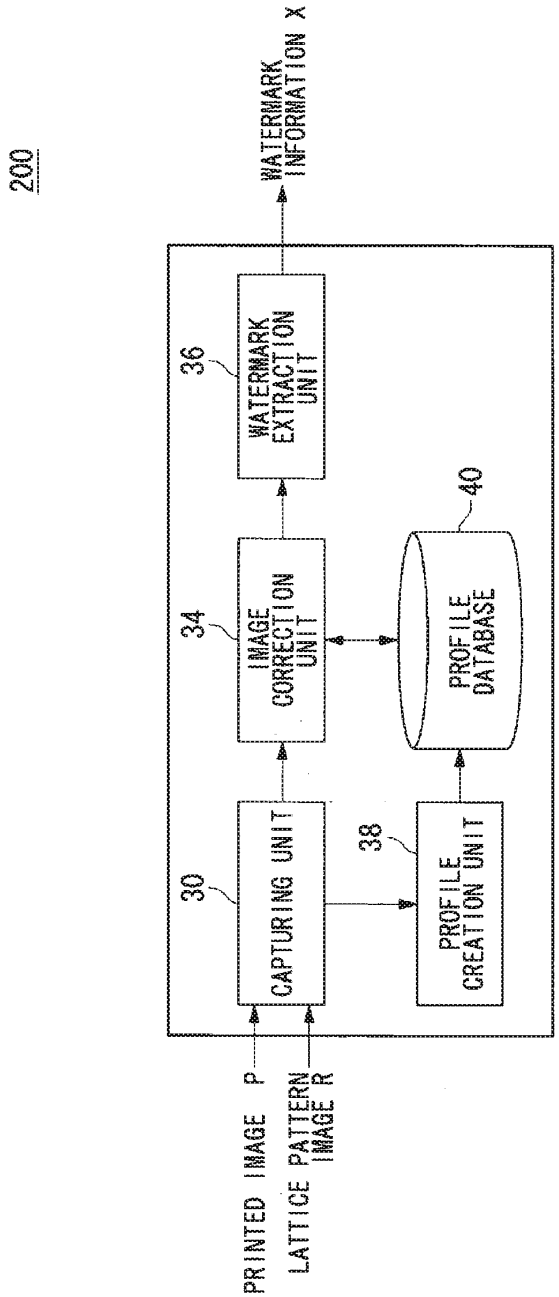

200
WATERMARK INFORMATION X
36
WATERMARK EXTRACTION UNIT
34
IMAGE CORRECTION UNIT
40
PROFILE DATABASE
30
CAPTURING UNIT
38
PROFILE CREATION UNIT
PRINTED IMAGE P
LATTICE PATTERN IMAGE R

FIG.27

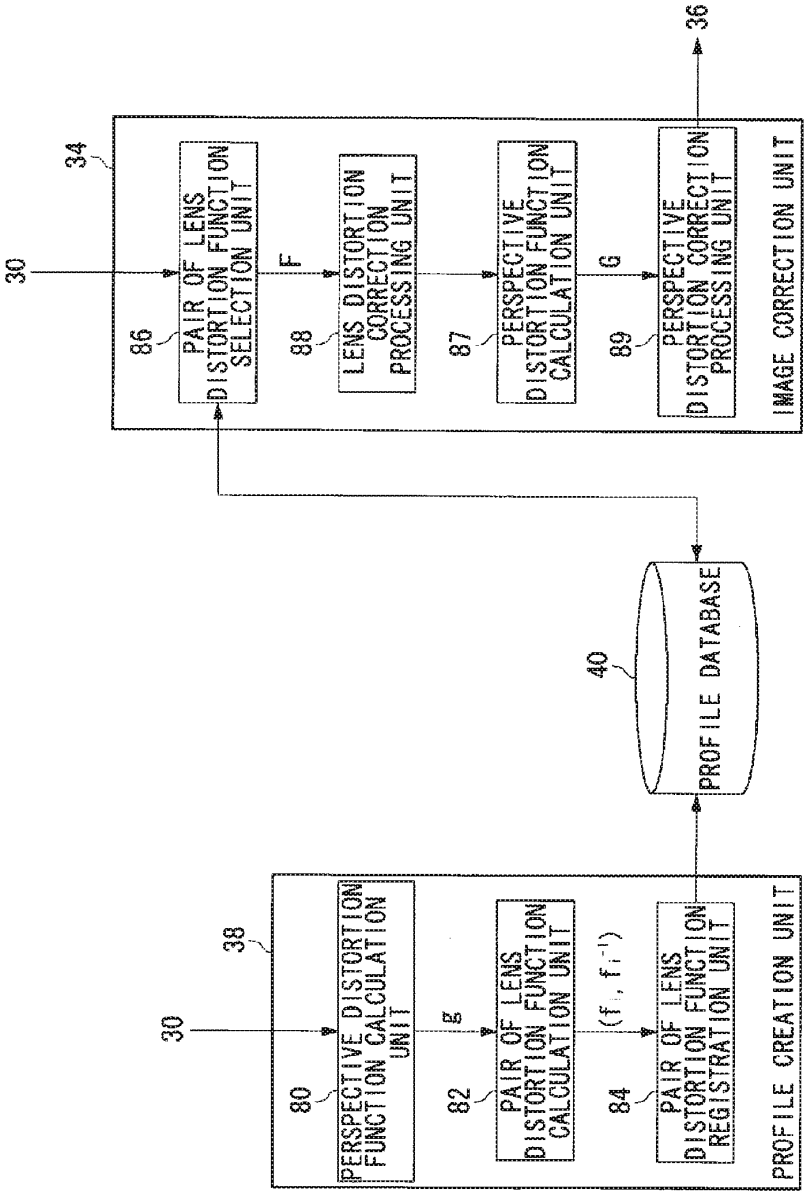

30
34
PAIR OF LENS DISTORTION FUNCTION SELECTION UNIT
86
F
LENS DISTORTION CORRECTION PROCESSING UNIT
88
PERSPECTIVE DISTORTION FUNCTION CALCULATION UNIT
87
G
PERSPECTIVE DISTORTION CORRECTION PROCESSING UNIT
89
36
IMAGE CORRECTION UNIT
40
PROFILE DATABASE
30
38
PERSPECTIVE DISTORTION FUNCTION CALCULATION UNIT
80
g
PAIR OF LENS DISTORTION FUNCTION CALCULATION UNIT
82
PAIR OF LENS DISTORTION FUNCTION REGISTRATION UNIT
84
PROFILE CREATION UNIT

FIG.28

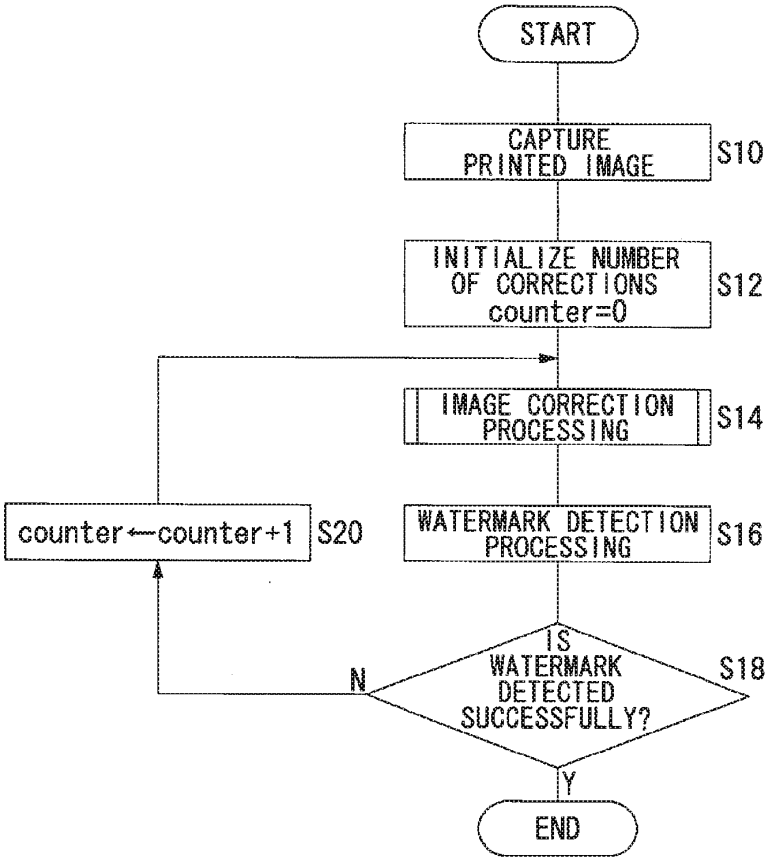

START
CAPTURE PRINTED IMAGE
S10
INITIALIZE NUMBER OF CORRECTIONS counter=0
S12
IMAGE CORRECTION PROCESSING
S14
WATERMARK DETECTION PROCESSING
S16
IS WATERMARK DETECTED SUCCESSFULLY?
S18
N
counter←counter+1
S20
Y
END

FIG.29

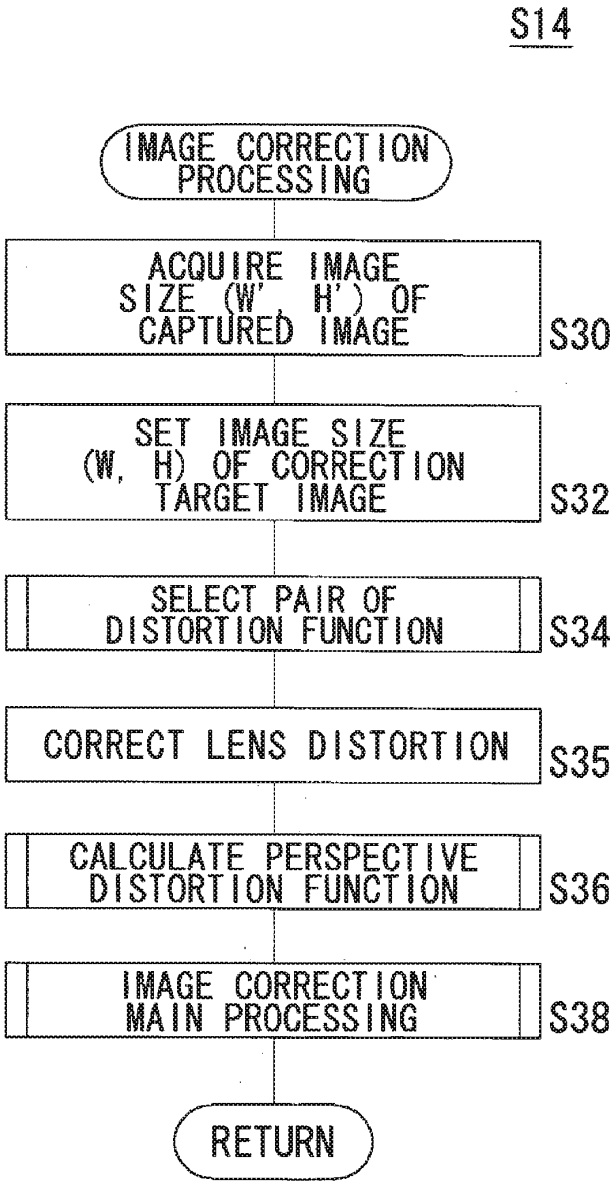

S14
IMAGE CORRECTION PROCESSING
ACQUIRE IMAGE SIZE (W', H') OF CAPTURED IMAGE
S30
SET IMAGE SIZE (W, H) OF CORRECTION TARGET IMAGE
S32
SELECT PAIR OF DISTORTION FUNCTION
S34
CORRECT LENS DISTORTION
S35
CALCULATE PERSPECTIVE DISTORTION FUNCTION
S36
IMAGE CORRECTION MAIN PROCESSING
S38
RETURN

FIG.30

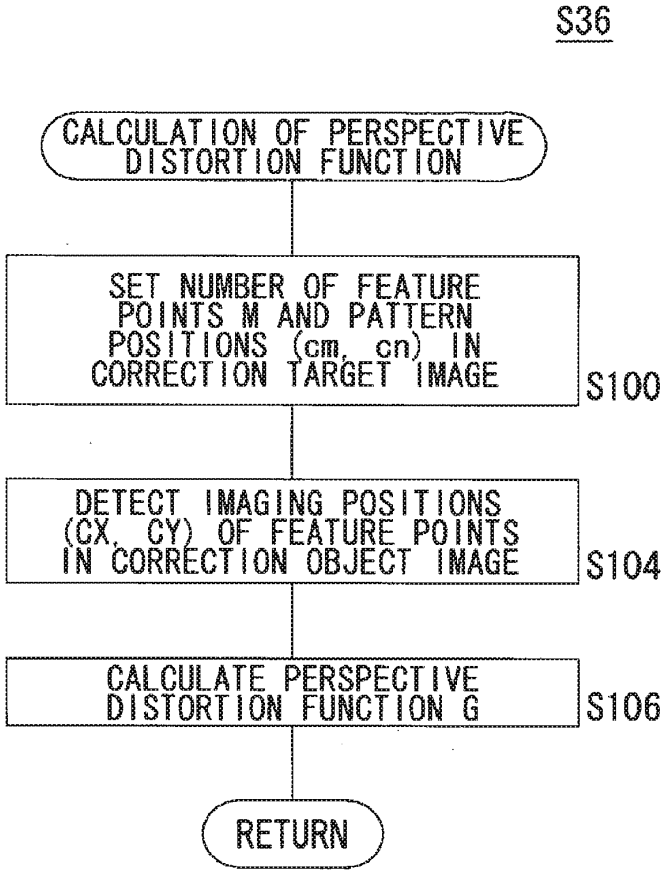

S36
CALCULATION OF PERSPECTIVE DISTORTION FUNCTION
SET NUMBER OF FEATURE POINTS M AND PATTERN POSITIONS (cm, cn) IN CORRECTION TARGET IMAGE
S100
DETECT IMAGING POSITIONS (CX, CY) OF FEATURE POINTS IN CORRECTION OBJECT IMAGE
S104
CALCULATE PERSPECTIVE DISTORTION FUNCTION G
S106
RETURN

FIG.31

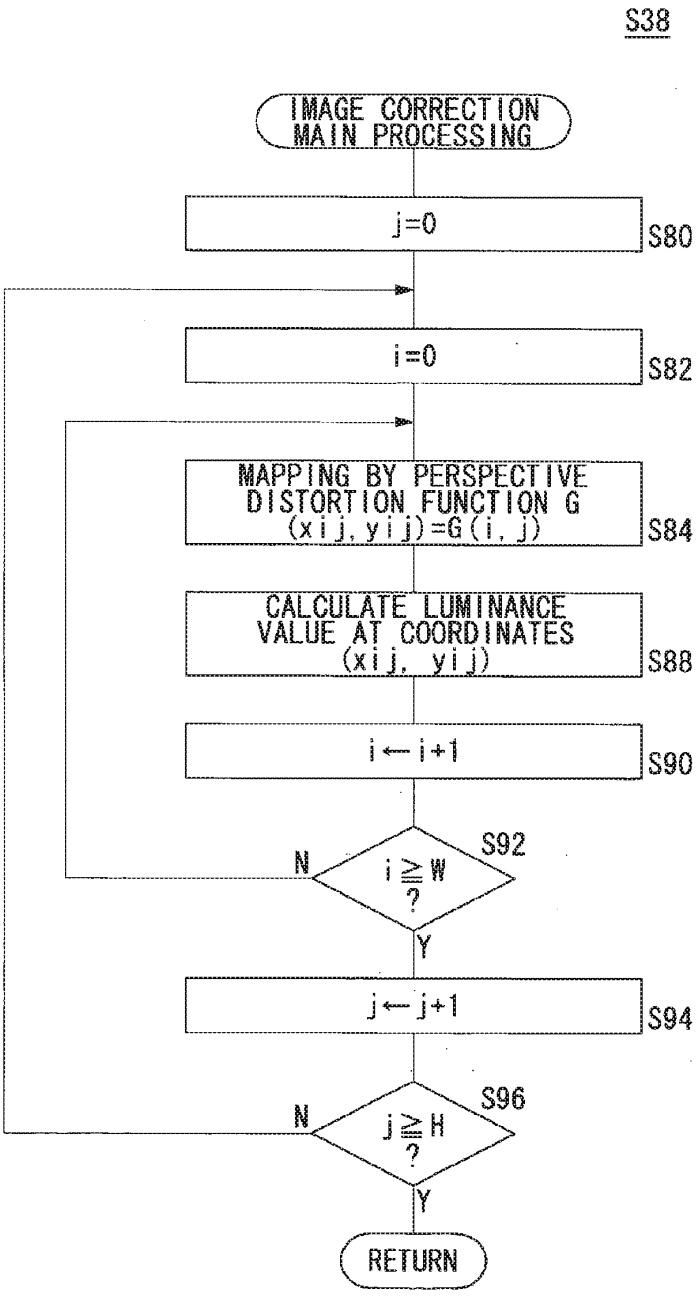

S38
IMAGE CORRECTION MAIN PROCESSING
j=0
S80
i=0
S82
MAPPING BY PERSPECTIVE DISTORTION FUNCTION G
(xij, yij)=G(i, j)
S84
CALCULATE LUMINANCE VALUE AT COORDINATES
(xij, yij)
S88
i←i+1
S90
i≧W ?
S92
N
Y
j←j+1
S94
j≧H ?
S96
N
Y
RETURN

FIG.32A

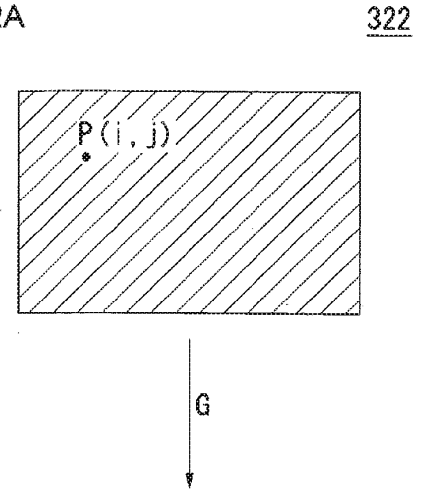


FIG.32B

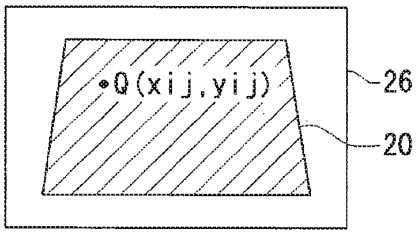


FIG.32C

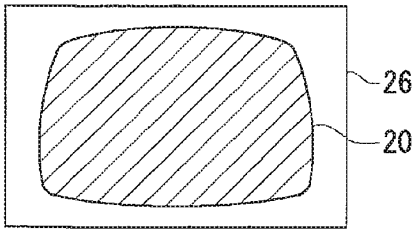


FIG.33

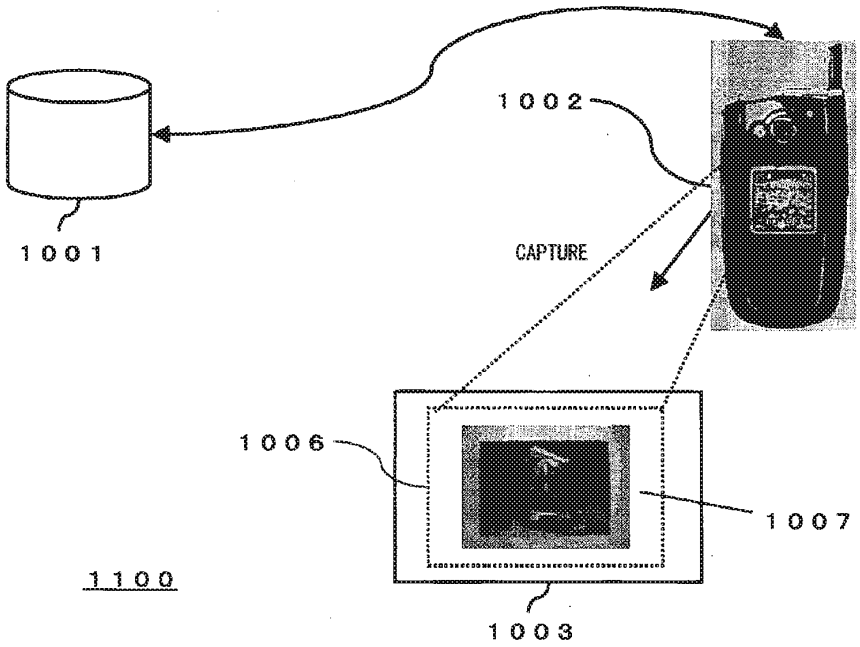


FIG.34

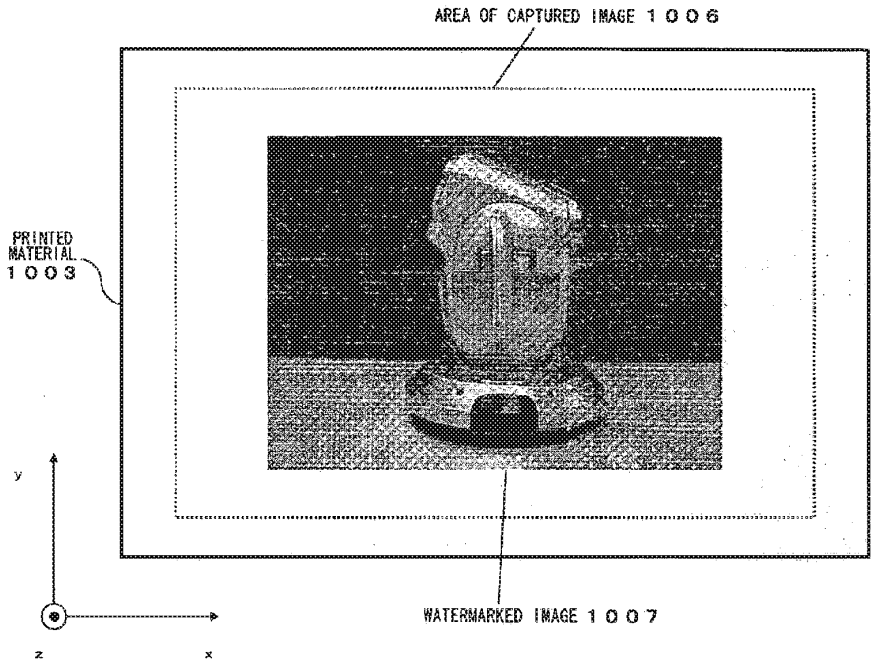

AREA OF CAPTURED IMAGE 1006
PRINTED MATERIAL 1003
WATERMARKED IMAGE 1007
y
z
x

FIG.35A

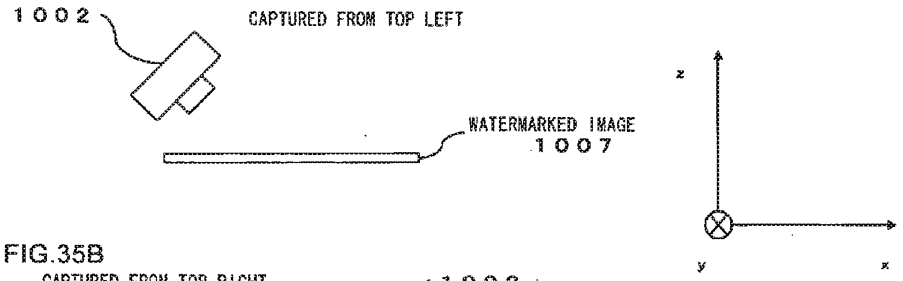


FIG.35B

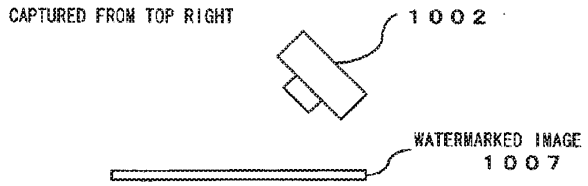


FIG.35C

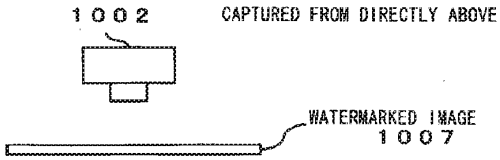


FIG.36

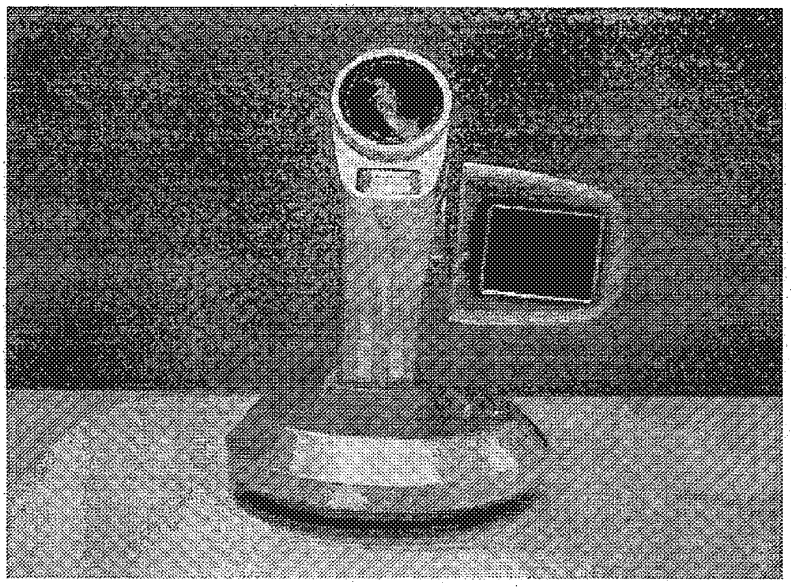


FIG.37

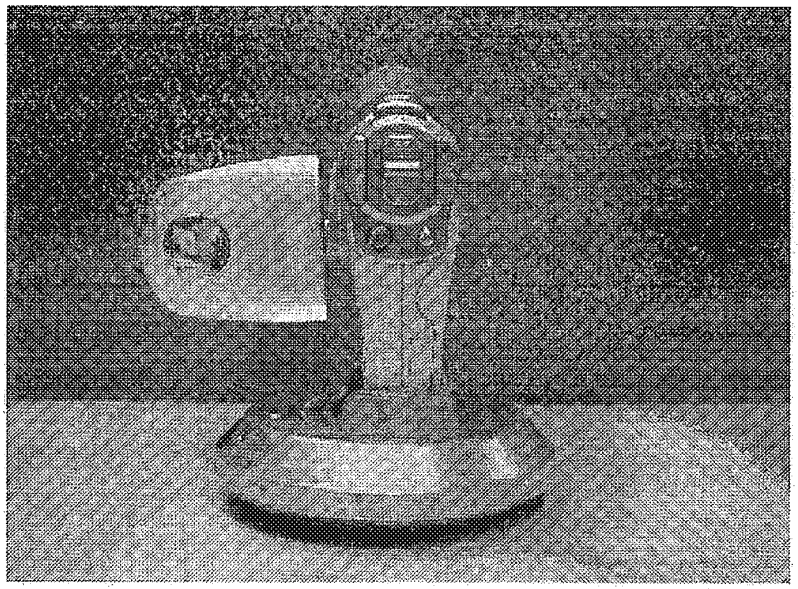


FIG.38

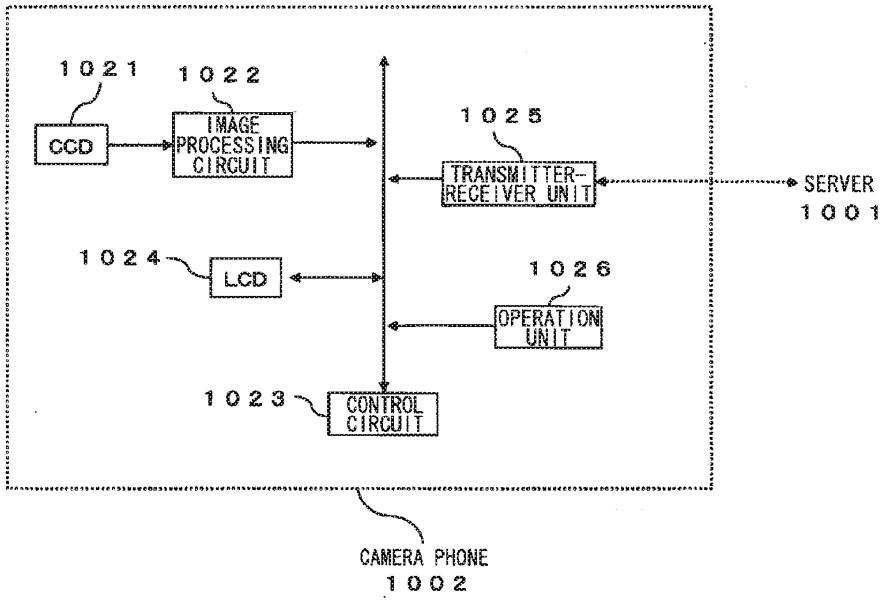

1021
1022
CCD
IMAGE PROCESSING CIRCUIT
1025
TRANSMITTER-RECEIVER UNIT
SERVER
1001
1024
LCD
1026
OPERATION UNIT
1023
CONTROL CIRCUIT
CAMERA PHONE
1002

FIG.39

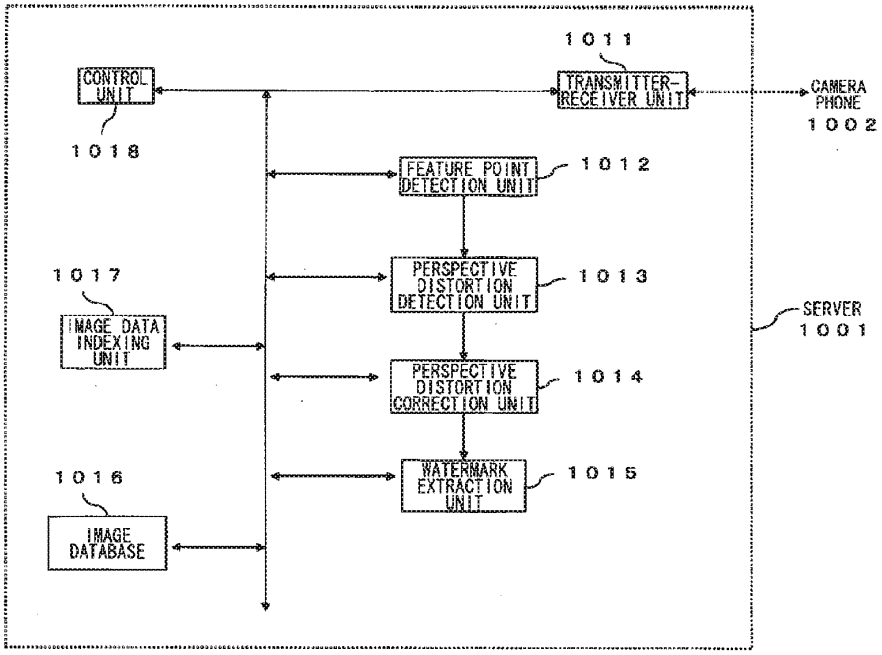

1011
CONTROL UNIT
TRANSMITTER-RECEIVER UNIT
CAMERA PHONE
1002
1018
FEATURE POINT DETECTION UNIT
1012
1017
PERSPECTIVE DISTORTION DETECTION UNIT
1013
IMAGE DATA INDEXING UNIT
SERVER
1001
PERSPECTIVE DISTORTION CORRECTION UNIT
1014
1016
WATERMARK EXTRACTION UNIT
1015
IMAGE DATABASE

FIG.40

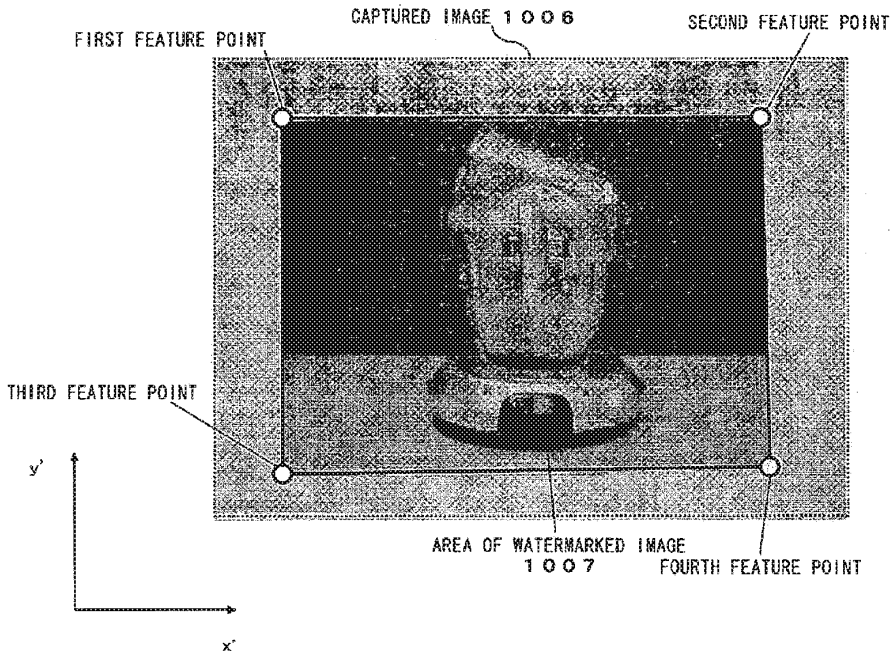

CAPTURED IMAGE 1006
FIRST FEATURE POINT
SECOND FEATURE POINT
THIRD FEATURE POINT
y'
x'
AREA OF WATERMARKED IMAGE 1007
FOURTH FEATURE POINT

FIG.41

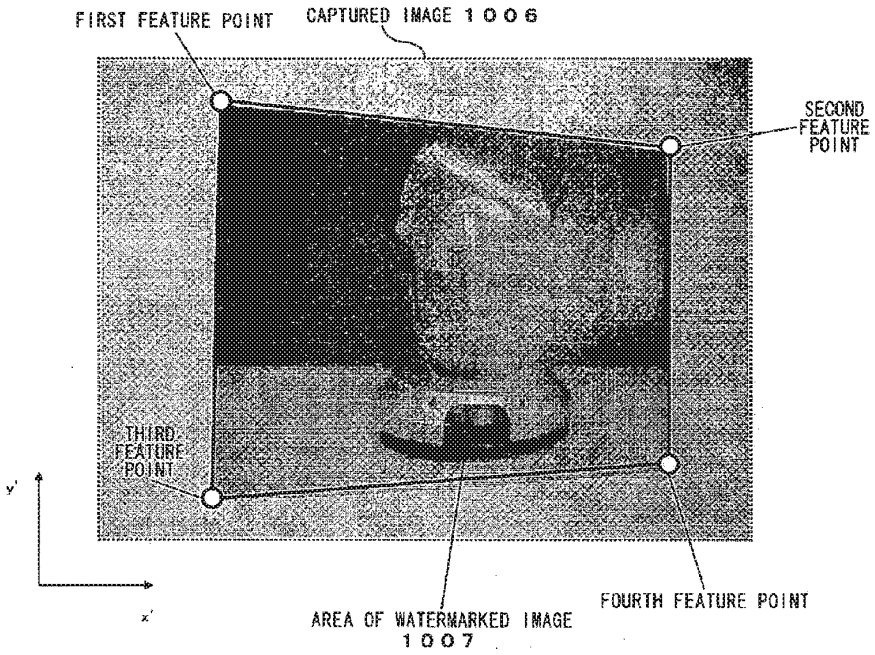

FIRST FEATURE POINT
CAPTURED IMAGE 1006
SECOND FEATURE POINT
THIRD FEATURE POINT
y'
x'
AREA OF WATERMARKED IMAGE 1007
FOURTH FEATURE POINT

FIG.42

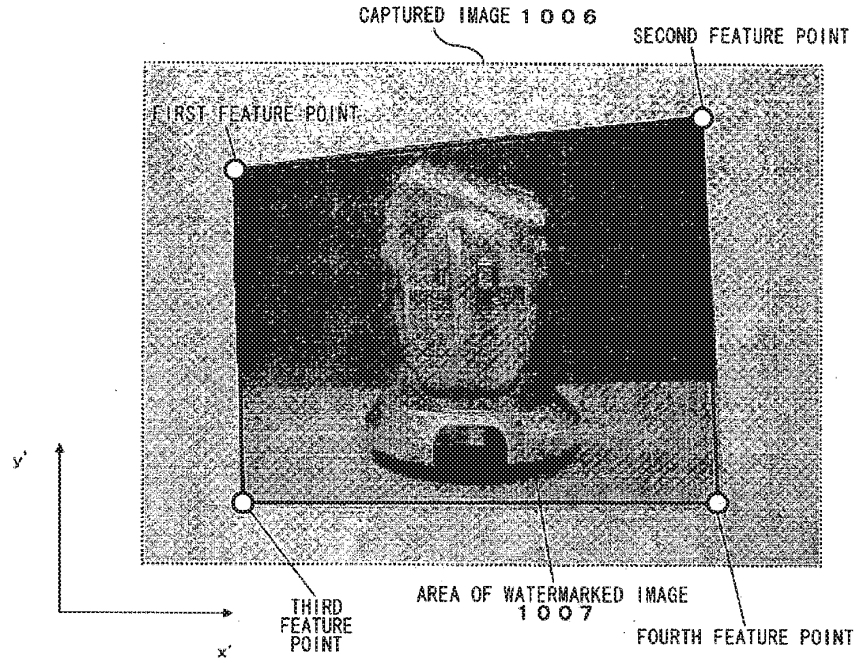

CAPTURED IMAGE 1006
SECOND FEATURE POINT
FIRST FEATURE POINT
y'
x'
THIRD FEATURE POINT
AREA OF WATERMARKED IMAGE 1007
FOURTH FEATURE POINT

FIG.43

IMAGE DATA INDEXING UNIT 1017

PRODUCT ID	PERSPECTIVE DISTORTION INFORMATION	CONTENTS OF IMAGE DATA	TOP ADDRESS OF IMAGE DATA
0001	1	DETAILED FRONT VIEW OF PRODUCT A	100
0001	2	DETAILED BACK VIEW OF PRODUCT A	200
0001	0	DETAILED SIDE VIEW OF PRODUCT A	300
0002	1	DETAILED FRONT VIEW OF PRODUCT B	700
.....	.....	.....	
0026	2	DETAILED BACK VIEW OF PRODUCT Z	1400

FIG.44

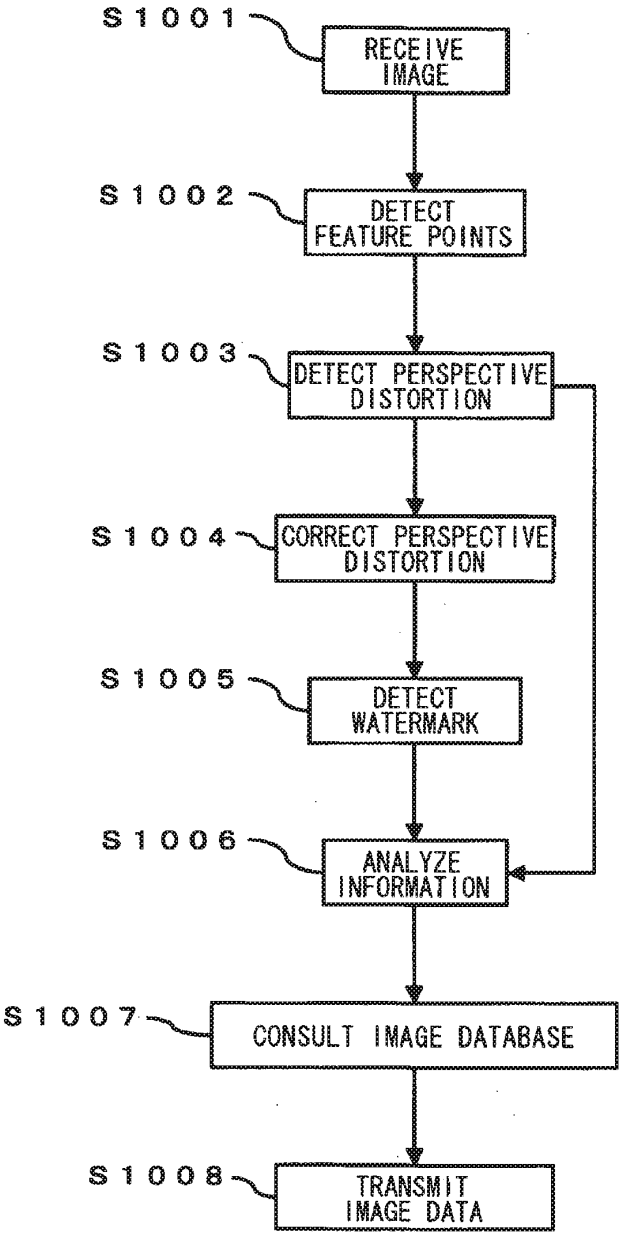

S1001
RECEIVE IMAGE
S1002
DETECT FEATURE POINTS
S1003
DETECT PERSPECTIVE DISTORTION
S1004
CORRECT PERSPECTIVE DISTORTION
S1005
DETECT WATERMARK
S1006
ANALYZE INFORMATION
S1007
CONSULT IMAGE DATABASE
S1008
TRANSMIT IMAGE DATA

FIG.45A

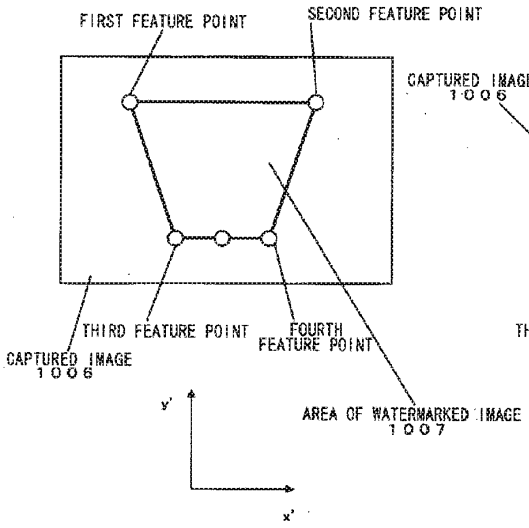


FIG.45B

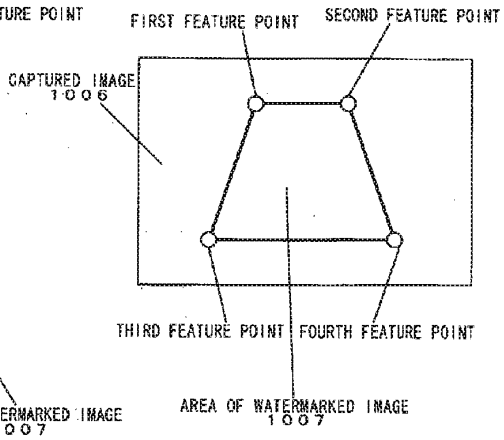


FIG.46

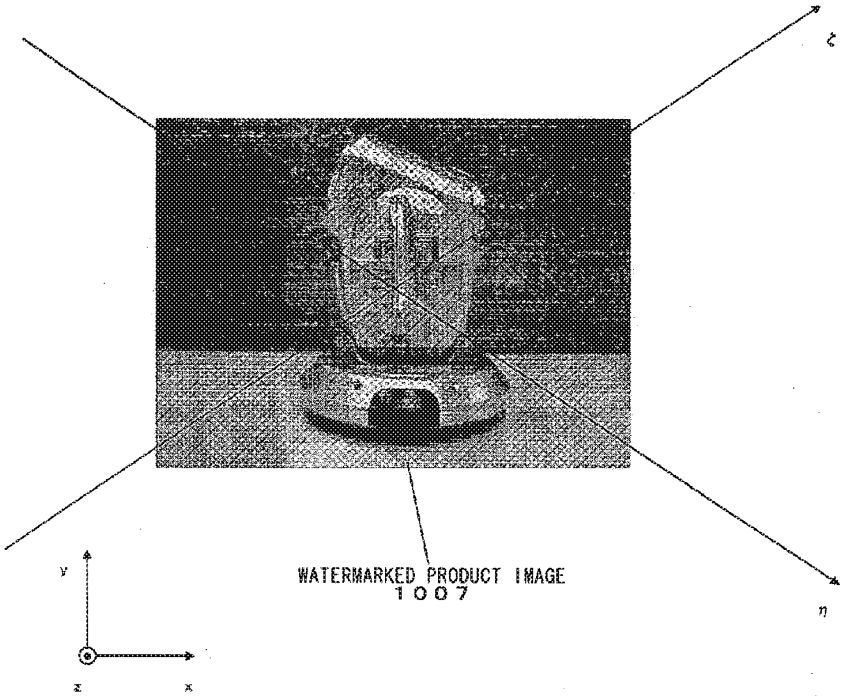


FIG.47

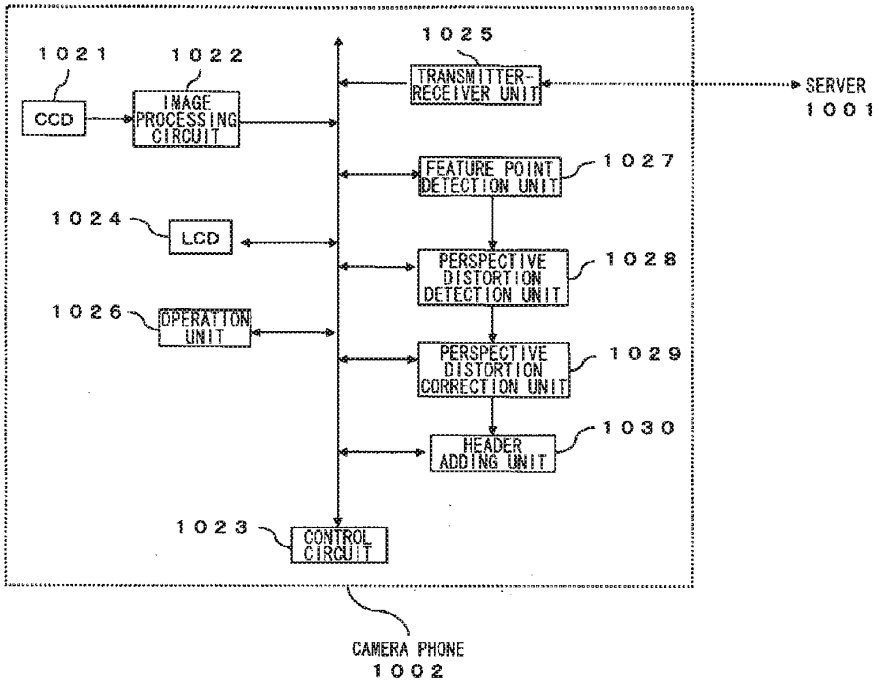

1021
1022
1025
CCD
IMAGE PROCESSING CIRCUIT
TRANSMITTER-RECEIVER UNIT
SERVER
1001
FEATURE POINT DETECTION UNIT
1027
1024
LCD
PERSPECTIVE DISTORTION DETECTION UNIT
1028
1026
OPERATION UNIT
PERSPECTIVE DISTORTION CORRECTION UNIT
1029
HEADER ADDING UNIT
1030
1023
CONTROL CIRCUIT
CAMERA PHONE
1002

FIG.48

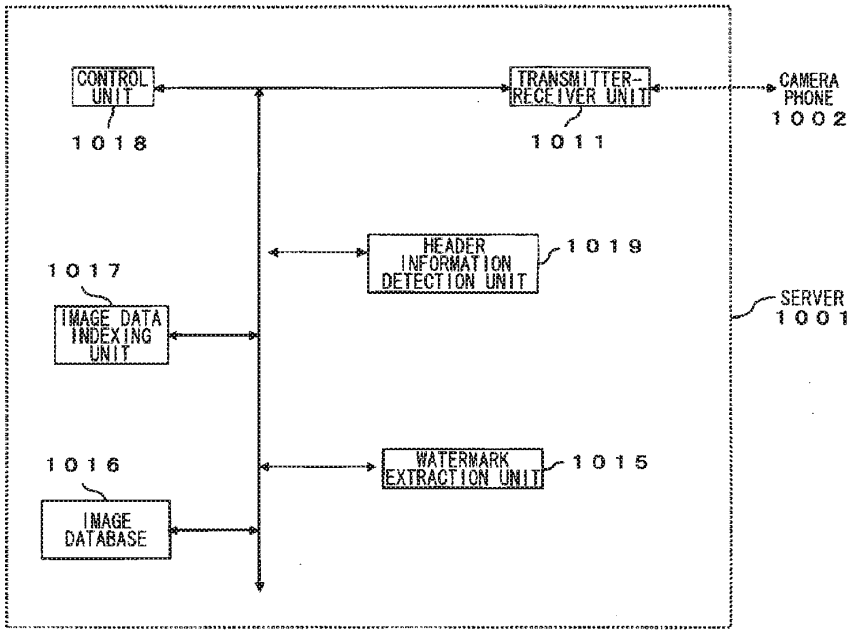

CONTROL UNIT
1018
TRANSMITTER-RECEIVER UNIT
1011
CAMERA PHONE
1002
HEADER INFORMATION DETECTION UNIT
1019
1017
IMAGE DATA INDEXING UNIT
SERVER
1001
1016
IMAGE DATABASE
WATERMARK EXTRACTION UNIT
1015

FIG.49

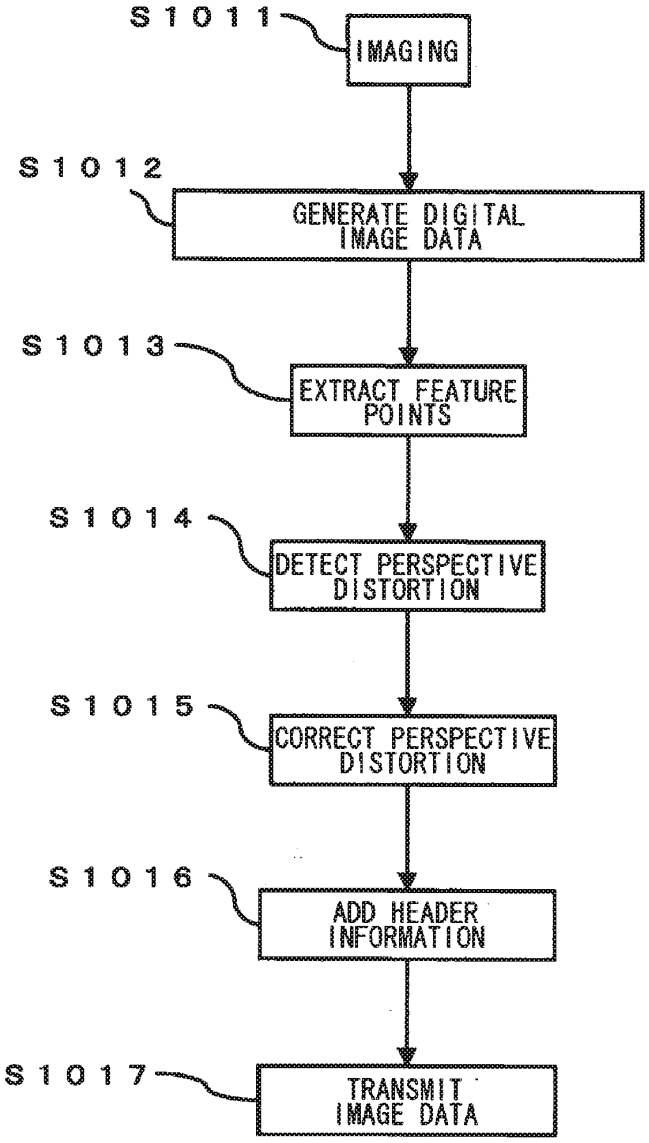

S1011
IMAGING
S1012
GENERATE DIGITAL IMAGE DATA
S1013
EXTRACT FEATURE POINTS
S1014
DETECT PERSPECTIVE DISTORTION
S1015
CORRECT PERSPECTIVE DISTORTION
S1016
ADD HEADER INFORMATION
S1017
TRANSMIT IMAGE DATA

FIG.50

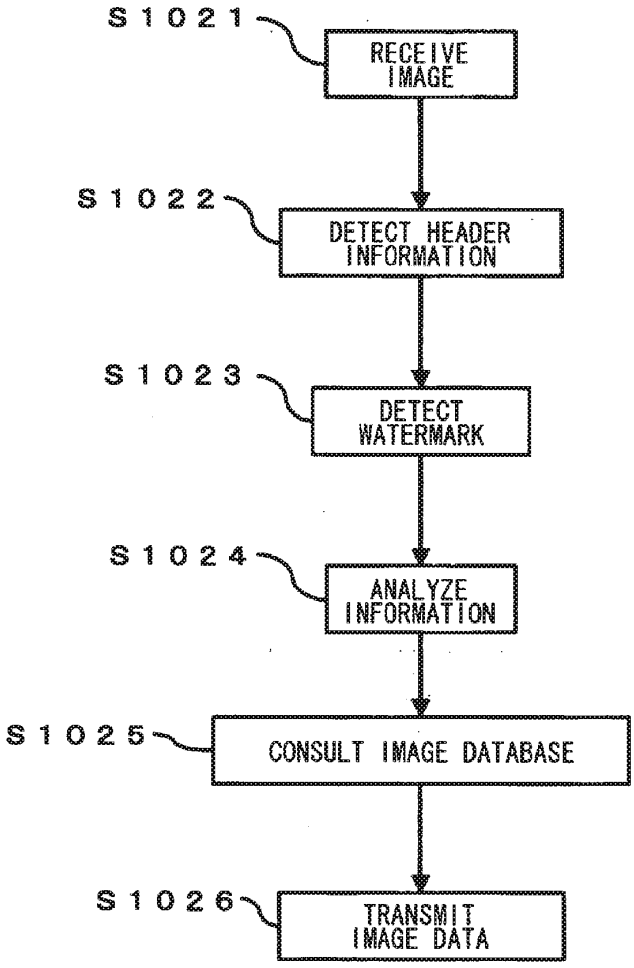

S1021
RECEIVE IMAGE
S1022
DETECT HEADER INFORMATION
S1023
DETECT WATERMARK
S1024
ANALYZE INFORMATION
S1025
CONSULT IMAGE DATABASE
S1026
TRANSMIT IMAGE DATA

FIG.51

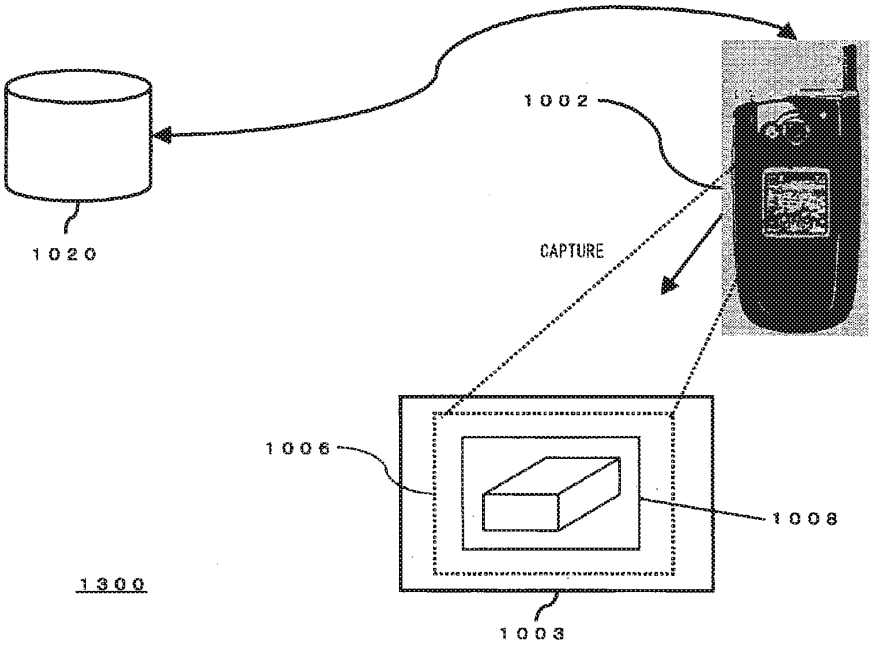


FIG.52

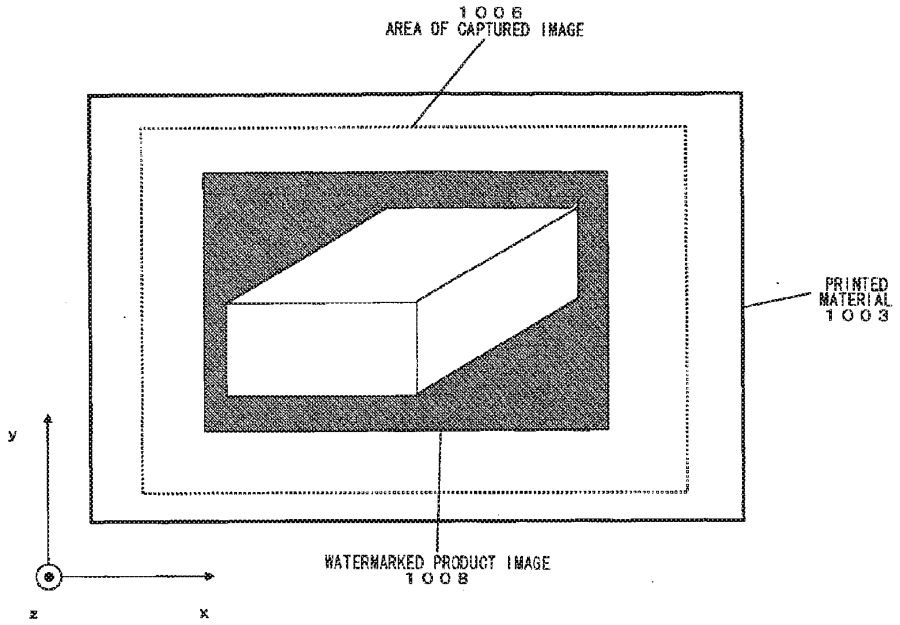

1006
AREA OF CAPTURED IMAGE
PRINTED MATERIAL
1003
WATERMARKED PRODUCT IMAGE
1008
y
z
x

FIG.53

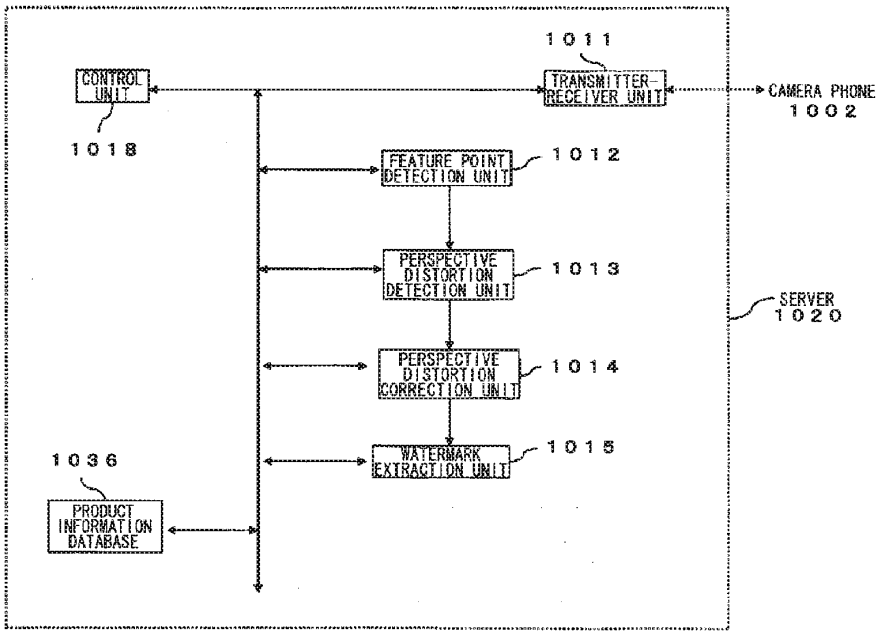
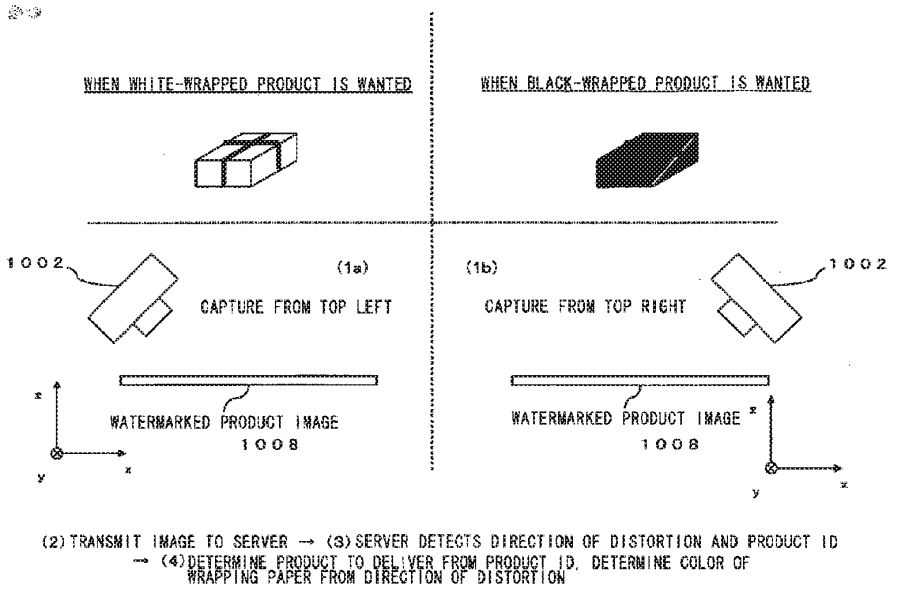

1011
CONTROL UNIT
TRANSMITTER-RECEIVER UNIT
CAMERA PHONE
1002
1018
FEATURE POINT DETECTION UNIT
1012
PERSPECTIVE DISTORTION DETECTION UNIT
1013
SERVER
1020
PERSPECTIVE DISTORTION CORRECTION UNIT
1014
WATERMARK EXTRACTION UNIT
1015
1036
PRODUCT INFORMATION DATABASE

FIG.54

PRODUCT DATABASE 1036

PRODUCT ID	PERSPECTIVE DISTORTION INFORMATION	USER-REQUESTED PRODUCT AND WRAPPING
1001	1	PRODUCT A, WHITE WRAPPING
1001	2	PRODUCT A, BLACK WRAPPING
1001	0	PRODUCT A, NO WRAPPING
1002	1	PRODUCT B, BLUE WRAPPING
.....	.....	.....

FIG.55



(2) TRANSMIT IMAGE TO SERVER → (3) SERVER DETECTS DIRECTION OF DISTORTION AND PRODUCT ID → (4) DETERMINE PRODUCT TO DELIVER FROM PRODUCT ID, DETERMINE COLOR OF WRAPPING PAPER FROM DIRECTION OF DISTORTION

FIG.56A

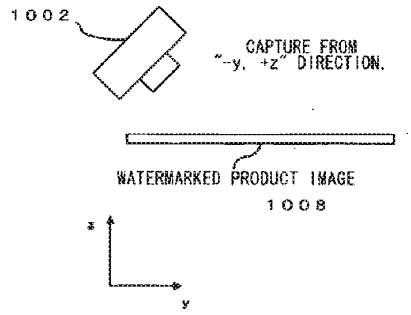


FIG.56B

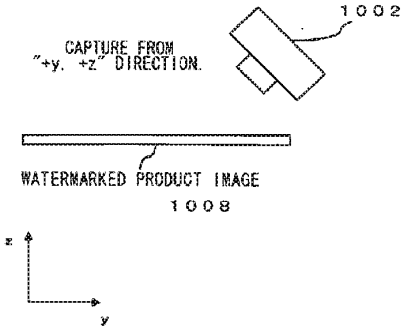


FIG.57

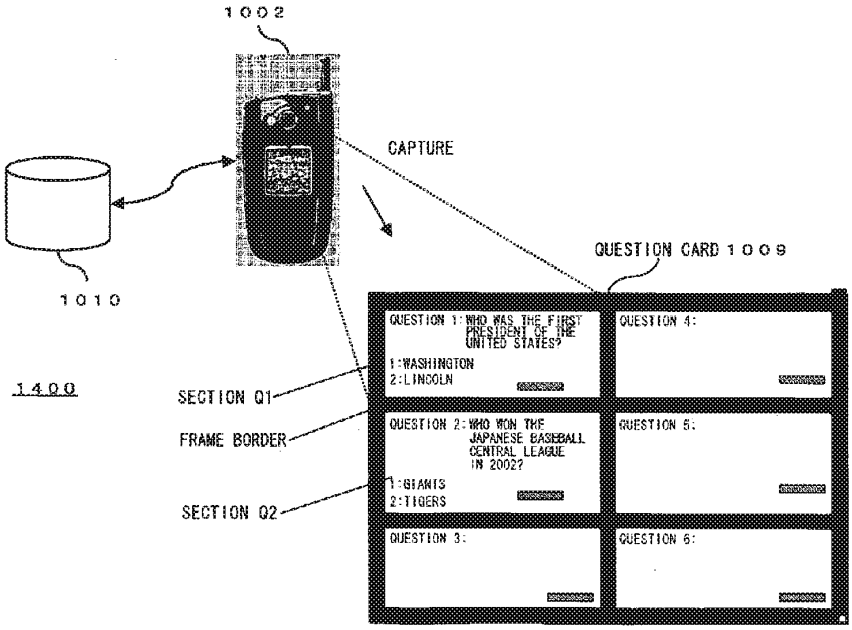

1002
CAPTURE
QUESTION CARD 1009
1010
1400
SECTION Q1
FRAME BORDER
SECTION Q2
QUESTION 1: WHO WAS THE FIRST PRESIDENT OF THE UNITED STATES?
1:WASHINGTON
2:LINCOLN
QUESTION 4:
QUESTION 2: WHO WON THE JAPANESE BASEBALL CENTRAL LEAGUE IN 2002?
1:GIANTS
2:TIGERS
QUESTION 5:
QUESTION 3:
QUESTION 6:

FIG.58A

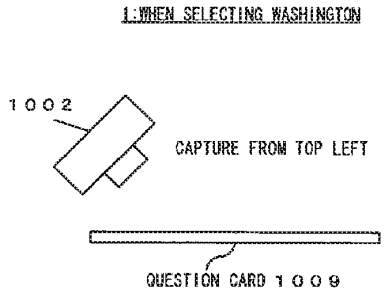


FIG.58B

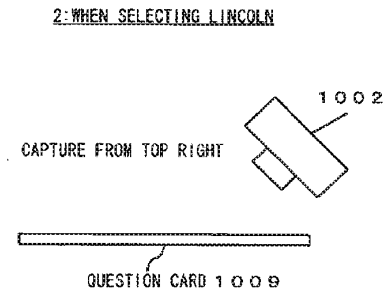


FIG.59

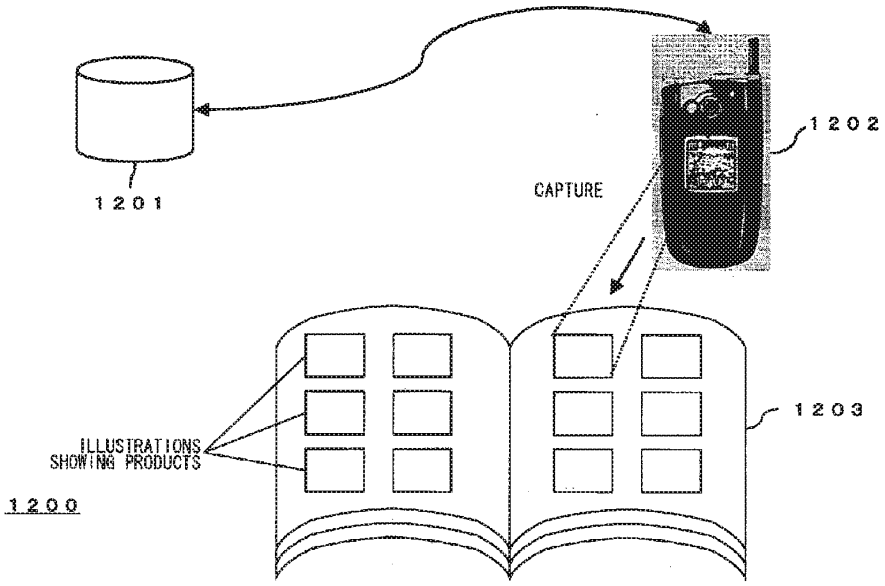

1201
CAPTURE
1202
1203
ILLUSTRATIONS SHOWING PRODUCTS
1200

IMAGE CORRECTION APPARATUS AND METHOD, IMAGE CORRECTION DATABASE CREATING METHOD, INFORMATION DATA PROVISION APPARATUS, IMAGE PROCESSING APPARATUS, INFORMATION TERMINAL, AND INFORMATION DATABASE APPARATUS

TECHNICAL FIELD

[0001] The invention relates to image processing technologies, and more particularly to an image correction apparatus and a method for correcting images, and an image correction database creating method of that apparatus. The present invention also relates to an information data provision apparatus, an image processing apparatus, an information terminal, and an information database apparatus.

BACKGROUND TECHNOLOGY

[0002] There are systems in which digital images having electronic watermarks embedded therein are printed on printing media, and the printed images are captured by a digital camera, a scanner, or the like and re-digitized to detect the embedded electronic watermarks. For example, when issuing tickets or cards to users, identification information on the issuers and/or the users is embedded into images in the form of electronic watermarks and printed on the tickets or cards so as not to be visually detectable. When the tickets or cards are used, the electronic watermarks can be detected to avoid counterfeiting, unauthorized acquisition, and other frauds. Besides, unauthorized duplication of copyrighted materials, securities, and the like can be precluded by embedding copyright information, device identification information, and the like as electronic watermarks when printing images with copy machines or printers.

[0003] In general, when printed images are captured and digitized by a digital camera or a scanner, lens distortion and perspective distortion occur in the captured images. Here, the lens distortion depends on the shape and focal length of the lens of the capturing device, and the perspective distortion is ascribable to a tilt of the optical axis at the time of capturing. As a result, the printed images and the captured images cause pixel deviation therebetween. This makes it difficult for electronic watermarks embedded in the printed images to be extracted from the captured images properly, and thus requires distortion correction on the captured images.

[0004] The patent document 1 discloses an image correction apparatus which performs the following processing: generating a mapping function pertaining to perspective distortion based on position deviations of feature points of a calibration pattern near a screen center; evaluating differences between ideal positions of the feature points and actual positions of the same on an image across the entire screen by using the mapping function; calculating a correction function for correcting lens distortion; and correcting image data.

[0005] Moreover, there are systems in which information embedded as electronic watermarks is extracted from digital image data transmitted from clients, and services (such as contents download services and product sales services) are provided to the clients based on the extracted information (for example, see patent document 2).

[0006] FIG. **59** is a block diagram of a product sales system **1200**, an example of such a system. The product sales system **1200** comprises a server **1201**, a camera with communication facilities (camera-equipped cellular phone **1202**), and a catalog (a printed material **1203**). Various illustrations showing products are printed on the printed material **1203**. These illustrations and the sales products correspond on a one-to-one basis. In each illustration, identification information on the product (such as product ID) is invisibly embedded in the form of an electronic watermark.

[0007] In such a product sales system **1200**, when a client captures an illustration on the printed material **1203** with his/her camera-equipped cellular phone **1202**, the data on the captured image generated by the camera-equipped cellular phone **1202** is transmitted to the server **1201**. The server **1201** extracts the information embedded as an electronic watermark from data on the captured image, and determines from the extracted result the product the client wants to purchase. [Patent document 1] Japanese Patent Publication No. 2940736 [Patent document 2] Japanese Publication of PCT International Application No. 2002-544637

[0008] To correct image distortion ascribable to capturing, it is necessary to acquire information on the distortion characteristics of the capturing device and information on the tilt of the optical axis at the time of capturing, and apply geometric transform to the captured image. Fine distortion correction can be made by using profile data that shows the detailed distortion characteristics of the lens, whereas the profile data requires a large storage capacity and takes long to process.

[0009] In addition, how finely image distortion must be examined and corrected depends on the tolerance of watermarks to image distortion. When the watermarks have relatively high tolerance to image distortion, fine distortion correction is wasteful. With low tolerance to image distortion, on the other hand, the watermarks cannot be detected properly by rough distortion correction. A mismatch between the tolerance of watermarks when embedded and the precisions of image correction when extracting the watermarks can thus deteriorate the detection accuracy and the detection efficiency of the watermarks.

[0010] Moreover, when selling products of the same model but different colors in the foregoing product sales system **1200**, the printed material **1203** must carry illustrations of the products of the same model as many as the number of color variations. This produces a problem of increased space of the printed material **1203**.

[0011] The print space can be reduced by preparing product images separately from images in which only color information is embedded (for example, for eight color variations, eight images are prepared separately). For example, when purchasing a product in red, two images, i.e., the illustration of the product and an image for representing red are captured in succession. The number of images required here is only the number of products plus the number of types of color information, being smaller than with the method where color information is given to each individual product (the number of images required is the number of products multiplied by the number of colors). The print space thus decreases significantly. In this case, however, the server **1201** is put under high load since it must process both the product images and the color information images.

[0012] Then, instead of printing illustrations corresponding to the number of color variations on the printed material **1203**, illustrations corresponding to the products alone may be printed on the printed material **1203** so that the client presses accompanying buttons on the capturing device to select desired product colors.

[0013] More specifically, the client initially captures the illustration of a desired product with the camera-equipped cellular phone **1202**. Next, the client presses an accompanying button on the camera-equipped cellular phone **1202** to select the desired color of the product. The data on the captured image and the information selected by button depression are then transmitted from the camera-equipped cellular phone **1202** to the server **1201**.

[0014] Such a method, however, requires that the client make a burdensome selecting operation by button depression after the capturing operation.

DISCLOSURE OF THE INVENTION

[0015] The present invention has been achieved in view of the foregoing. It is thus an object of the present invention to provide an image correction technology capable of correcting image distortion efficiently with high precision. Another object of the present invention is to provide an information processing technology of high convenience, using electronic watermarks.

[0016] To solve the foregoing problems, an image correction apparatus according to one of the aspects of the present invention comprises: a lens distortion calculation unit which calculates lens distortion correction information with respect to each zoom magnification, based on known images captured at respective different zoom magnifications; and a memory unit which stores the lens distortion correction information in association with the zoom magnifications.

[0017] As employed herein, "storing the lens distortion correction information in association with the zoom magnifications" shall not only refer to the cases where the lens distortion correction information is stored in association with the zoom magnifications themselves, but also cover the cases where it is stored substantially in association with the zoom magnifications. For example, given that the CCD (Charge-Coupled Device) surface or film surface for subject images to be formed on has a constant longitudinal length, the angle of view and the focal length both vary in accordance with the zoom magnification. Thus, the expression "storing . . . in association with the zoom magnifications" shall also cover the cases where the lens distortion correction information is stored in association with the angles of view or focal lengths.

[0018] Another aspect of the present invention also provides an image correction apparatus. This apparatus comprises: a memory unit which contains lens distortion correction information in association with zoom magnifications of a lens; a selector unit which selects lens distortion correction information corresponding to a zoom magnification employed at the time of capturing of an input captured image from the memory unit; and a distortion correction unit which corrects distortion of the captured image ascribable to capturing based on the lens distortion correction information selected.

[0019] The selector unit may select from the memory unit a plurality of candidate pieces of lens distortion correction information in accordance with the zoom magnification employed at the time of capturing, and correct a row of sample points forming a known shape in the captured image by using each of the plurality of pieces of lens distortion correction information for error pre-evaluation. Thereby, the selector unit may select one piece of lens distortion correction information from among the plurality of pieces of lens distortion correction information.

[0020] As employed herein, "a row of sample points forming a known shape" refers to the cases where the shape the row of sample points are supposed to form if without any capturing distortion is known. For example, a row of sample points assumed on the image frame of a captured image are known to fall on a straight line if there is no capturing distortion. In another example, a row of sample points assumed on the outline of a person's face captured are known to fall at least on a smooth curve.

[0021] Yet another aspect of the present invention also provides an image correction apparatus. This apparatus comprises: a lens distortion calculation unit which calculates based on known images captured at respective different zoom magnifications a lens distortion correction function for mapping points in a lens-distorted image onto points in an image having no lens distortion and a lens distortion function, or an approximate inverse function of the lens distortion correction function, with respect to each lens magnification; and a memory unit which stores the pairs of lens distortion correction functions and lens distortion functions in association with the zoom magnifications.

[0022] As employed herein, "storing the pairs of lens distortion correction functions and lens distortion functions in association with the zoom magnifications" is not limited to the cases of storing such information as functional expressions and coefficients. It also covers the cases where the correspondence between input values and output values of these functions are stored in the form of a table. For example, the correspondence between coordinate values in an image and coordinate values mapped by these functions may be stored as a table.

[0023] Yet another aspect of the present invention also provides an image correction apparatus. This apparatus comprises: a memory unit which contains pairs of lens distortion correction functions for mapping points in a lens-distorted image onto points in an image having no lens distortion and lens distortion functions, or approximate inverse functions of the lens distortion correction functions, in association with respective zoom magnifications of a lens; a selector unit which selects the lens distortion function corresponding to a zoom magnification employed at the time of capturing of an input captured image from the memory unit; and a distortion correction unit which corrects distortion of the captured image ascribable to capturing based on the lens distortion function selected. According to this configuration, it is possible to correct lens distortion ascribable to capturing.

[0024] Yet another aspect of the present invention also provides an image correction apparatus. This apparatus comprises: a memory unit which contains lens distortion functions for mapping points in an image having no lens distortion onto points in a lens-distorted image in association with respective zoom magnifications of a lens; a selector unit which selects the lens distortion function corresponding

to a zoom magnification employed at the time of capturing of an input captured image from the memory unit; a perspective distortion calculation unit which calculates a perspective distortion function for mapping points in an image having no perspective distortion onto points in a perspective-distorted image, by using an image whose lens distortion is corrected by the lens distortion function selected; and a distortion correction unit which corrects distortion of the captured image ascribable to capturing based on the perspective distortion function calculated by the perspective distortion calculation unit. According to this configuration, it is possible to correct perspective distortion and lens distortion ascribable to capturing.

[0025] Yet another aspect of the present invention provides an image correction database creating method. This method comprises: calculating based on known images captured at respective different zoom magnifications a lens distortion correction function for mapping points in a lens-distorted image onto points in an image having no lens distortion and a lens distortion function, or an approximate inverse function of the lens distortion correction function, with respect to each lens magnification; and registering the pairs of lens distortion correction functions and lens distortion functions into a database in association with the zoom magnifications.

[0026] Yet another aspect of the present invention provides an image correction method. This method comprises: consulting a database in which pairs of lens distortion correction functions for mapping points in a lens-distorted image onto points in an image having no lens distortion and lens distortion functions, or approximate inverse functions of the lens distortion correction functions, are registered in association with respective zoom magnifications of a lens, and selecting the lens distortion function corresponding to a zoom magnification employed at the time of capturing of an input captured image; and correcting distortion of the captured image ascribable to capturing based on the lens distortion function selected.

[0027] Yet another aspect of the present invention also provides an image correction method. This method comprises: consulting a database in which lens distortion functions for mapping points in an image having no lens distortion onto points in a lens-distorted image are registered in association with respective zoom magnifications of a lens, and selecting the lens distortion function corresponding to a zoom magnification employed at the time of capturing of an input captured image; calculating a perspective distortion function for mapping points in an image having no perspective distortion onto points in a perspective-distorted image, by using an image whose lens distortion is corrected by the lens distortion function selected; and correcting distortion of the captured image ascribable to capturing based on the perspective distortion function calculated.

[0028] An information provision apparatus according to yet another aspect of the present invention comprises: an electronic watermark extraction unit which extracts information embedded by electronic watermark technology from imaging data obtained by an imaging device; a distortion detection unit which detects image distortion from the imaging data; an information data storing unit which stores information data; a selector unit which selects information data stored in the information data storing unit based on the information embedded by the electronic watermark technology, extracted by the electronic watermark extraction unit, and the image distortion detected by the distortion detection unit; and an output unit which outputs the information data selected by the selector unit to exterior.

[0029] The foregoing information data refers to text data, image data, moving image data, voice data, etc.

[0030] An information provision apparatus according to yet another aspect of the present invention comprises: an electronic watermark extraction unit which extracts information embedded by electronic watermark technology from imaging data obtained by an imaging device; a distortion detection unit which detects image distortion from the imaging data; an information data storing unit which stores information data; a selector unit which selects information data stored in the information data storing unit based on the information embedded by the electronic watermark technology, extracted by the electronic watermark extraction unit, and the image distortion detected by the distortion detection unit; and a display unit which displays contents of the information data selected by the selector unit.

[0031] An image processing apparatus according to yet another aspect of the present invention comprises: an electronic watermark extraction unit which extracts information embedded by electronic watermark technology from imaging data obtained by an imaging device; a distortion detection unit which detects image distortion from the imaging data; an image data storing unit which stores image data; and a selector unit which selects image data stored in the image data storing unit based on the information embedded by the electronic watermark technology, extracted by the electronic watermark extraction unit, and the image distortion detected by the distortion detection unit.

[0032] An image processing apparatus according to yet another aspect of the present invention comprises: a distortion detection unit which detects image distortion from imaging data obtained by an imaging device; a distortion correction unit which corrects the image distortion of the imaging data based on the image distortion detected by the distortion detection unit; an electronic watermark extraction unit which extracts information embedded by electronic watermark technology from the imaging data whose image distortion is corrected by the distortion correction unit; an image data storing unit which stores image data; and a selector unit which selects image data stored in the image data storing unit based on the information embedded by the electronic watermark technology, extracted by the electronic watermark extraction unit, and the image distortion detected by the distortion detection unit.

[0033] An information terminal according to yet another aspect of the present invention comprises: an imaging unit; a distortion detection unit which detects image distortion from imaging data obtained by the imaging unit; a distortion correction unit which corrects the image distortion of the imaging data based on the image distortion detected by the distortion detection unit; and a transmission unit which transmits the imaging data whose image distortion is corrected by the distortion correction unit and information on the image distortion detected by the distortion detection unit to exterior.

[0034] An image processing apparatus according to yet another aspect of the present invention comprises: a recep-

tion unit which receives imaging data and information on image distortion transmitted from an information terminal; an electronic watermark extraction unit which extracts information embedded by electronic watermark technology from the imaging data; an information data storing unit which stores information data; and a selector unit which selects information data stored in the information data storing unit based on the information embedded by the electronic watermark technology, extracted by the electronic watermark extraction unit, and the information on the image distortion received by the reception unit.

[0035] An information terminal according to yet another aspect of the present invention comprises: an imaging unit; a distortion detection unit which detects image distortion from imaging data obtained by the imaging unit; a distortion correction unit which corrects the image distortion of the imaging data based on the image distortion detected by the distortion detection unit; an electronic watermark extraction unit which extracts information embedded by electronic watermark technology from the imaging data whose image distortion is corrected by the distortion correction unit; and a transmission unit which transmits the information embedded by the electronic watermark technology, extracted by the electronic watermark extraction unit, and information on the image distortion detected by the distortion detection unit to exterior.

[0036] An information database apparatus according to yet another aspect of the present invention comprises: a distortion detection unit which detects image distortion from imaging data obtained by an imaging device; an information data storing unit which stores information data; and a selector unit which selects information data stored in the information data storing unit based on the image distortion detected by the distortion detection unit.

[0037] A data structure according to yet another aspect of the present invention is one to be transmitted from an information terminal having an imaging unit, the data structure containing information on image distortion detected from imaging data obtained by the imaging unit.

[0038] It should be appreciated that any combinations of the foregoing components, and any conversions of expressions of the present invention from/into methods, apparatuses, systems, recording media, computer programs, and the like are also intended to constitute applicable aspects of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0039] FIG. **1** is a block diagram of an electronic watermark embedding apparatus according to a first embodiment;

[0040] FIGS. **2**A to **2**D are diagrams for explaining a block embedding method of the block embedding unit of FIG. **1**;

[0041] FIG. **3** is a diagram for explaining a printed image output from the electronic watermark embedding apparatus of FIG. **1**;

[0042] FIG. **4** is a block diagram of an electronic watermark extracting apparatus according to the first embodiment;

[0043] FIG. **5** is a diagram for explaining a printed image captured by the electronic watermark extracting apparatus of FIG. **4**;

[0044] FIG. **6** is a diagram for explaining a pixel deviation due to capturing;

[0045] FIG. **7** is a diagram for explaining the detailed configuration of the profile creation unit and the image correction unit of FIG. **4**;

[0046] FIGS. **8**A and **8**B are diagrams for explaining the relationship between the angle of view and the focal length of a zoom lens;

[0047] FIGS. **9**A and **9**B are diagrams for explaining lens distortion function pairs to be stored in the profile database of FIG. **7**;

[0048] FIG. **10** is a flowchart for explaining the steps by which the electronic watermark extracting apparatus creates a profile database;

[0049] FIG. **11** is a diagram for explaining a lattice pattern image to be used as a calibration pattern;

[0050] FIG. **12** is a diagram for explaining a lens distortion function pair;

[0051] FIG. **13** is a flowchart showing an overall flow of the steps for extracting an electronic watermark according to the first embodiment;

[0052] FIG. **14** is a flowchart for showing a general flow of the image correction processing of FIG. **13**;

[0053] FIG. **15** is a flowchart showing the detailed steps for selecting a lens distortion function pair in FIG. **14**;

[0054] FIG. **16** is a flowchart showing the detailed steps of the image correction main processing of FIG. **14**;

[0055] FIG. **17** is a diagram for explaining how a point in a correction target image is mapped onto a point in a correction object image;

[0056] FIG. **18** is a diagram for explaining the method of calculating the luminance value at a point mapped by a lens distortion function;

[0057] FIG. **19** is a flowchart showing the detailed steps of the image area determination processing of FIG. **13**;

[0058] FIG. **20** is a diagram for explaining how feature points are extracted from a lens-distortion-corrected image;

[0059] FIG. **21** is a flowchart for showing the detailed steps for selecting a lens distortion function pair, where a method of selection for a speed-priority system and a method of selection for a precision-priority system can be switched;

[0060] FIG. **22** is a flowchart showing the detailed steps for the pre-evaluation of correction functions of FIG. **21**;

[0061] FIGS. **23**A to **23**C are diagrams for explaining how approximation errors of a Bezier curve are evaluated;

[0062] FIG. **24** is a flowchart showing the detailed steps for acquiring a row of sample points between feature points in FIG. **22**;

[0063] FIG. **25**A is a diagram for explaining how edge detection processing is performed on an original image area, and FIG. **25**B is a diagram for explaining spline approximation on each side of the original image area;

[0064] FIG. **26** is a block diagram showing the electronic watermark extracting apparatus according to a second embodiment;

[0065] FIG. **27** is a diagram for explaining the detailed configuration of the profile creation unit and the image correction unit of FIG. **26**;

[0066] FIG. **28** is a flowchart showing an overall flow of the electronic watermark extracting steps according to the second embodiment;

[0067] FIG. **29** is a flowchart for showing a general flow of the image correction processing of FIG. **28**;

[0068] FIG. **30** is a flowchart showing the detailed steps for the calculation of a perspective distortion function of FIG. **29**;

[0069] FIG. **31** is a flowchart showing the detailed steps of the image correction main processing of FIG. **29**;

[0070] FIGS. **32**A to **32**C are diagrams for explaining how a point in a correction target image is mapped onto a point in a correction object image;

[0071] FIG. **33** is a block diagram of an image data provision system according to a third embodiment;

[0072] FIG. **34** is a conceptual rendering of a watermarked product image;

[0073] FIGS. **35**A to **35**C are diagrams showing directions in which a client captures the watermarked product image in the third embodiment;

[0074] FIG. **36** is an image of a digital camera, or an example of the product, as viewed from the front;

[0075] FIG. **37** is an image of the digital camera, or an example of the product, as viewed from behind;

[0076] FIG. **38** is a block diagram of a camera-equipped cellular phone according to the third embodiment;

[0077] FIG. **39** is a block diagram of a server according to the third embodiment,

[0078] FIG. **40** is a captured image when the watermarked product image is captured from directly above ("+z" side of FIG. **34**);

[0079] FIG. **41** is a captured image when the watermarked product image is captured from top left ("+z, −x" side of FIG. **34**);

[0080] FIG. **42** is a captured image when the watermarked product image is captured from top right ("+z, +x" side of FIG. **34**);

[0081] FIG. **43** is a diagram showing the contents of the image data indexing unit of the server according to the third embodiment;

[0082] FIG. **44** is a flowchart showing the processing of the server **1001** according to the third embodiment;

[0083] FIGS. **45**A and **45**B are diagrams showing captured images according to a modification of the third embodiment;

[0084] FIG. **46** is a diagram for explaining ξ-axis and η-axis with reference to the watermarked product image according to the third embodiment;

[0085] FIG. **47** is a block diagram of a camera-equipped cellular phone according to a fourth embodiment;

[0086] FIG. **48** is a block diagram of a server according to the fourth embodiment;

[0087] FIG. **49** is a flowchart showing the processing of the camera-equipped cellular phone according to the fourth embodiment;

[0088] FIG. **50** is a flowchart showing the processing of the server according to the fourth embodiment;

[0089] FIG. **51** is a block diagram of a product purchase system according to a fifth embodiment;

[0090] FIG. **52** is a diagram showing a watermarked product image according to the fifth embodiment;

[0091] FIG. **53** is a block diagram of a server in the product purchase system according to the fifth embodiment;

[0092] FIG. **54** is a diagram showing the contents of the product database of the server according to the fifth embodiment;

[0093] FIG. **55** is a conceptual diagram of the product purchase system according to the fifth embodiment;

[0094] FIGS. **56**A and **56**B are conceptual diagrams of the product purchase system according to a modification of the fifth embodiment;

[0095] FIG. **57** is a diagram showing the configuration of a quiz answering system according to a sixth embodiment;

[0096] FIGS. **58**A and **58**B are diagrams showing directions in which a client captures the watermarked product image according to the sixth embodiment; and

[0097] FIG. **59** is a block diagram of a product sales system which uses electronic watermarks.

BEST MODE FOR CARRYING OUT THE INVENTION

First Embodiment

[0098] An electronic watermark system according to a first embodiment of the present invention includes an electronic watermark embedding apparatus **100** as shown in FIG. **1** and an electronic watermark extracting apparatus **200** as shown in FIG. **4**. The electronic watermark embedding apparatus **100** generates printed images having electronic watermarks embedded therein. The electronic watermark extracting apparatus **200** captures the printed images and extracts the embedded electronic watermarks. For example, the electronic watermark embedding apparatus **100** is used to issue tickets and cards, and the electronic watermark extracting apparatus **200** is used to detect counterfeit tickets and cards. Both the apparatuses may be configured as a server to be accessed from network terminals.

[0099] FIG. **1** is a block diagram of the electronic watermark embedding apparatus **100** according to the first embodiment. In terms of hardware, these components can be achieved by an arbitrary computer CPU, a memory, and other LSIs. In terms of software, they can be achieved by programs or the like that are loaded on a memory and have the functions for processing images and embedding electronic watermarks. The functional blocks shown here are

achieved by the cooperation of these. It will thus be understood by those skilled in the art that these functional blocks may be achieved in various forms including hardware alone, software alone, and a combination of these.

[0100] An image forming unit **10** converts an input digital image I into a printing resolution of W pixels in the horizontal direction (also referred to as x-axis direction) and H pixels in the vertical direction (also referred to as y-axis direction). For example, the image sizes W=640 and H=480.

[0101] A block embedding unit **12** embeds watermark information X into the digital image I having the printing resolution, converted by the image forming unit **10**. Here, the block embedding unit **12** divides the digital image I into square blocks of predetermined size, and embeds identical watermark bits into some blocks redundantly. This method of embedding the watermark information X into the digital image I is referred to as "block embedding method." The blocks of the digital image I where the watermark bits are embedded are referred to as "embedded blocks." For example, the block size N is four.

[0102] FIGS. **2**A to **2**D are diagrams for explaining the block embedding method of the block embedding unit **12**. FIG. **2**A is a diagram for explaining how the digital image I is divided into blocks. The digital image I having a matrix of W×H pixels is divided into embedded blocks **22** of N×N pixels.

[0103] The block embedding unit **12** selects embedded blocks **22** of the digital image I for respective watermark bits constituting the watermark information X to be embedded into. The block embedding unit **12** embeds identical watermark bits into the respective embedded blocks **22** redundantly. FIG. **2**B is a diagram for explaining the digital image I in which watermark bits are embedded. The diagram will deal with an example where the watermark information X consists of a watermark bit string (0, 1, 1, 0). From the digital image I, the block embedding unit **12** selects an embedded block **22***a* intended for the first watermark bit "**0**" to be embedded into, an embedded block **22***b* for the second watermark bit "**1**" to be embedded into, an embedded block **22***c* for the third watermark bit "**1**" to be embedded into, and an embedded block **22***d* for the fourth watermark bit "**0**" to be embedded into. The block embedding unit **12** then embeds the watermark bits into the respective blocks **22***a* to **22***d* redundantly.

[0104] FIG. **2**C is a diagram for explaining watermark bits embedded in an embedded block **22**. Here, description will be given of an example where the block size N is four and the watermark bits are "**1**." As shown in the diagram, 16 watermark bits "**1**" are embedded into the embedded block **22** redundantly.

[0105] FIG. **2**D is a diagram for explaining a pixel deviation to occur while extracting the watermark bits, and its influence on the detection of the watermark bits. Suppose that an embedded block **28** detected from a captured image has an actual endpoint **29** that is horizontally one pixel off an ideal endpoint **23** of the embedded block **22** in the original image as shown in the diagram. Even in this case, 12 identical watermark bits "**1**" are detected redundantly from the area where the embedded block **22** of the original image and the embedded block **28** of the captured image overlap with each other. As a result, it is possible to detect the correct watermark bit by a majority vote within the block. The block embedding method can thus improve the tolerance for pixel deviations.

[0106] A printing unit **14** prints the digital image I having the watermark information X embedded by the block embedding unit **12** onto a printing medium, thereby generating a printed image P. It should be noted that while the diagram shows the printing unit **14** as being one of the components of the electronic watermark embedding apparatus **100**, the printing unit **14** may be configured as a printer which lies outside the electronic watermark embedding apparatus **100**. In that case, the electronic watermark embedding apparatus **100** and the printer are connected with a peripheral connection cable or over a network.

[0107] FIG. **3** is a diagram for explaining the output printed image P. The digital image I having an electronic watermark embedded therein (also referred to as original image) is printed on a printing medium **24**. The area **20** where the original image is printed on (hereinafter, referred to simply as original image area **20**) is typically surrounded by margins of the printing medium **24**.

[0108] FIG. **4** is a block diagram showing the electronic watermark extracting apparatus **200** according to the first embodiment. A capturing unit **30** captures printed images P having electronic watermarks embedded therein or lattice pattern images R, thereby converting the same into an electronic form. A profile creation unit **38** detects position deviations of lattice points in the lattice pattern images R captured at different zoom magnifications, and generates correction information on distortion occurring in the images. The correction information is stored into a profile database **40** in association with the zoom magnifications. An image correction unit **34** selects correction information corresponding to a zoom magnification employed at the time of capturing a printed image P from the profile database **40**, and corrects distortion occurring in the captured image of the printed image P. An image area determination unit **32** determines the original image area **20** in the distortion-corrected captured image. A watermark extraction unit **36** divides the original image area **20** in the distortion-corrected captured image into blocks, and detects watermark bits embedded in the respective blocks to extract watermark information X. These components can also be achieved in various forms, including any combinations of hardware such as a CPU and a memory and pieces of software having the functions for processing images and extracting electronic watermarks.

[0109] The profile creation unit **38**, the image correction unit **34**, and the profile database **40** of the electronic watermark extracting apparatus **200** constitute an example of the image correction apparatus according to the present invention.

[0110] The capturing unit **30** captures printed images P generated by the electronic watermark embedding apparatus **100**, and digitizes the printed images P. While the diagram shows the capturing unit **30** as being one of the components of the electronic watermark extracting apparatus **200**, the capturing unit **30** may be configured as a digital camera or scanner which lies outside the electronic watermark extracting apparatus **200**. In that case, the electronic watermark extracting apparatus **200** and the digital camera or scanner are connected with a peripheral connection cable or over a

network. When the digital camera has wireless communication facilities in particular, images captured by the digital camera are transmitted to the electronic watermark extracting apparatus **200** by wireless.

[0111] FIG. **5** is a diagram for explaining a printed image P captured. When the capturing unit **30** captures the printed image P, it captures the entire original image area **20** of the printing medium **24**, typically with the margins around the original image area **20**. That is, the captured area **26** is typically wider than the original image area **20** on the printing medium **24**. Since the image captured by the capturing unit **30** thus includes margins on the printing medium **24**, the original image area **20** must be cut out after the distortion of the captured image is corrected.

[0112] The image correction unit **34** performs a distortion correction on the entire captured image. When the printed image P is captured by the capturing unit **30**, a lens distortion and a perspective distortion can occur in the captured image. The image correction unit **34** corrects the distortions occurring in the image so that the embedded electronic watermark can be extracted properly. The distortion correction uses functions intended for correcting distortion, which are stored in the profile database **40**.

[0113] The image area determination unit **32** applies edge extraction and other processing to the captured image whose distortion is corrected by the image correction unit **34**, and determines the area of the original image. This cuts out the original image area **20**, removing the margins from the captured area **26** of FIG. **5**.

[0114] The watermark extraction unit **36** divides the original image area **20** determined by the image area determination unit **32** into blocks of N×N pixels, and detects watermark bits from respective blocks to extract the watermark information X. When detecting the watermark bits embedded by the block embedding method, distortion of the embedded blocks, if any, can make the watermark detection difficult. Since the distortion is corrected by the image correction unit **34**, however, the accuracy of the watermark detection is guaranteed. Moreover, even if some pixel deviation remains after the distortion correction, it is possible to detect correct watermark bits since the watermark bits are embedded redundantly in the respective blocks.

[0115] FIG. **6** is a diagram for explaining a pixel deviation due to capturing. Suppose that an embedded block **60** of the captured image does not match with the embedded block **50** of the original image as shown in the diagram. With respect to an endpoint **52** of the embedded block **50** in the original image, the endpoint **62** of the embedded block **60** in the captured image is one pixel off in both horizontal and vertical directions. Even in such situations, identical watermark bits (here, shown by "1") are detected redundantly from the area where the embedded block **50** of the original image and the embedded block **60** of the captured image overlap with each other. The watermark extraction unit **36** can thus detect the proper watermark bit.

[0116] FIG. **7** is a diagram for explaining the detailed configuration of the profile creation unit **38** and the image correction unit **34**. The profile creation unit **38** includes a perspective distortion function calculation unit **80**, a lens distortion function pair calculation unit **82**, and a lens distortion function pair registration unit **84**. The image correction unit **34** includes a lens distortion function pair selection unit **86** and a lens distortion correction processing unit **88**.

[0117] Initially, description will be given of how correction information is registered into the profile database **40**. To measure lens distortion, the capturing unit **30** captures the lattice pattern image R, and supplies it to the profile creation unit **38**. When a zoom lens is used for capturing, the zoom magnification is changed to capture the lattice pattern image R with a plurality of angles of view θ_j. The perspective distortion function calculation unit **80** of the profile creation unit **38** accepts input of the image area of the lattice pattern image R, and detects position deviations of the intersections in the pattern of the lattice pattern image R ascribable to perspective distortion. The perspective distortion function calculation unit **80** thereby calculates a perspective distortion function g for mapping points in an image having no perspective distortion onto points in a perspective-distorted image.

[0118] The lens distortion function pair calculation unit **82** accepts input of the perspective distortion function g calculated by the perspective distortion function calculation unit **80**, and detects position deviations of the intersections in the pattern of the lattice pattern image R in consideration of the perspective distortion. The lens distortion function pair calculation unit **82** thereby calculates a lens distortion correction function f_i and a lens distortion function f_i^{-1} at an angle of view θ_j. Here, the lens distortion correction function f_i is one for mapping points in a lens-distorted image onto points in an image having no lens distortion. The lens distortion function f_i^{-1} is an approximate inverse function of the lens distortion correction function f_i, and maps points in an image having no lens distortion onto points in a lens-distorted image. The pair of the lens distortion correction function f_i and the lens distortion function f_i^{-1} will be referred to as a lens distortion function pair (f_i, f_i^{-1}).

[0119] The lens distortion function pair registration unit **84** registers the lens distortion function pair (f_i, f_i^{-1}) calculated by the lens distortion function pair calculation unit **82** into the profile database **40** in association with the angle of view θ_j.

[0120] Next, description will be given of the image correction using the foregoing profile database **40**. The capturing unit **30** supplies a captured printed image P to the image correction unit **34**. The lens distortion function pair selection unit **86** of the image correction unit **34** accepts the input of the captured image of the printed image P, and determines the angle of view θ employed at the time of capturing from image information. The lens distortion function pair selection unit **86** then selects a lens distortion function pair (F, F^{-1}) corresponding to the angle of view θ employed at the time of capturing from the profile database **40**, and supplies the lens distortion function F^{-1} to the lens distortion correction processing unit **88**. The lens distortion correction processing unit **88** corrects the lens distortion of the entire captured image by using the lens distortion function F^{-1}, and supplies the corrected captured image to the image area determination unit **32**.

[0121] FIGS. **8**A and **8**B are diagrams for explaining the relationship between the angle of view and the focal length of a zoom lens. FIG. **8**A shows the state where a lens **94** is focused on a subject **90**. The vertex V of the subject **90**

corresponds to the vertex v of the subject image on the imaging area of a CCD **96**. Here, the principle point **95** lies at the center of the lens **94**, and the focal length f is the distance between the principle point **95** and a single point (referred to as focus) into which parallel light incident in the normal direction of the lens converges. The optical axis **92** is a straight line that passes the principle point **95** and has a gradient in the normal direction of the lens **94**. The angle ω formed between the optical axis **92** and a straight line that connects the principle point and the vertex V of the subject **90** is called a half angle of view, and twice ω is called the angle of view. As employed herein, the half angle of view ω will be referred to simply as "the angle of view."

[0122] The height of the subject **90** to be focused will be referred to as Y, and the height of the subject image on the imaging area of the CCD **96** as y. The magnification m is the ratio of the height y of the subject image formed on the CCD **96** with respect to the actual height Y of the subject **90**, and is given by m=y/Y. Here, a perfect in-focus state will be defined as follows:

[0123] Definition 1: A Subject is in Perfect Focus

[0124] That a subject is in perfect focus refers to situations where the straight line that connects the vertex of the subject and the vertex of the subject image formed on the CCD surface passes the principle point, and the distance from the principle point to the CCD surface in the normal direction of the lens is equal to the focal length.

[0125] Under the perfect in-focus state in terms of definition 1, the point at which the optical axis **92** and the imaging area of the CCD **96** cross each other will be referred to as a focus center **98**.

[0126] Lenses are broadly classified into two types, or single-focus lenses and zoom lenses. Single-focus lenses are incapable of changing their focal length f. In contrast, zoom lenses are composed of a combination of two or more lenses each, and can change the focal length f, the principle point, and the like freely by adjusting the distances between the lenses and the distances from the respective lenses to the imaging area of the CCD **96**. Description will now be given of how to change the magnification of a subject by using a zoom lens. Initially, a change in magnification will be defined as follows:

[0127] Definition 2: A Change in Magnification

[0128] A change in magnification shall refer to changing the height of the subject image formed on the CCD surface without changing the distance between the subject plane and the CCD surface, while maintaining the perfect in-focus state.

[0129] What are significant are "without changing the distance between the subject plane and the CCD surface" and "while maintaining the perfect in-focus state." For example, a person who holds a camera can move away from a subject to make the image formed on the CCD surface smaller, whereas this does not apply to a change in magnification since the distance between the subject plane and the CCD surface varies.

[0130] FIG. **8**B shows an example where the focal length of the lens **94** is changed from f to f' with a change in magnification by definitions 1 and 2. Changing the focal length moves the principle point **97** of the lens **94**. The straight line that connects the vertex V of the subject **90** and the vertex v' of the subject image formed on the imaging area of the CCD **97** passes the principle point **97** of the lens **94** after the focal length is changed. The distance between the subject **90** and the CCD **96** is the same as in FIG. **8**A, i.e., is in perfect focus in terms of definition 1.

[0131] Here, the height of the subject image formed on the imaging area of the CCD **96** varies from y to y' (>y), so that the magnification is changed into m=y'/Y. The angle of view is also changed from ω to ω' (>ω). It should be noted that in actual cameras, a zoom lens is composed of a combination of two or more lenses. The distances between the lenses and the distances from the respective lenses to the CCD surface are adjusted to adjust the focal length and the position of the principle point, thereby changing the magnification.

[0132] It is known that lens distortion or distortion aberration to be corrected depends on the angle of view ω. This property is described in "KOGAKU NYUMON (User Engineer's Guide to Optics)" KISHIKAWA Toshio, Optronics Books, 1990. For a single-focus lens which is incapable of changing its focal length and thus makes no change in the angle of view, it is only necessary that a single lens distortion function pair be prepared and registered in the profile database **40**. With a zoom lens, on the other hand, it is necessary to determine lens distortion function pairs (f_i, f_i^{-1}) at various angles of view θ_i by changing the magnification while maintaining the perfect in-focus state, and register them in the profile database **40**.

[0133] FIGS. **9**A and **9**B are diagrams for explaining lens distortion function pairs to be stored in the profile database **40**. FIG. **9**A shows the structure of the database on lens distortion function pairs for a single-focus lens. With a single-focus lens, the profile database **40** contains a table **42** in which the model names of cameras are stored in association with respective lens distortion function pairs. Here, the model name A is associated with a lens distortion function pair (f_A, f_A^{-1}), and the model name B a lens distortion function pair (f_B, f_B^{-1}).

[0134] FIG. **9**B shows the structure of the database on lens distortion function pairs for a zoom lens. With a zoom lens, the profile database **40** contains a table **44** in which the model names of cameras are stored in association with the diagonal lengths of the CCDs of the cameras and pointers to lens distortion function pair tables. Here, the model name A is associated with a diagonal length d_A and a pointer to a lens distortion function pair table **46**.

[0135] The lens distortion function pair table **46** is one for situations where the zoom lens of the camera having the model name A is changed in magnification. Labeling the angles of view with i, the lens distortion function pair table **46** contains labels i, the angles of view θ_i, and lens distortion function pairs (f_i, f_i^{-1}) in association with one another. This lens distortion function pair table **46** may contain the lens distortion function pairs (f_i, f_i^{-1}) in association with focal lengths or zoom magnifications instead of the angles of view. In that case, the diagonal lengths d of the CCDs need not be stored in the database since a lens distortion function can be selected uniquely based on the focal length even without arithmetically calculating θ, to select the lens distortion function pairs.

[0136] FIG. **10** is a flowchart for explaining the steps by which the electronic watermark extracting apparatus **200** creates the profile database **40**.

[0137] The profile creation unit **38** initializes a variable i to 0, and determines the value of a constant M by the equation M=(Max−Min)/r (S**200**). Here, Min and Max are the minimum magnification and maximum magnification of the zoom lens, respectively, and r is the minimum unit of change in magnification. For a single-focus lens, M=0.

[0138] The capturing unit **30** captures a lattice pattern image R (S**202**). FIG. **11** is a diagram for explaining the lattice pattern image R to be used as a calibration pattern. For example, the lattice pattern image R has a checkered pattern, consisting of checks having a size of L×L pixels. The lattice size L of the lattice patterned image R is about the same as the block size N of the watermark according to the block embedding method employed by the electronic watermark embedding apparatus **100**. For example, when the block size N is eight, the lattice size L may be eight or so. It should be noted that the block size N shall be set uniformly throughout this electronic watermark system, or be notified to the electronic watermark extracting apparatus **200** in some way in advance.

[0139] The lattice pattern image R is captured under the following condition:

[0140] [Capturing Condition]

[0141] (1) The image of the lattice pattern image R formed on the CCD surface has a height equal to the diagonal length d of the CCD, an inherent value of the capturing apparatus. In other words, the lattice pattern image R is imaged on the entire CCD surface so that the lattice pattern image R is displayed on the entire display screen of the capturing apparatus.

[0142] (2) The plane that includes the lattice pattern image R is in perfect focus in terms of definition 1.

[0143] When capturing the lattice pattern image R with a camera, it is difficult to capture the image from exactly right above. There occurs some perspective distortion due to deviations of the optical axis. Then, processing for correcting the perspective distortion is performed initially.

[0144] The perspective distortion function calculation unit **80** detects the imaging positions of the intersections in the lattice pattern of the captured image of the lattice pattern image R (S**204**). Suppose that the number of intersections in the lattice pattern detected is N, and the coordinates of the respective intersections are (X_k, Y_k) (k=0, . . . , N−1).

[0145] Next, the perspective distortion function calculation unit **80** determines pattern positions (m_k, n_k) on the lattice pattern image R (k=0, . . . , N−1) corresponding to the detected intersections (X_k, Y_k) (k=0, . . . , N−1), respectively (S**206**). The pattern positions (m_k, n_k) show the coordinates of the intersections in the lattice pattern on the distortion-free lattice pattern image R. Since the lattice arrangement of the lattice pattern image R is known in advance, it is easily possible to determine the pattern positions (m_k, n_k) corresponding to the coordinates (X_k, Y_k) of the intersections on the captured image of the lattice pattern image R.

[0146] The perspective distortion function calculation unit **80** calculates a perspective distortion function g based on the relationship between the positions (X_k, Y_k) of the intersections on the captured image of the lattice pattern image R and the corresponding pattern positions (m_k, n_k) (S**208**). Here, the perspective distortion function g is determined not by using all the intersections but by using only intersections lying near the center of the captured image of the lattice pattern image R. For example, a fourth of all the intersections are used as the intersections lying near the center. The reason for this is that the areas closer to the center are less susceptible to lens distortion, and the perspective distortion function g can thus be determined more accurately.

[0147] It is known that the imaging positions (X_k, Y_k) of the intersections on the captured image of the lattice pattern image R and the corresponding pattern positions (m_k, n_k) have the following relationship. This property is described in "GAZO RIKAI, 3JIGEN-NINSHIKI NO SURI (Image Understanding: A Mathematical Approach to 3D Recognition)" KANAYA Ken'ichi, Morikita Shuppan, 1990.

$$X_k=(cm_k+dn_k+e)/(am_k+bn_k+1), \text{ and}$$

$$Y_k=(fm_k+gn_k+h)/(am_k+bn_k+1).$$

[0148] Given pairs of corresponding points $\{(X_k, Y_k)\}$ and $\{(m_k, n_k)\}$, where k=0, . . . , (N−1)/4, the coefficients a to h in the foregoing equations are determined by using a least-square method as follows:

$$J=\Sigma_{k=0}^{(N-1)/4}\{(X_k(am_k+bn_k+1)-(cm_k+dn_k+e))^2+(Y_k(am_k+bn_k+1)-(fm_k+gn_k+h))^2\}\rightarrow\min.$$

[0149] The coefficients a to h that minimize J can be determined by solving the foregoing equation for $\partial J/\partial a=0, \ldots, \partial J/\partial h=0$.

[0150] Consequently, the perspective distortion function g for mapping the pattern positions (m_k, n_k) onto the reference positions (X_k', Y_k') of the intersections on the captured image of the lattice pattern image R is determined:

$$(X_k', Y_k')=g(m_k, n_k), \text{ where } k=0, \ldots, N-1$$

[0151] Next, processing for determining a lens distortion function pair is performed based on the perspective distortion function g calculated. The lens distortion function pair calculation unit **82** maps all the pattern positions (m_k, n_k) (k=0, . . . , N−1) by using the calculated perspective distortion function g, thereby determining the reference positions (X_k', Y_k') (k=0, . . . , N−1).

[0152] The imaging positions (X_k, Y_k) of the intersections on the captured image of the lattice pattern image R are off the original positions due to both perspective distortion and lens distortion. Meanwhile, the reference positions (X_k', Y_k') onto which the pattern positions (m_k, n_k) are mapped by using the perspective distortion function g are off the original positions due to the perspective distortion alone. That is, the deviations between the reference positions (X_k', Y_k') and the imaging positions (X_k, Y_k) of the intersections on the captured image are ascribable to the lens distortion. The relationship therebetween can thus be examined to determine the lens distortion correction function f_i for resolving the lens distortion.

[0153] Based on the pairs of corresponding points $\{(X_k', Y_k')\}$ and $\{(X_k, Y_k)\}$ (k=0, . . . , N−1), the lens distortion function pair calculation unit **82** calculates the lens distortion correction function f_i (S**210**) by the following polynominal equations:

$$X_k'=a_1X_k^4+b_1X_k^3Y_k+c_1X_k^2Y_k^2+d_1X_kY_k^3+e_1Y_k^4+g_1X_k^3+h_1X_k^2Y_k+i_1X_kY_k^2+j_1Y_k^3+k_1X_k^2+l_1X_kY_k+m_1Y_k^2+n_1X_k+o_1Y_k+p_1,$$

and

$$X_k=a_2X_k^4+b_2X_k^3Y_k+c_2X_k^2Y_k^2+d_2X_kY_k^3+e_2Y_k^4+g_2X_k^3+h_2X_k^2Y_k+i_2X_kY_k^2+j_2Y_k^3+k_2X_k^2+l_2X_kY_k+m_2Y_k^2+n_2X_k+o_2Y_k+p_2.$$

[0154] Here, the coefficients a_1 to p_1 and a_2 to p_2 are calculated by a least-square method as follows:

$$J=\Sigma_{k=0}^{N-1}[(X_k-a_1X_k^4+b_1X_k^3Y_k+c_1X_k^2Y_k^2+d_1X_kY_k^3+e_1Y_k^4+g_1X_k^3+h_1X_k^2Y_k+i_1X_kY_k^2+j_1Y_k^3+k_1X_k^2+l_1X_kY_k+m_1Y_k^2+n_1X_k+o_1Y_k+p_1))^2+((Y_k-a_2X_k^4+b_2X_k^3Y_k+c_2X_k^2Y_k^2+d_2X_kY_k^3+e_2Y_k^4+g_2X_k^3+h_2X_k^2Y_k+i_2X_kY_k^2+j_2Y_k^3+k_2X_k^2+l_2X_kY_k+m_2Y_k^2+n_2X_k+o_2Y_k+p_2))^2]\rightarrow\min.$$

[0155] Consequently, the lens distortion correction function f_i for expressing the relationship between the positions (X_k, Y_k) of the intersections on the captured image and the reference positions (X_k', Y_k') is obtained. Then, since the image correction requires two-way calculations, the lens distortion function f_i^{-1}, or an approximate inverse function of the lens distortion correction function f_i, is also determined. As is the case with the lens distortion correction function f_i, the lens distortion function f_i^{-1} is calculated by using a least-square method.

$(X_k', Y_k')=f_i(X_k, Y_k)$, where $k=0, \ldots, N-1$, and

$(X_k, Y_k)=f_i^{-1}(X_k', Y_k')$, where $k=0, \ldots, N-1$.

[0156] FIG. **12** is a diagram for explaining a lens distortion function pair (f_i, f_i^{-1}). In general, captured images are deformed in a barrel shape or pincushion shape due to lens distortion. An image **300** having lens distortion ascribable to capturing is transformed into an image **310** having no lens distortion by the lens distortion correction function f_i. Conversely, the image **310** having no lens distortion is transformed into the lens-distorted image **300** by the lens distortion function f_i^{-1}.

[0157] Return now to FIG. **10**. The lens distortion function pair calculation unit **82** determines the angle of view θ_j employed at the time of capturing from the focal length f_i and the diagonal length d of the CCD surface (S**212**) by using the following equation. If the captured image of the lattice pattern image R is provided in EXIF (Exchangeable Image File Format), the focal length f_i at the time of capturing can be acquired from the EXIF information included in the image data:

$$\theta_i=\tan^{-1}(d/2f_i).$$

[0158] The lens distortion function pair registration unit **84** registers the lens distortion function pair (f_i, f_i^{-1}) into the profile database **40** (S**214**) in association with the angle of view θ_i (S**214**).

[0159] The variable i is incremented by one (S**216**). If the variable is smaller than M (Y at S**218**), the processing returns to step S**202**. The lattice pattern image R is captured again with a zoom magnification of the next level, followed by the processing of calculating the perspective distortion function g and the lens distortion function pairs (f_i, f_i^{-1}). If the variable i is not smaller than M (N at S**218**), the processing for creating the profile database **40** ends.

[0160] Consequently, in the case of a single-focus lens, a single lens distortion function pair (f, f_i^{-1}) is registered in the profile database **40**. With a zoom lens, the angles of view θi and the lens distortion function pairs (f_i, f_i^{-1}) at respective magnifications are registered in the profile database **40** in association with each other.

[0161] Description will now be given of the steps by which the electronic watermark extracting apparatus **200** having the foregoing configuration extracts an electronic watermark.

[0162] FIG. **13** is a flowchart showing the overall flow of the steps for extracting an electronic watermark. The capturing unit **30** captures a printed image P (S**10**). The image correction unit **34** initializes the number of corrections "counter" so that counter=0 (S**12**).

[0163] The image correction unit **34** performs image correction processing to be detailed later on the image of the printed image P captured by the capturing unit **30** (S**14**). Hereinafter, distorted images to be corrected will be referred to as "correction object images." Distortion-free images to be the targets of the correction will be referred to as "correction target images." In the image correction processing S**14**, coordinates (i, j) on the correction target image are transformed into coordinates (x_{ij}, Y_{ij}) on the correction object image by using a lens distortion function stored in the profile database **40**. Luminance values in the respective coordinates (x_{ij}, y_{ij}) are then determined by bi-linear interpolation or the like, and set as the luminance values in the original coordinates (i, j) on the correction target image.

[0164] The image area determination unit **32** determines the original image area **20** in the captured image whose distortion is corrected by the image correction unit **34** (S**15**). The watermark extraction unit **36** performs processing for detecting watermark information X from the original image area determined by the image area determination unit **32** (S**16**). This watermark detection processing is performed by detecting watermark bits from the original image area **20** in units of blocks. The watermark extraction unit **36** checks if significant watermark information X is obtained, thereby determining whether a watermark is detected successfully or not (S**18**).

[0165] If a watermark is detected successfully (Y at S**18**), the processing ends. If the watermark detection fails (N at S**18**), the number of corrections counter is incremented by one (S**20**). The processing returns to step S**14** to repeat the image correction processing and try watermark detection again. Here, thresholds and other parameters are adjusted to select a lens distortion function from the profile database **40** again before the image correction processing is performed to retry the watermark detection. The number of corrections counter is incremented while the image correction processing and the watermark detection processing are repeated until a watermark is detected successfully.

[0166] FIG. **14** is a flowchart for showing a general flow of the image correction processing S**14** of FIG. **13**. The image correction unit **34** acquires the image size (W', H') of the correction object image, assuming that the entire captured image of the printed image P as the correction object image (S**30**). Next, the image correction unit **34** sets the image size (W, H) of the correction target image (S**32**). The distortion correction will eventually transform the captured image into an image having W pixels in the horizontal direction and H pixels in the vertical direction.

[0167] The lens distortion function pair selection unit **86** of the image correction unit **34** makes an inquiry to the profile database **40**, thereby acquiring the lens distortion function pair corresponding to the angle of view employed at the time of capturing (S**34**). The lens distortion correction processing unit **88** performs image correction main processing by using the lens distortion function acquired by the lens distortion function pair selection unit **86** (S**38**).

[0168] FIG. **15** is a flowchart showing the detailed steps for selecting a lens distortion function pair at S**34** of FIG. **14**.

Samsung Exhibit 1002, Page 285 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

Initially, the lens distortion function pair selection unit **86** determines if the lens of the camera used for capturing is a zoom lens (S**50**). This determination can be made depending on whether or not the EXIF information included in the correction object image contains any item pertaining to the focal length.

[**0169**] If not a zoom lens (N at S**50**), the lens distortion function pair selection unit **86** acquires the model name of the camera used for capturing from the EXIF information on the correction object image. The lens distortion function pair selection unit **86** makes an inquiry to the profile database **40** with the model name as a key, acquires the lens distortion function pair associated with the model name (S**52**), and ends the processing.

[**0170**] If a zoom lens (Y at S**50**), the lens distortion function pair selection unit **86** calculates the angle of view θ from the EXIF information included in the correction object image (S**54**). The angle of view θ is calculated on the assumption that the following precondition holds:

[**0171**] [Precondition]

[**0172**] The subject is in perfect focus.

[**0173**] That is, pictures out of focus can cause errors when corrected. Under the foregoing precondition, the lens distortion function pair selection unit **86** acquires the diagonal length d of the CCD of the camera from the profile database **40**, and acquires the capturing focal length f from the EXIF information of the correction object image. The lens distortion function pair selection unit **86** then calculates the angle of view θ by the following equation:

$$\theta=\tan^{-1}(d/2f).$$

[**0174**] The lens distortion function pair selection unit **86** searches the profile database **40** with the model name obtained from the EXIF information and the angle of view θ calculated at step S**54** as a key. The lens distortion function pair selection unit **86** thereby selects the lens distortion function pair (f_i, f_i^{-1}) corresponding to a label i that minimizes the difference $|\theta-\theta_i|$ between the angle of view θ_i registered in the profile database **40** and the angle of view θ calculated (S**58**), and ends the processing.

[**0175**] Hereinafter, a lens distortion function pair that the lens distortion function pair selection unit **86** thus acquires from the profile database **40** will be denoted as (F, F^{-1}).

[**0176**] FIG. **16** is a flowchart showing the detailed steps of the image correction main processing S**38** of FIG. **14**. The lens distortion correction processing unit **88** initializes the y-coordinate value j of the correction target image to 0 (S**80**). Next, it initializes the x-coordinate value i of the correction target image to 0 (S**82**).

[**0177**] The lens distortion correction processing unit **88** maps a point P(i, j) in the correction target image onto a point $Q(x_{ij}, y_{ij})$ in the correction object image (S**86**) by using the lens distortion function F^{-1}:

$$(x_{ij}, y_{ij})=F^{-1}(i, j).$$

[**0178**] FIG. **17** is a diagram for explaining how a point in a correction target image is mapped onto a point in a correction object image. A correction target image **320** is an image having no lens distortion. A correction object image **340** is a lens-distorted image. The point P(i, j) in the correction target image **320** is mapped onto the point $Q(x_{ij}, y_{ij})$ in the correction object image **340** by the lens distortion function F^{-1}.

[**0179**] The lens distortion correction processing unit **88** calculates the luminance value $L(x_{ij}, y_{ij})$ at the point $Q(x_{ij}, y_{ij})$ by interpolating the luminance values of peripheral pixels by using a bi-linear interpolation method or the like. The luminance value $L(x_{ij}, y_{ij})$ calculated is set as the luminance value at the point P(i, j) of the correction target image (S**88**).

[**0180**] FIG. **18** is a diagram for explaining the method of calculating the luminance value $L(x_{ij}, y_{ij})$ at the point $Q(x_{ij}, y_{ij})$ which is mapped by the lens distortion function F^{-1}. Suppose that four pixels p, q, r, and s lie in the vicinity of the point $Q(x_{ij}, y_{ij})$, and have coordinates (x', y'), (x', y'+1), (x'+1, y'), and (x'+1, y'+1), respectively. The feet of perpendiculars drawn from the point Q to the sides pr and qs will be represented by points e and f, respectively. The feet of perpendiculars drawn from the point Q to the sides pq and rs will be represented by points g and h, respectively.

[**0181**] The point Q is one that divides the segment ef at an internal division ratio of v:(1−v), and divides the segment gh at an internal division ratio of w:(1−w). The luminance value $L(x_{ij}, y_{ij})$ at the point Q is determined from the luminance values L(x', y'), L(x', y'+1), L(x'+1, y'), and L(x'+1, y'+1) at the four points p, q, r, and s by bi-linear interpolation as shown by the following equation:

$$L(x_{ij}, y_{ij})=(1-v)\times\{(1-w)\times L(x', y')+w\times L(x'+1, y')\}+v\times\{(1-w)\times L(x', y'+1)+w\times L(x'+1, y'+1)\}.$$

[**0182**] While the luminance value at the point Q is determined by interpolating the luminance values of four pixels nearby, the method of interpolation is not limited thereto. More than four pixel points may be also used for interpolation.

[**0183**] Referring to FIG. **16**, after the processing of step S**88**, the x-coordinate value i is incremented by one (S**90**). If the x-coordinate value i is smaller than the width W' of the correction object image (N at S**92**), the processing returns to step S**86**. The processing for determining the luminance value of a pixel is thus repeated while increasing the coordinate value in the x-axis direction.

[**0184**] If the x-coordinate value i reaches or exceeds the width W' of the correction object image (Y at S**92**), it means that the luminance values of the pixels at the current y-coordinate value j are obtained through the x-axis direction. The y-coordinate value j is then incremented by one (S**94**). If the y-coordinate value j reaches or exceeds the height H' of the correction object image (Y at S**96**), the processing ends since the luminance values are obtained of all the pixels of the correction target image. If the y-coordinate value j is smaller than the height H' of the correction object image (N at S**96**), the processing returns to step S**82**. The x-coordinate value is thus initialized to zero again, and the processing for determining the luminance value of a pixel is repeated while the coordinate value is increased in the x-axis direction under the new y-coordinate value j.

[**0185**] FIG. **19** is a flowchart showing the detailed steps of the image area determination processing S**15** of FIG. **13**. The image area determination unit **32** extracts feature points from the image whose lens distortion is corrected by the image correction unit **34**, and calculates an image size (w, h) (S**120**).

Samsung Exhibit 1002, Page 286 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

[0186] FIG. **20** is a diagram for explaining how feature points are extracted from a lens-distortion-corrected image **350**. A correction target image **322** of the diagram corresponds to the original image area **20** of the lens-distortion-corrected image **350**, and has a size of W in width and H in height. The image area determination unit **32** detects vertexes at the four corners of the original image area **20** and points on each side, which are shown by dots, as feature points of the lens-distortion-corrected image **350**. Since its lens distortion is eliminated by the image correction unit **34**, the lens-distortion-corrected image **350** has four sides of straight shape which can be detected easily by edge extraction processing or the like. The coordinate values of the vertexes at the four corners, or (x0, y0), (x1, y1), (x2, y2), and (x3, y3), can be determined accurately from the rows of feature points detected. Using the coordinate values of these vertexes at the four corners, the width w and the height h of the original image area **20** can be calculated by the following equations:

$$w=x2-x0=x3-x1, \text{ and}$$

$$h=y1-y0=y3-y2.$$

[0187] The image area determination unit **32** initializes the y-coordinate value j of the correction target image to 0 (S**122**). Next, it initializes the x-coordinate value i of the correction target image to 0 (S**124**).

[0188] The image area determination unit **32** maps a point P(i, j) in the correction target image onto a point $Q(x_{ij}, y_{ij})$ in the lens distortion corrected image as shown in FIG. **20** (S**126**) by the following equations:

$$x_{ij}=i\times w/(W-1)+x0, \text{ and}$$

$$y_{ij}=j\times h/(H-1)+y0.$$

[0189] The image area determination unit **32** calculates the luminance value $L(x_{ij}, y_{ij})$ at the point $Q(x_{ij}, y_{ij})$ by interpolating the luminance values of peripheral pixels by using a bi-linear interpolation method or the like. The luminance value $L(x_{ij}, y_{ij})$ calculated is set as the luminance value at the point P(i, j) of the correction target image (S**128**).

[0190] The image area determination unit **32** increments the x-coordinate value i by one (S**130**). If the x-coordinate value i is smaller than the width W of the correction target image (N at S**132**), the image area determination unit **32** returns to step S**126**. The processing for determining the luminance value of a pixel is thus repeated while increasing the coordinate value in the x-axis direction.

[0191] If the x-coordinate value i reaches or exceeds the width W of the correction target image (Y at S**132**), it means that the luminance values of the pixels at the current y-coordinate value j are obtained through the x-axis direction. The y-coordinate value j is then incremented by one (S**134**). If the y-coordinate value j reaches or exceeds the height H of the correction target image (Y at S**136**), the processing ends since the luminance values are obtained of all the pixels of the correction target image. If the y-coordinate value j is smaller than the height H of the correction target image (N at S**136**), the processing returns to step S**124**. The x-coordinate value is thus initialized to zero again, and the processing for determining the luminance value of a pixel is repeated while the coordinate value is increased in the x-axis direction under the new y-coordinate value j.

[0192] Description will now be given of a modification of the present embodiment. When selecting a lens distortion function pair at S**34** of FIG. **15**, it is actually rare for the precondition that the subject is in perfect focus to hold. The angle of view θ calculated at step S**54** thus has some errors. Errors can also occur during the calculation of the lens distortion function. Due to these system errors, selecting a lens distortion function pair corresponding to the calculated angle of view θ from the profile database **40** does not necessarily ensure that the selected lens distortion function pair is optimum one. For this reason, the method of making an inquiry to the profile database **40** by using the calculated angle of view θ as a key is selected from between the following two, depending on system requirements and the method of embedding electronic watermarks:

[0193] [Method of Selection for a Speed-Priority System]

[0194] This method applies when the foregoing system errors are allowable. To give priority to the processing speed, simply select the lens distortion function pair (f_i, f_i^{-1}) corresponding to a label i that minimizes the difference $|\theta-\theta_i|$ between the angle of view θ_i registered in the profile database **40** and the angle of view θ calculated, similarly to step S**58** shown in FIG. **15**.

[0195] [Method of Selection for a Precision-Priority System]

[0196] This method applies when the system errors are not allowable. With reference to the angle of view θ calculated, acquire a plurality of lens distortion function pairs as candidates from the profile database **40**. Pre-evaluate which of the lens distortion function pairs can best correct the image, and then select the lens distortion function pair of the highest evaluation.

[0197] For example, the method of selection for a speed-priority system is used when the size N of the watermark embedded blocks is large and the system errors have only a small impact. The method of selection for a speed-priority system is used when the size N of the watermark embedded blocks is small and the system errors have a significant impact. Alternatively, either of the methods may be specified depending on the characteristics of applications to which the present invention is applied. For example, in entertainment applications, the speed-priority method is selected since the response rate has a higher priority than the watermark detection rate. In the meantime, examples of applications for which the precision-priority method is selected include a ticket authentication system.

[0198] FIG. **21** is a flowchart for showing the detailed steps for selecting a lens distortion function pair (S**34**), where the method of selection for a speed-priority system and the method of selection for a precision-priority system can be switched. Description will be given only of differences from FIG. **15**. The lens distortion function pair selection unit **86** determines whether priority is given to speed or not (S**56**). For example, the lens distortion function pair selection unit **86** selects either one of the speed-priority method and the precision-priority method automatically, depending on the size N of the watermark embedding blocks. Alternatively, either one of a speed-priority mode and a precision-priority mode may be specified by the user.

[0199] If priority is given to speed (Y at S56), step S58 is executed as in FIG. 15. If priority is not given to speed (N at S56), pre-evaluation is performed on correction functions (S60)

[0200] FIG. 22 is a flowchart showing the detailed steps for the pre-evaluation on correction functions at S60 of FIG. 21. The lens distortion function pair selection unit 86 acquires lens distortion correction functions f_j (j=0, 1, . . . , N−1) corresponding to N successive labels across a label i as candidates (S62). Here, the label i is one that minimizes the difference $|\theta-\theta_j|$ between the angle of view θ_j registered in the profile database 40 and the angle of view θ calculated.

[0201] M feature points are defined on the correction object image, and a row of P sample points (X_m, Y_m) (m=0, 1, . . . , P−1) are acquired between the feature points of the correction object image (S64). For example, when the correction object image is an oblong rectangular in shape, the feature points are the vertexes at the four corners. The row of sample points includes points sampled on each of the sides which connect the adjoining vertexes. Here, the row of sample points shall include the feature points lying on both ends. That is, both (X_0, Y_0) and (X_{P-1}, Y_{P-1}) are feature points. In another example, a row of points on the edge of an object in the correction object image, such as a personal figure, may be acquired as the row of sample points. For example, a row of sample points may be defined on the outline of a person's face or eye.

[0202] The number of sample points P is determined with reference to the lattice size L of such a lattice pattern image R as a checker pattern. For example, L takes on such values as 16 and 32. Since a row of sample points is determined between two feature points selected from among M feature points, the maximum possible number of combinations of feature points is ${}_MC_2$. These combinations are not applicable unless the lines connecting the feature points form a known shape.

[0203] The variable j is initialized to zero (S66). The row of sample points (X_m, Y_m) (m=0, 1, . . . , P−1) are mapped by the lens distortion correction function f_j (S68). The row of sample points mapped by the lens distortion correction function f_j shall be denoted as (X_m^j, Y_m^j) (m=0, 1, . . . , P−1):

$$(X_m^j, Y_m^j)=f_j(X_m, Y_m), \text{ where } m=0, 1, \ldots, P-1.$$

[0204] Next, a Bezier curve H' of qth order is calculated with the row of mapped sample points (X_m^j, Y_m^j) (m=0, 1, . . . , P−1) as control points (S70). The order q is determined depending on what kind of line the row of sample points between the feature points are supposed to fall on if without lens distortion. When the correction target image is an oblong rectangular and the feature points are the vertexes at the four corners, the row of sample points between the feature points are supposed to fall on the sides of the oblong rectangular. In this case, the order is determined to be q=1. By the definition of Bezier curves, a Bezier curve of first order forms a straight line which connects between feature points.

[0205] The sum D_j of errors between the calculated Bezier curve and the control points is calculated (S72) by the following equation:

$$D_j=\Sigma_{m=0}^{P-1}[(Y_m^j-(H'(X_m^j))^2].$$

The foregoing equation is one for evaluating approximation errors of the Bezier curve when sampled in the x direction.

[0206] FIGS. 23A to 23C are diagrams for explaining how approximation errors of a Bezier curve are evaluated. FIG. 23A shows five sample points. FIG. 23B shows a row of sample points of FIG. 23A mapped by a lens distortion correction function f_j. FIG. 23C shows the state where a Bezier curve of q=1, i.e., a straight line is applied to the row of mapped sample points. The sample points have errors d_{j0} to d_{j4}, respectively. The sum D_j of errors is given by $D_j=d_{j0}+d_{j1}+d_{j2}+d_{j3}+d_{j4}$.

[0207] Return now to FIG. 22. The variable j is incremented by one (S74). If j is smaller than N (Y at S76), the lens distortion function pair selection unit 86 returns to step S68 and performs the processing for calculating the sum D_j of errors as to the next lens distortion correction function f_j. If j is not smaller than N (N at S76), the lens distortion function pair selection unit 86 selects the lens distortion function pair (f_j, f_j^{-1}) corresponding to a label j that minimizes the sum D_j of errors (j=0, 1, . . . , N−1) (S78), and ends the processing.

[0208] FIG. 24 is a flowchart showing the detailed steps for acquiring a row of sample points between feature points at S64 of FIG. 22. For example, the following description will deal with a method in which the image frame of the correction object image, i.e., the original image area 20 is detected to extract a row of sample points.

[0209] Initially, at step S40, a threshold T intended for edge determination is set. Here, the threshold T is given by T=T0−counter×Δ. As can be seen from the flowchart of FIG. 13, counter is the number of corrections. T0 is the threshold for the first correction. That is, each time the number of corrections increases, the threshold T is decreased by Δ and the processing of steps S14, S15, and S16 of FIG. 13 is performed.

[0210] For example, suppose that a pixel A lying at the end of a margin has a luminance value of 200, a pixel B lying at the end of the original image area 20 next to the foregoing pixel A has a luminance value of 90, T0 is 115, and Δ is 10. When a difference between the luminance values of the pixels A and B is greater than the threshold T, the pixels A and B shall be determined to have an edge therebetween. In the first correction (counter=0), the pixels A and B are determined not to have an edge therebetween since the difference between the luminance values is 110 and the threshold T is 115. In the second correction (counter=1), however, the pixels A and B are determined to have an edge therebetween since the threshold T falls to 105.

[0211] Next, at step S42, the image correction unit 34 performs edge detection processing. Here, the luminance difference between adjoining pixels is compared with the threshold T set at step S40, and if the difference is greater, the corresponding pixel is considered as an edge. FIG. 25A is a diagram for explaining how the edge detection processing is performed on the original image area 20. The coordinate system has an x-axis in the horizontal direction and a y-axis in the vertical direction, with the top left vertex of the captured area 26 as the point of origin. The original image area 20 shown hatched has four vertexes A, B, C, and D at coordinates (X0, Y0), (X1, Y1), (X2, Y2), and (X3, Y3), respectively. Starting from a point E((X0+X2)/2, 0) on the x-axis, pixels are scanned in the y-axis direction. If the luminance values of two pixels adjoining in the y-axis direction have a difference greater than the threshold T, the

border between the two pixels is determined to be an edge. Then, starting from that point, pixels are scanned to the right and to the left in the x-axis direction, thereby searching for locations where a difference between the luminance values of two pixels adjoining in the y-axis direction exceeds the threshold T likewise. This detects the horizontal edges of the original image area **20**.

[**0212**] Vertical edges are also detected likewise. Starting from a point F(0, (Y0+Y1)/2) on the y-axis, pixels are scanned in the x-axis direction. Locations where a difference between the luminance values of two pixels adjoining in the x-axis direction exceeds the threshold T are thus searched for, thereby detecting vertical edges of the original image area **20**.

[**0213**] It should be noted that the foregoing has dealt with the case where the vertical or horizontal edges of the original image area **20** are detected based on a difference between the luminance values of two pixels adjoining in the y-axis or x-axis direction. Instead, edges may be detected by using edge detection templates. For example, edges may be detected based on the results of comparison between matching calculations obtained by using a Prewitt edge detector and a threshold T.

[**0214**] Note that the threshold T decreases from the initial value **T0** as the number of corrections counter increases in value. The criterion for edge detection thus relaxes gradually with the increasing number of corrections. Extracting edges by using higher thresholds T can sometimes fail to detect edges properly due to noise in the captured image. In such cases, the value of the threshold T is lowered to detect edges with a relaxed criterion.

[**0215**] Returning to FIG. **24**, the image correction unit **34** determines the number of samples N for making a curve approximation to each of the sides of the original image area **20**. For example, N is set so that N=Nmin+counter×N0. Here, Nmin is a value to be determined depending on the order of the spline curve, and N0 is a constant. As the number of corrections counter increases, the number of samples N increases. This enhances the approximation accuracy on each side. The image correction unit **34** selects sample points as many as the fixed parameter N from among a row of edge-points detected at step **S42**, and makes a spline approximation to each side of the original image area **20** (**S46**). A row of sample points are obtained by sampling the points on the spline curve determined thus. Alternatively, the N sample points or control points of the spline curve may be used simply as a row of sample points.

[**0216**] FIG. **25**B is a diagram for explaining the spline approximation to each side of the original image area **20**. Sides **71**, **72**, **73**, and **74** of the original image area **20** are each approximated, for example, with a cubic spline curve $a_i x^3+b_i x^2+c_i x+d$ by using three points on each side and two vertexes on both ends as the sample points. Here, the spline curve has four parameters, and Nmin is set so that Nmin=2. As the number of corrections increases, the image correction unit **34** may increase the number of samples N and the order of the spline curve as well. The order can be increased to obtain more accurate shapes of the respective sides of the original image area **20** on the captured printed image P.

[**0217**] As has been described, according to the electronic watermark extracting apparatus **200** of the present embodiment, lens distortion function pairs for respective angles of view are prepared in the database in advance. Then, lens distortion is corrected by using a lens distortion function pair corresponding to the angle of view employed at the time of capturing. The distortion occurring in the image can thus be corrected with high precision, which can increase the frequency of detection of electronic watermarks.

[**0218**] The angle of view calculated and the lens distortion correction functions registered contain some errors, whereas the lens distortion correction functions can be pre-evaluated to select more suitable lens distortion correction functions. Moreover, whether or not to make a pre-evaluation on the lens distortion correction functions can be determined depending on the size of the embedded blocks of electronic watermarks. Since image distortion can thus be corrected with precision suited to the tolerance of the electronic watermarks for image distortion, it is possible to avoid needless distortion correction processing while maintaining the detection accuracy of the watermarks.

Second Embodiment

[**0219**] The first embodiment has been dealt with the case of performing a lens distortion correction alone, on the assumption that the correction object image has no perspective distortion or the effect of perspective distortion is as small as negligible. In the second embodiment, in contrast, the perspective distortion of the correction object image will also be corrected. Since the rest of the configuration and operation are the same as in the first embodiment, description will be given only of differences from the first embodiment.

[**0220**] FIG. **26** is a block diagram showing the electronic watermark extracting apparatus **200** according to the second embodiment. In the electronic watermark extracting apparatus **200** according to the first embodiment shown in FIG. **4**, the image correction unit **34** corrects the lens distortion of the captured image before the image area determination unit **32** cuts out the original image area **20** from the lens-distortion-corrected image. The present embodiment, on the other hand, is configured without the image area determination unit **32**. The reason for this is that the image correction unit **34** also performs the processing of cutting out the original image area **20** while performing correction processing on perspective distortion. Consequently, in the present embodiment, the image correction unit **34** supplies the lens- and perspective-distortion-corrected original image area **20** to the watermark extraction unit **36** directly. The watermark extraction unit **36** then extracts watermark information X embedded in the distortion-corrected original image area **20**.

[**0221**] FIG. **27** is a diagram for explaining the detailed configuration of the profile creation unit **38** and the image correction unit **34** according to the second embodiment. The profile creation unit **38** has the same configuration as that of the profile creation unit **38** of the first embodiment shown in FIG. **7**.

[**0222**] The image correction unit **34** according to the present embodiment includes a lens distortion function pair selection unit **86**, a lens distortion correction processing unit **88**, a perspective distortion function calculation unit **87**, and a perspective distortion correction processing unit **89**.

[**0223**] The capturing unit **30** supplies a captured printed image P to the image correction unit **34**. The lens distortion

function pair selection unit **86** of the image correction unit **34** accepts the input of the captured image of the printed image P, and determines from the image information the angle of view θ employed at the time of capturing. The lens distortion function pair selection unit **86** then selects a lens distortion function pair (F, F^{-1}) corresponding to the angle of view θ from the profile database **40**, and supplies the lens distortion correction function F to the lens distortion correction processing unit **88**.

[**0224**] The lens distortion correction processing unit **88** corrects lens distortion occurring in the captured image by using the lens distortion function F^{-1}, and supplies the lens-distortion-corrected image to the perspective distortion function calculation unit **87**. Using the lens-distortion-corrected image, the perspective distortion function calculation unit **87** calculates a perspective distortion function G which expresses the perspective distortion of the original image area **20** in the captured image, and then supplies the calculated perspective distortion function G to the perspective distortion correction processing unit **89**.

[**0225**] The perspective distortion correction processing unit **89** corrects the perspective distortion of the original image area **20** by using the perspective distortion function G, and supplies the corrected original image area **20** to the watermark extraction unit **36**.

[**0226**] FIG. **28** is a flowchart showing the overall flow of the electronic watermark extraction steps. A difference from the electronic watermark extraction steps according to the first embodiment shown in FIG. **13** consists in that the image area determination processing S**15** for extracting the original image area **20** is not included. In other respects, the steps are the same as in the first embodiment. According to the present embodiment, the original image area **20** is extracted while the perspective distortion is corrected in the image correction processing S**14**.

[**0227**] FIG. **29** is a flowchart for showing a general flow of the image correction processing S**14** by the image correction unit **34** of the present embodiment. Differences from the image correction processing S**14** of the first embodiment shown in FIG. **14** consist in that: the selection of a lens distortion function pair (S**34**) is followed by the correction of lens distortion (S**35**); after the lens distortion is corrected, a perspective distortion function is calculated further (S**36**); and in the image correction main processing S**38**, image correction is performed by using the perspective distortion function.

[**0228**] Description will now be given of the step for correcting lens distortion at S**35**. As in the procedure described in FIG. **16** of the first embodiment, the lens distortion correction processing unit **88** performs mapping by using the lens distortion function F^{-1}, thereby correcting the lens distortion occurring in the entire correction object image.

[**0229**] FIG. **30** is a flowchart showing the detailed steps for calculating a perspective distortion function at S**36** of FIG. **29**. Using the entire captured image of the printed image P as the correction object image, the image correction unit **34** sets the number of feature points M and pattern positions (cm_k, cn_k) (k=0, 1, . . . , M−1) of the same in the correction target image (S**100**). The positions of the feature points in the correction target image shall be known. For example, when vertexes at four corners of a rectangular correction target image are set as feature points, M=4 and the feature positions fall on (0, 0), (W−1, 0), (0, H−1), and (W−1, H−1). In another example, each side of a rectangular correction target image may be marked at regular intervals for feature points. Points on the edge of such an object as a personal figure in the correction target image may be used as the feature points.

[**0230**] Based on the information on the feature points set at step S**100**, the perspective distortion function calculation unit **87** performs processing for detecting corresponding feature points in the correction object image whose lens distortion is corrected. The perspective distortion function calculation unit **87** thereby determines the imaging positions (CX_k, CY_k) (k=0, 1, . . . , M−1) of the feature points in the correction object image (S**104**). Take, for example, the case of detecting vertexes at the four corners of the correction object image, or original image area **20**, as feature points. Here, the vertexes of the original image area **20** are found by tracing the edges of the original image area **20** by using an edge filter or other techniques. Pixels near the vertexes are then Fourier-transformed to detect the phase angles for accurate positioning of the vertexes. When feature points consist of points on each side of the correction object image, the perspective distortion function calculation unit **87** performs processing for detection marks lying on the image frame of the original image area **20**.

[**0231**] The perspective distortion function calculation unit **87** calculates a perspective distortion function G from the relationship between the feature points (CX_k, CY_k) detected at step S**104** and the corresponding pattern positions (cm_k, cn_k) in the correction target image by using a least-square method (S**106**). This perspective distortion function G is calculated by the same steps as with the calculation of the perspective distortion function g at S**208** of FIG. **10**. That is, since the feature points (CX_k, CY_k) detected from the correction object image whose lens distortion is corrected are unaffected by lens distortion, deviations between the detected feature points (CX_k, CY_k) and the corresponding pattern positions (cm_k, cn_k) of the correction target image are ascribable to perspective distortion. The relationship therebetween thus satisfies the equations of the perspective distortion described in the calculation of the perspective distortion function g at S**208** of FIG. **10**. By determining the coefficients of these perspective distortion equations, the perspective distortion function calculation unit **87** can calculate the perspective distortion function G.

[**0232**] FIG. **31** is a flowchart showing the detailed steps of the image correction main processing S**38** according to the present embodiment. The perspective distortion correction processing unit **89** initializes the y-coordinate value j of the correction target image to 0 (S**80**). Next, it initializes the x-coordinate value i of the correction target image to 0 (S**82**).

[**0233**] The perspective distortion correction processing unit **89** maps a point P(i, j) of the correction target image by using the perspective distortion function G (S**84**). The point mapped by the perspective distortion function G will be denoted as Q(x_{ij}, y_{ij}):

$$(x_{ij}, y_{ij}) = G(i, j)$$

[**0234**] FIGS. **32**A to **32**C are diagrams for explaining how a point in a correction target image is mapped onto a point

in a correction object image. FIG. **32**A shows a correction target image **322** which corresponds to the original image area **20** in the captured image. The correction target image **322** has a size of W in width and H in height. FIG. **32**C shows a correction object image **342** which is a captured image having both lens distortion and perspective distortion. The entire captured area **26**, including the original image area **20**, is lens- and perspective-distorted. At step S**35** of FIG. **29**, the lens distortion correction processing unit **88** corrects the lens distortion of the correction object image **342** of FIG. **32**C by using the lens distortion function F^{-1}. This transforms the correction object image **324** into a lens-distortion-corrected image **330** of FIG. **32**B. In the lens-distortion-corrected image **330**, the lens distortion of the entire captured area **26** including the original image area **20** is eliminated, whereas the perspective distortion still remains.

[**0235**] At step S**84** of FIG. **31**, the point P(i, j) in the correction target image **322** is mapped onto the point $Q(x_{ij}, y_{ij})$ in the lens-distortion-corrected image **330** which has the perspective distortion, by using the perspective distortion function G as shown in FIG. **32**.

[**0236**] The perspective distortion correction unit **89** calculates the luminance value $L_c(x_{ij}, y_{ij})$ at the point $Q(x_{ij}, y_{ij})$ by interpolating the luminance values of peripheral pixels by a bi-linear interpolation method or the like. The luminance value $L_c(x_{ij}, y_{ij})$ calculated is set as the luminance value at the point P(i, j) of the correction target image (S**88**).

[**0237**] The x-coordinate value i is incremented by one (S**90**). If the x-coordinate value i is smaller than the width W of the correction target image (N at S**92**), the processing returns to step S**84**. The processing for determining the luminance value of a pixel is thus repeated while increasing the coordinate value in the x-axis direction.

[**0238**] If the x-coordinate value i reaches or exceeds the width W of the correction target image (Y at S**92**), it means that the luminance values of the pixels at the current y-coordinate value j are obtained through the x-axis direction. The y-coordinate value j is then incremented by one (S**94**). If the y-coordinate value j reaches or exceeds the height H of the correction target image (Y at S**96**), the processing ends since the luminance values are obtained of all the pixels of the correction target image. If the y-coordinate value j is smaller than the height H of the correction target image (N at S**96**), the processing returns to step S**82**. The x-coordinate value is initialized to zero again, and the processing for determining the luminance value of a pixel is repeated while the coordinate value is increased in the x-axis direction under the new y-coordinate value j.

[**0239**] As described above, the electronic watermark extracting apparatus **200** according to the present embodiment can utilize lens distortion correction functions to detect the position deviations of feature points ascribable to perspective distortion, and determine the perspective distortion function accurately upon each capturing. Consequently, even when an image has perspective distortion aside from lens distortion, the lens distortion and the perspective distortion can be processed separately for accurate distortion correction.

[**0240**] Up to this point, the present invention has been described in conjunction with an embodiment thereof. The foregoing embodiment has been given solely by way of illustration. It will be understood by those skilled in the art that various modifications may be made to combinations of the foregoing components and processes, and all such modifications are also intended to fall within the scope of the present invention.

[**0241**] The foregoing embodiment has deal with the case where a perspective distortion function is calculated for the purpose of correcting perspective distortion. Instead, in one modification, profile data on lattice configurations that show several patterns of perspective distortion may be stored in the profile database **40** in advance. For example, when capturing the lattice pattern image R, the optical axis is tilted in various directions and angles so that a plurality of lattice patterns having perspective distortion are captured and stored in the profile database **40** in advance. Then, during image correction, perspective distortion is corrected by using the most suitable one of the lattice patterns.

[**0242**] The foregoing description has dealt with the case where the lens distortion function pairs are registered in the profile database **40**. Nevertheless, the correspondence between the points in the correction target image and the points in the correction object image may be stored in the profile database **40** in the form of tables, not functions. In this case, the correction target image may be sectioned into lattices according to the size of the embedded blocks of the watermark. The correspondence between the lattice points alone is then stored into the profile database **40** as profile data on lens distortion.

[**0243**] In the foregoing steps of detecting a watermark, if watermark detection fails, the threshold and other parameters are adjusted and the image correction processing is repeated to retry the watermark detection. Nevertheless, if watermark detection fails or if the number of corrections exceeds a predetermined number, the image correction unit **34** may request the capturing unit **30** to capture the printed image P again.

[**0244**] The data on the lens distortion function pairs may be stored in the profile database **40** as classified by the models of capturing devices including digital cameras and scanners. The electronic watermark extracting apparatus **200** may acquire model information on the capturing device, and select and use the data on lens distortion function pairs suited to the model that is used when capturing the printed image P.

[**0245**] The foregoing embodiment has dealt with the case where image correction is performed on the original image area **20** of an image in which an electronic watermark is embedded by the "block embedding method." Nevertheless, this is just an example of embodiment of the image correction technology of the present invention. According to the configuration and processing steps described in the foregoing embodiment, it is possible to correct images in which electronic watermarks are embedded by other methods. Moreover, according to the configurations and processing steps of image correction described in the foregoing embodiment, it is possible to correct ordinary images having no electronic watermark embedded therein. For example, the image correction technology of the present invention is not limited to the correction of captured images of printed images, but may also be applied to the correction of images obtained by photographing actual subjects such as a personal figure and a landscape with a camera.

Third Embodiment

[0246] FIG. **33** is a block diagram of an image data provision system **1100** to which the present invention is applied. This image data provision system **1100** is intended to provide two-dimensional images of a product (here, digital camera), or a three-dimensional object, taken from various points of view to clients.

[0247] The product image data provision system **1100** comprises a server **1001**, a camera-equipped cellular phone **1002**, and a printed material **1003**. A watermarked product image **1007** is printed on the printed material **1003**.

[0248] FIG. **34** shows a conceptual rendering of the watermarked product image **1007**. This watermarked product image **1007** is a side view of the product (here, digital camera), a three-dimensional object. Identification information corresponding to the product is embedded in this image in the form of an electronic watermark.

[0249] In the following description of the present embodiment, as shown in the diagram, the horizontal direction of the watermarked product image **1007** will be referred to as x direction and the vertical direction of the watermarked product image **1007** as y direction. The direction perpendicular to the watermarked product image **1007**, piercing the image from the back to the front, will be referred to as z direction.

[0250] A client captures the watermarked product image **1007** with the camera (camera-equipped cellular phone **1002**) tilted according to the desired point of view of a two-dimensional image of the product. The digital image data obtained by this capturing is transmitted to the server **1001**.

[0251] Receiving this image data, the server **1001** corrects perspective distortion that occurs in the image data since the camera is tilted by the client when capturing. Next, the information embedded by the electronic watermark technology is detected from the corrected image data. Based on the information embedded by the electronic watermark technology and perspective distortion information obtained during correction, two-dimensional image data on the corresponding product, taken from a point of view (such as obliquely above and obliquely sideways), is selected from an image database of the server **1001**. The two-dimensional image data selected from the image database is returned to the camera-equipped cellular phone **1002**.

[0252] For example, as shown in FIG. **35**A, when the client captures the watermarked product image **1007** from top left ("+z, −x" side), the server **1001** transmits two-dimensional image data of the product as viewed from the front (FIG. **36**) to the camera-equipped cellular phone **1002** of the client.

[0253] When the client captures the watermarked product image **1007** from top right ("+z, +x" side) as shown in FIG. **35**B, the server **1001** transmits two-dimensional image data of the product as viewed from behind (FIG. **37**) to the camera-equipped cellular phone **1002** of the client.

[0254] When the client captures the watermarked product image **1007** from directly above ("+z" side) as shown in FIG. **35**C, the server **1001** transmits high-resolution two-dimensional image data of the product as viewed sideways (not shown) to the camera-equipped cellular phone **1002** of the client.

[0255] FIG. **38** is a block diagram of the camera-equipped cellular phone **1002** according to the present embodiment. The camera-equipped cellular phone **1002** includes a CCD **1021**, an image processing circuit **1022**, a control circuit **1023**, an LCD **1024**, a transmitter-receiver unit **1025**, an operation unit **1026**, etc. It should be noted that the diagram shows only those components of the camera-equipped cellular phone **1002** that are necessary for camera facilities and communications with the server **1001**. The rest of the configuration is omitted from the diagram.

[0256] Imaging data on a captured image **1006** (see FIG. **34**) captured by the CCD **1021** is digitally converted into digital image data by the image processing circuit **1022**.

[0257] The transmitter-receiver unit **1025** performs data communication processing with exterior. Specifically, it transmits the digital image data to the server **1001** and receives data transmitted from the server **1001**.

[0258] The LCD **1024** displays the digital image data and data transmitted from exterior.

[0259] The operation unit **1026** has buttons for making a call, as well as a shutter button and the like necessary for capturing

[0260] The image processing circuit **1022**, the LCD **1024**, the transmitter-receiver unit **1025**, and the operation unit **1026** are connected with the control circuit **1023**.

[0261] FIG. **39** is a block diagram of the server **1001** according to the present embodiment. The server **1001** comprises such components as a transmitter-receiver unit **1011**, a feature point detection unit **1012**, a perspective distortion detection unit **1013**, a perspective distortion correction unit **1014**, a watermark extraction unit **1015**, an image database **1016**, an image data indexing unit **1017**, and a control unit **1018**.

[0262] The transmitter-receiver unit **1011** performs transmission and reception processing with exterior. Specifically, it receives digital image data transmitted from the camera-equipped cellular phone **1002**, and transmits information data to the camera-equipped cellular phone **1002**.

[0263] The feature point detection unit **1012** performs processing for detecting feature points from the digital image data received by the transmitter-receiver unit **1011**. Here, the feature points are ones intended for cutting out the area of the watermarked product image **1007** (for example, four feature points lying at the four corners of the frame of the watermarked product image **1007**). The method for detecting these feature points is described, for example, in the specification of a patent application filed by the applicant (Japanese Patent Application No. 2003-418272).

[0264] The feature point detection unit **1012** also performs image decoding processing, if necessary, before the feature point detection processing. For example, when the digital image data is JPEG image data, the feature point detection processing must be preceded by decoding processing for converting the JPEG image data into a two-dimensional array of data that expresses level values at respective coordinates.

[0265] The perspective distortion detection unit **1013** detects perspective distortion from the digital image data transmitted from the camera-equipped cellular phone **1002**.

Then, based on this perspective distortion, it estimates the capturing direction in which the image is captured by the camera-equipped cellular phone **1002**. Now, the method of estimating the capturing direction will be described below.

[**0266**] FIG. **40** shows a captured image **1006** of the watermarked product image **1007** when captured from directly above (the "+z" side of FIG. **34**). FIG. **41** shows the captured image **1006** of the watermarked product image **1007** when captured from top left (the "+z, −x" side of FIG. **34**). FIG. **42** shows the captured image **1006** of the watermarked product image **1007** when captured from top right (the "+z, +x" side of FIG. **34**). In FIGS. **40** to **42**, the horizontal direction of the captured image **1006** will be referred to as x' direction, and the vertical direction as y' direction.

[**0267**] Referring to FIG. **40** (or FIG. **41**, FIG. **42**), the capturing direction is detected based on the relationship between a distance d_{13} and a distance d_{24}. Here, d_{13} is the distance between a first feature point which falls on the top left corner ("−x', +y'" side) of the area of the watermarked product image **1007** and a third feature point which falls on the bottom left ("−x', −y'" side) of the same. Then, d_{24} is the distance between a second feature point which falls on the top right corner ("+x', +y'" side) of the area of the watermarked product image **1007** and a fourth feature point which falls on the bottom right corner ("+x', −y'" side) of the same.

[**0268**] Referring to FIG. **40**, when the watermarked product image **1007** is captured from directly above, $d_{13}=d_{24}$. Thus, if the distances between the feature points detected by the feature point detection unit **1012** have the relationship $d_{13}=d_{24}$, the perspective distortion detection unit **1013** recognizes that the captured image **1006** is one obtained when the watermarked product image **1007** is captured from directly above (the "+z" side of FIG. **34**).

[**0269**] Referring to FIG. **41**, when the watermarked product image **1007** is captured from top left, $d_{13}>d_{24}$. Thus, if the distances between the feature points detected by the feature point detection unit **1012** have the relationship $d_{13}>d_{24}$, the perspective distortion detection unit **1013** recognizes that the captured image **1006** is one obtained when the watermarked product image **1007** is captured from top left (the "+z, −x" side of FIG. **34**).

[**0270**] Referring to FIG. **42**, when the watermarked product image **1007** is captured from top right, $d_{13}<d_{24}$. Thus, if the distances between the feature points detected by the feature point detection unit **1012** have the relationship $d_{13}<d_{24}$, the perspective distortion detection unit **1013** recognizes that the captured image **1006** is one obtained when the watermarked product image **1007** is captured from top right (the "+z, +x" side of FIG. **34**).

[**0271**] It should be appreciated that the perspective distortion detection unit **1013** need not necessarily make determinations as mentioned above, or:

[**0272**] if $d_{13}=d_{24}$, the image is captured from above;

[**0273**] if $d_{13}<d_{24}$, the image is captured from top right; and

[**0274**] if $d_{13}>d_{24}$, the image is captured from top left.

Instead, the perspective distortion detection unit **1013** may assume a certain positive value a and make determinations as follows:

[**0275**] if $|d_{13}-d_{24}|<\alpha$, the image is captured from above;

[**0276**] if $d_{24}-d_{13}\geqq\alpha$, the image is captured from top right; and

[**0277**] if $d_{13}-d_{24}\geqq\alpha$, the image is captured from top left.

Here, α is a parameter for allowing deviations in perspective distortion occurring at the time of capturing.

[**0278**] The perspective distortion detection unit **1013** may also assume a certain positive value β (where $\beta>\alpha$), so that

$$\text{if } |d_{13}-d_{24}|>\beta,$$

it aborts the subsequent processing of the digital image data, determining that the subsequent correction of the perspective distortion or the detection of a watermark is impossible.

[**0279**] The perspective distortion correction unit **1014** corrects the perspective distortion of the digital image data detected by the perspective distortion detection unit **1013**. The method of correcting perspective distortion is described, for example, in the specification of a patent application filed by the applicant (Japanese Patent Application No. 2003-397502).

[**0280**] From the digital image data whose perspective distortion is corrected by the perspective distortion correction unit **1014**, the watermark extraction unit **1015** extracts information embedded by the electronic watermark technology. The method of extracting this electronic watermark information is described, for example, in the publication of an unexamined patent application filed by the applicant (Japanese Patent Laid-Open Publication No. 2003-244419).

[**0281**] The image database **1016** contains two-dimensional image data obtained by capturing a variety of products, or three-dimensional objects, from various angles.

[**0282**] The image data indexing unit **1017** contains index information on the two-dimensional image data stored in the image database **1016**. More specifically, referring to FIG. **43**, the image data indexing unit **1017** contains information on the contents of the two-dimensional image data and information on the top addresses of the two-dimensional image data in the image database **1016**, with product ID indicating the product model/model number and perspective distortion information as two index keys. The product ID corresponds to the electronic watermark information embedded in digital image data, extracted from the digital image data by the watermark extraction unit **1015**. The information on the top addresses is used to index the images. Any information may be used as long as the images can be identified uniquely.

[**0283**] The perspective distortion information corresponds to the perspective distortion detected by the perspective distortion detection unit **1013**, i.e., the capturing direction at the time of capturing by the client. When the client captures the watermarked product image **1007** from directly above, the perspective distortion information will be "0." When the client captures the watermarked product image **1007** from top left, the perspective distortion information will be "1."

When the client captures the watermarked product image **1007** from top right, the perspective distortion information will be "2."

[**0284**] The control unit **1018** controls the components of the server **1001**.

[0285] It should be noted that in terms of hardware, these components can be achieved by an arbitrary computer CPU, a memory, and other LSIs. In terms of software, they can be achieved by programs or the like that are loaded on a memory and have the functions for processing images and embedding electronic watermarks. The functional blocks shown here are achieved by the cooperation of these. It will thus be understood by those skilled in the art that these functional blocks may be achieved in various forms including hardware alone, software alone, and a combination of these.

[0286] FIG. **44** is a flowchart showing the processing of the server **1001** according to the present embodiment.

[0287] At step S**1001**, the transmitter-receiver unit **1011** receives digital image data transmitted from the camera-equipped cellular phone **1002**. At step S**1002**, the feature point detection unit **1012** performs processing for detecting feature points intended for cutting out the area of the watermarked product image **1007** (for example, four feature points lying at the four corners of the frame of the watermarked product image **1007**) from the digital image data received by the transmitter-receiver unit **1011**. If necessary, the feature point detection unit **1012** performs image decoding processing before the feature point detection processing.

[0288] At step S**1003**, the perspective distortion detection unit **1013** detects perspective distortion of the digital image data transmitted from the camera-equipped cellular phone **1002**. The method of detecting the perspective distortion is as described above.

[0289] At step S**1004**, the perspective distortion correction unit **1014** corrects the perspective distortion detected by the perspective distortion detection unit **1013**.

[0290] At step **1005**, the watermark extraction unit **1015** extracts information embedded by the electronic watermark technology, from the digital image data whose perspective distortion is corrected by the perspective distortion correction unit **1014**.

[0291] At step S**1006**, the image data indexing unit **1017** is consulted with the information extracted by the watermark extraction unit **1015** and the perspective distortion information detected by the perspective distortion detection unit **1013** as index keys. In consequence, the type of two-dimensional image data requested by the user is identified.

[0292] At step S**1007**, the image database **1016** is consulted to acquire the two-dimensional image data identified at the foregoing step S**1006**.

[0293] At step S**1008**, the transmitter-receiver unit **1011** performs the processing of transmitting the two-dimensional image data acquired from the image database **1016** to the camera-equipped cellular phone **1002**.

[0294] According to the present embodiment, the client can transfer a plurality of pieces of information (the product to view and the desired point of view) to the server of the image database by a single capturing operation. Conventionally, the client had to select the desired point of view by pressing a button down after capturing the watermarked image of the product to view. Otherwise, the administrator of the image database had to provide a number of watermarked images corresponding to the combinations of products and the points of view.

[0295] According to the present embodiment, it is therefore possible to reduce the operation burden on the client and improve the economic efficiency for the administrator of the image database as well.

Modification 1 of Third Embodiment

[0296] The third embodiment has dealt with the case where the watermarked product image **1007** is captured with the camera tilted according to the desired point of view of the two-dimensional image of the product, a three-dimensional object. The capturing directions, however, are not limited to the three directions in the foregoing example.

[0297] Suppose, for example, that the client wants to view an image of the product taken from the top (the ceiling side). Then, the client can acquire the image taken from the ceiling side from the server **1001** by capturing the watermarked product image **1007** from the "+z, +y" side of FIG. **34**.

[0298] Suppose also that the client wants to view an image of the product taken from the bottom (the floor side). Then, the client can acquire the image taken from the floor side from the server **1001** by capturing the watermarked product image **1007** from the "+z, −y" side.

[0299] In such cases, referring to FIGS. **45**A and **45**B, the capturing direction is detected based on the relationship between a distance d_{12} and a distance d_{34}. Here, d_{12} is the distance between the first feature point which falls on the top left corner ("−x', +y'" side) of the area of the watermarked product image **1007** and the second feature point which falls on the top right corner ("+x', +y'" side) of the same. Then, d_{34} is the distance between the third feature point which falls on the bottom left corner ("−x', −y'" side) of the area of the watermarked product image **1007** and the fourth feature point which falls on the bottom right corner ("+x', −y'" side) of the same.

[0300] More specifically:

[0301] i) if $d_{12}>d_{34}$, the server **1001** recognizes that the image is captured from the "+z, +y" side, and that the client wants the image of the product taken from the top (the ceiling side); and

[0302] ii) if $d_{12}<d_{34}$, the server **1001** recognizes that the image is captured from the "+z, −y" side, and that the client wants the image of the product taken from the bottom (the floor side).

Modification 2 of Third Embodiment

[0303] As shown in FIG. **46**, the two diagonals of the watermarked product image **1007** will now be referred to as ξ-axis and η-axis, respectively. If the client wants an image of the rear of the product as viewed from the ceiling side, he/she can capture the watermarked product image **1007** from the "+z, +ξ" side to obtain the corresponding image. If the client wants an image of the rear of the product as viewed from the floor side, he/she can capture the watermarked product image **1007** from the "+z, +η" side to obtain the corresponding image.

[0304] In such cases:

[0305] iii) if $d_{12}>d_{34}$ and $d_{13}<d_{24}$, the server **1001** recognizes that the image is captured from the "+z, +ξ" side; and

[0306] iv) if $d_{12}<d_{34}$ and $d_{13}<d_{24}$, the server **1001** recognizes that the image is captured from the "+z, +η" side.

Modification 3 of Third Embodiment

[0307] The foregoing examples have dealt with a system for providing images of a digital camera, a three-dimensional object, taken from respective points of view to clients. Nevertheless, the present invention may also be applied to a system for providing images of a passenger vehicle, a three-dimensional object, taken from respective points of view to clients.

Experomental Example of Third Embodiment

[0308] A system having the same configuration as that of the image data provision system **1100** described in the third embodiment was constructed and subjected to an experiment. In this experiment, the diagonal length of a subject image (corresponding to the watermarked product image **1007** of the third embodiment) was 70.0 mm, the diagonal length of the CCD was 8.86 mm (⅓.8 inch), the focal length of the camera lens was 7.7 mm, and the distance from the subject to the lens center was set to range from 70 to 100 mm.

[0309] As a result, even if the subject image was captured with perspective distortion, it was possible to correct the perspective distortion and extract the information embedded by the electronic watermark technology unless the angle formed between the normal to the subject image and the optical axis of the camera exceeded 20°.

[0310] The present invention would have poor practicability if information embedded by the electronic watermark technology could not be extracted from images that were captured at angles considerably off from directly above. In fact, as shown from the foregoing experimental result, the information embedded by the electronic watermark technology can be extracted even when the images are captured at angles off from directly above as largely as 20°. The present invention thus has high practicability.

[0311] In this experiment, the testing system was set to make the following determinations: if the angle formed between the normal to the subject image and the optical axis of the camera was below 5°, the subject image was captured from directly above; and if the angle formed between the normal to the subject image and the optical axis of the camera reaches or exceeds 5°, the subject image was captured obliquely . In this experiment, misrecognition of the capturing direction was not observed at all.

Fourth Embodiment

[0312] The third embodiment has dealt with the case where the perspective distortion of the digital image transmitted from the camera-equipped cellular phone **1002** is detected and corrected by the server **1001**.

[0313] In the present embodiment, on the other hand, the camera-equipped cellular phone **1002** performs perspective distortion detection and correction before transmitting digital image data to the server **1001**. The information on the perspective distortion detected is stored in a header area of the digital image data. The data area of the digital image data contains the image data whose perspective distortion is corrected.

[0314] FIG. **47** is a block diagram of the camera-equipped cellular phone **1002** according to the present embodiment.

[0315] The camera-equipped cellular phone **1002** includes a CCD **1021**, an image processing circuit **1022**, a control circuit **1023**, an LCD **1024**, a transmitter-receiver unit **1025**, an operation unit **1026**, a feature point detection unit **1027**, a perspective distortion detection unit **1028**, a perspective distortion correction unit **1029**, a header adding unit **1030**, etc. It should be noted that the diagram shows only those components of the camera-equipped cellular phone **1002** that are necessary for camera facilities, perspective distortion correcting functions, and communications with the server **1001**. The rest of the configuration is omitted from the diagram.

[0316] The CCD **1021**, the image processing circuit **1022**, the control circuit **1023**, the LCD **1024**, and the operation unit **1026** are the same as those of the camera-equipped cellular phone **1002** according to the third embodiment. Detailed description thereof will thus be omitted.

[0317] The feature point detection unit **1027** performs processing for detecting feature points of the area of the watermarked product image **1007** from the digital image data generated by the image processing circuit **1022**. As employed here, the feature points shall refer to four feature points lying at the four corners of the frame of the watermarked product image **1007**.

[0318] The perspective distortion detection unit **1028** detects perspective distortion of the digital image data. The method of detecting the perspective distortion is the same as with the perspective distortion detection unit **1013** of the server **1001** according to the third embodiment. Detailed description will thus be omitted.

[0319] The perspective distortion correction unit **1029** corrects the perspective distortion detected by the perspective distortion detection unit **1028**. As with the perspective distortion correction unit **1014** of the server **1001** according to the third embodiment, the examples of the correction method include the technology described in the specification of Japanese Patent Application No. 2003-397502.

[0320] The header adding unit **1030** adds the information on the perspective distortion detected by the perspective distortion detection unit **1028** to the header area of the digital image data.

[0321] The digital image data accompanied with the information on the perspective distortion is transmitted from the transmitter-receiver unit **22** to the server **1001**.

[0322] It should be appreciated that the information on the perspective distortion detected by the perspective distortion detection unit **1028** may be displayed on the LCD **1024**. This makes it possible for the client to check if his/her own choice is reflected on his/her capturing operation before transmitting the digital image data to the server **1001**.

[0323] It should be noted that in terms of hardware, these components can be achieved by an arbitrary computer CPU, a memory, and other LSIs. In terms of software, they can be achieved by programs or the like that are loaded on a memory and have the functions for processing images and embedding electronic watermarks. The functional blocks shown here are achieved by the cooperation of these. It will thus be understood by those skilled in the art that these

functional blocks may be achieved in various forms including hardware alone, software alone, and a combination of these.

[0324] FIG. **48** is a block diagram of the server **1001** according to the present embodiment. The server **1001** includes a transmitter-receiver unit **1011**, a watermark extraction unit **1015**, an image database **1016**, an image data indexing unit **1017**, a control unit **1018**,a header information detection unit **1019**, etc.

[0325] As in the server **1001** of the third embodiment, the transmitter-receiver unit **1011** performs data transmission and reception processing.

[0326] The watermark extraction unit **1015** extracts information embedded by the electronic watermark technology from digital image data received by the transmitter-receiver unit **1011**.

[0327] The header information detection unit **1019** detects perspective distortion information stored in the header area of the digital image data transmitted from the camera-equipped cellular phone **1002**.

[0328] As in the server **1001** of the third embodiment, the image database **1016** contains two-dimensional image data obtained by capturing a variety of products, or three-dimensional objects, from various angles.

[0329] The image data indexing unit **1017** also contains index data on the two-dimensional image data stored in the image database **1016** as in the server **1001** of the third embodiment (see FIG. **43**). Nevertheless, a difference from the server **1001** of the third embodiment lies in that the perspective distortion information, an index key, is detected by the header information detection unit **1019**.

[0330] It should be noted that in terms of hardware, these components can also be achieved by an arbitrary computer CPU, a memory, and other LSIs. In terms of software, they can be achieved by programs or the like that are loaded on a memory and have the functions for processing images and embedding electronic watermarks. The functional blocks shown here are achieved by the cooperation of these. It will thus be understood by those skilled in the art that these functional blocks may be achieved in various forms including hardware alone, software alone, and a combination of these.

[0331] FIG. **49** is a flowchart showing the processing of the camera-equipped cellular phone **1002** according to the present embodiment.

[0332] When the client presses down a shutter button on the operation unit **1026**, the CCD **1021** performs imaging processing (step **S1011**). At step **S1012**, the image processing circuit **1022** performs digital conversion processing on the imaging data.

[0333] At step **S1013**, the feature point detection unit **1027** performs processing for detecting feature points of the area of the watermarked product image **1007** (here, four feature points lying at the four corners of the frame of the watermarked product image **1007**) from the digital image data generated by the image processing circuit **1022**.

[0334] At step **S1014**, the perspective distortion detection unit **1028** detects perspective distortion of the digital image data. At step **S1015**, the perspective distortion correction unit **1029** corrects the perspective distortion of the digital image data detected by the perspective distortion detection unit **1028**.

[0335] At step **S1016**, the header adding unit **1030** adds the information on the perspective distortion detected by the perspective distortion detection unit **1028** to the header area of the digital image data whose perspective distortion is corrected by the perspective distortion correction unit **1029**.

[0336] At step **S1017**, the transmitter-receiver unit **1025** performs processing for transmitting the digital image data having the information on the perspective distortion added by the header adding unit **1030** to the server **1001**.

[0337] FIG. **50** is a flowchart showing the processing of the server **1001** according to the present embodiment.

[0338] At step **S1021**, the transmitter-receiver unit **1011** receives digital image data transmitted from the camera-equipped cellular phone **1002**. At step **S1022**, the header information detection unit **1019** detects perspective distortion information stored in the header area of the digital image data transmitted from the camera-equipped cellular phone **1002**.

[0339] At step **S1023**, the watermark extraction unit **1015** extracts information embedded by the electronic watermark technology from the digital image data received by the transmitter-receiver unit **1011**.

[0340] At step **S1024**, the image data indexing unit **1017** is consulted with the information extracted by the watermark extraction unit **1015** and the information perspective distortion information detected by the header information detection unit **1019** as index keys. In consequence, the type of two-dimensional image data requested by the user is identified.

[0341] At step **S1025**, the image database **1016** is consulted to acquire the two-dimensional image data identified at the foregoing step **S1024**.

[0342] At step **S1026**, the transmitter-receiver unit **1011** performs the processing for transmitting the two-dimensional image data acquired from the image database **1016** to the camera-equipped cellular phone **1002**.

[0343] According to the present embodiment, perspective distortion is detected and corrected by the client terminal. As compared to the third embodiment, this can reduce the load on the server which is in charge of watermark detection.

Modification 1 of Fourth Embodiment

[0344] In the fourth embodiment, the client terminal performs both detection and correction of perspective distortion. Instead, the client terminal may perform detection of perspective distortion alone, so that the correction is committed to the server side. In such cases, when the terminal determines that the perspective distortion included in the digital image data is too high, it may display a message on the LCD, requesting the client to recapture, instead of transmitting the image data to the server.

Modification 2 of Fourth Embodiment

[0345] In the fourth embodiment, perspective distortion is detected and corrected by the client terminal while electronic watermarks are extracted on the server side. Instead,

the extraction of electronic watermarks may also be performed by the client terminal. Here, the information embedded by the electronic watermark technology (product identification information) and the information on the detected perspective distortion (information corresponding to the desired point of view of the client) are transmitted from the client terminal to the server. The server determines the type of two-dimensional image data to provide to the client based on the product identification information and the information on the desired point of view of the client which are transmitted from the client terminal.

Modification 3 of Fourth Embodiment

[0346] The client terminal according to the foregoing modification 2 of the fourth embodiment may further comprise an image database. Then, based on the information embedded by the electronic watermark technology (product identification information) and the information on the detected perspective distortion (information corresponding to the desired point of view of the client), the client terminal may select an image from the image database and display the selected image on its display unit. Alternatively, a thumbnail of the selected image may be displayed on the display unit.

Fifth Embodiment

[0347] In the third and fourth embodiments, the client can acquire two-dimensional image data on a product as viewed from a desired point of view by capturing a watermarked product image while tilting the camera according to the point of view.

[0348] In the present embodiment, the client can select optional features of a product to purchase (the type of wrapping paper) by capturing a watermarked product image.

[0349] FIG **51** is a block diagram of a product purchase system **1300** according to the present embodiment. The product purchase system **1300** comprises a server **1020**, a camera-equipped cellular phone **1002**, and a printed material **1003**.

[0350] Referring to FIG. **52**, a watermarked product image **1008** is printed on the printed material **1003**. In the following description of the present embodiment, as in the third embodiment, the horizontal direction of the watermarked product image **1008** will be referred to as x direction, and the vertical direction of the watermarked product image **1008** as y direction. The direction perpendicular to the watermarked product image **1008**, piercing the image from the back to the front, will be referred to as z direction.

[0351] FIG **53** is a block diagram of the server **1020** according to the present embodiment. The server **1020** comprises such components as a transmitter-receiver unit **1011**, a feature point detection unit **1012**, a perspective distortion detection unit **1013**, a perspective distortion correction unit **1014**, a watermark extraction unit **1015**, a product information database **1036**, and a control unit **1018**. The transmitter-receiver unit **1011**, the feature point detection unit **1012**, the perspective distortion detection unit **1013**, the perspective distortion correction unit **1014**, the watermark extraction unit **1015**, and the control unit **1018** are the same as those of the server **1001** according to the third embodiment. Detailed description thereof will thus be omitted.

[0352] FIG. **54** shows the contents of the product database **1036** in the server **1020** of the present embodiment. The product database **1036** contains product-related information with product ID and perspective distortion information as two index keys. In the present embodiment, the products shall be gift products. Product IDs are ones corresponding to the types of the products (models, forms, or the like). The perspective distortion information pertains to the colors of wrapping paper for wrapping the products. FIG. **55** is a conceptual diagram of the product purchase system **1300** according to the present embodiment. When a client who wants to purchase a product wants the product wrapped in white wrapping paper, the client captures the watermarked product image **1008** placed on the x-y plane from top left ("−x, +z" side) by using a camera with communication facilities (the camera-equipped cellular phone **1002**) (see FIG. **55**(1*a*)). The watermarked product image **1008** contains a product ID which is embedded in the form of an electronic watermark.

[0353] When the client who wants to purchase the product wants the product wrapped in black wrapping paper, the client captures the watermarked product image **1008** from top right ("+x, +z" side) by using the camera-equipped cellular phone **1002** (see FIG. **55**(1*b*)).

[0354] The captured image is subjected to digital conversion processing, and the resulting digital image data is transmitted to the server **1001** (see FIG. **55**(2)). The perspective distortion correction function **1014** of the server **1020** corrects perspective distortion of the digital image data based on the information on the perspective distortion detected by the perspective distortion detection unit **1013**. Next, the watermark extraction unit **1015** extracts the information on the product ID embedded in the form of the electronic watermark from the perspective-distortion-corrected digital image data (see FIG. **55**(3)). Then, based on the product ID information and the perspective distortion information, the server **1020** consults the product information database **1036** and determines the product to deliver to the client and its wrapping method (see FIG. **55**(4)).

[0355] In this way, the product purchase system **1300** according to the present embodiment makes it possible for clients to select the colors of wrapping paper for products by means of the capturing angles.

Modification of Fifth Embodiment

[0356] In the foregoing embodiment, the client selects the color of the wrapping paper for the product, whether black or white, by capturing the printed mater **1003** from obliquely above (in either one of two directions). The client who uses the product purchase system **1300** may also select the color of the wrapping paper other than black and white by capturing the printed material **1003** in directions other than described in the foregoing embodiment.

[0357] For example, when the client who wants to purchase the product wants the product wrapped in blue wrapping paper, he/she captures the watermarked product image **1008** from "+z, −y" side by using the camera-equipped cellular phone **1002** (see FIG. **56**A). When the client who wants to purchase the product wants the product wrapped in red wrapping paper, the client captures the watermarked product image **1008** from "+z, +y" side by using the camera-equipped cellular phone **1002** (see FIG. **56**B).

Samsung Exhibit 1002, Page 297 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

[0358] In these cases, the capturing direction can be detected by the same method as in modification 1 of the third embodiment, described with reference to FIG. **45**.

Sixth Embodiment

[0359] The capturing angle of a camera may be utilized as a means for indicating client's intention in an interactive system.

[0360] FIG. **57** is a diagram showing the configuration of a quiz answering system **1400**, which is an example of such an interactive system. The quiz answering system **1400** comprises such components as a server **1010**, a camera-equipped cellular phone **1002**, and a question card **1009**.

[0361] The client changes the capturing angle of the camera-equipped cellular phone **1002** when capturing the question card **1009**, thereby answering the quiz printed on the question card **1009**. The question cars **1009** has quiz questions printed thereon, and is divided into sections corresponding to the questions. For example, question 1 is printed on the section Q1 of the question card **1009**. Question 2 is printed on the section Q2 of the question card **1009**. In each of the sections Q1, Q2, . . . , the identification number of the question card **1009** and the number of the quiz question are embedded in the form of electronic watermarks. For example, the identification number of the question card **1009** and the information indicating that the quiz question number is 1 are embedded in the section Q1 in the form of electronic watermarks.

[0362] Each section of the question card is bordered with a thick frame, so that the server **1010** can detect perspective distortion of the captured image from the distortion of the frame appearing on the captured image.

[0363] Description will now be given of an example of client operations in such a quiz answering system **1400**. For question 1 of the question card **1009** in FIG. **57**, asking "Who was the first president of the United States?", the client captures the section Q1 of the question card **1009** from top left as shown in FIG. **58**A when selecting "1: Washington." When selecting "2: Lincoln," the client captures the section Q1 of the question card **1009** from top right as shown in FIG. **58**B.

[0364] The digital image data on the question card **1009**, captured by the camera-equipped cellular phone **1002**, is transmitted to the server **1010**. The server **1010** corrects perspective distortion of the digital image data, and stores the direction of distortion (the number of the answer selected by the client) that is detected during this distortion correction. Then, the server **1010** extracts the identification number of the question card **1009** and the quiz question number embedded in the form of electronic watermarks from the distortion-corrected digital image data.

[0365] Furthermore, the server **1010** consults a database (a database that contains question numbers and the numbers of the corresponding right answers) based on the quiz question number extracted and the answer number detected, thereby determining if the answer from the client is correct.

[0366] Note that the foregoing example has dealt with the case where the question card **1009**, a printed material, contains both text information for showing quiz questions and electronic watermark information including quiz question numbers. Instead, the text information for showing quiz questions and the electronic watermark information such as quiz question numbers may appear not on a printed material but on a TV broadcasting screen. According to such an embodiment, it is possible to realize an online quiz show of audience participation type. Moreover, such an embodiment may be applied to telephone polling questionnaires in TV programs.

OTHER MODIFICATIONS

[0367] Other possible modifications include the following:

[0368] (1) Application for a restaurant menu: Watermark information is embedded in the pictures of dishes and provisions. The restaurant menu can be captured to display detailed information on dishes, guest reviews, etc. Other information such as the scent of the dishes is also applicable.

[0369] (2) Application for a museum guidebook: A museum guidebook can be captured to provide voice or visual descriptions on collections.

[0370] In both of the foregoing applications (1) and (2), description languages such as English, Japanese, and French can be switched depending on the capturing angle. For example, an identical watermarked image can be captured obliquely from the front to show Japanese description, and obliquely from behind to show English description. This has the advantage that menus and pamphlets need not be prepared for each individual language.

[0371] The foregoing embodiments disclosed herein are to be considered in all respects as illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than by the foregoing description of the embodiments, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

[0372] The foregoing embodiments have dealt with the cases where the client captures a watermarked product image obliquely. Nevertheless, the client may put the camera directly above a watermarked image and capture the image with the camera tilted. For example, suppose that the client captures the image while holding the camera as tilted the left side up and the right side down. Then, in the captured image, the left edge of the area of the watermarked image (in FIG. **42**, between the first and third feature points) becomes smaller in length than the right edge (in FIG. **42**, between the second and fourth feature points). In such cases, the server determines that the client captures the watermarked image from top right ("+z, +x" direction of FIG. **34**).

[0373] The foregoing embodiments have dealt with the cases where the client captures in oblique directions an image in which product information is embedded by the electronic watermark technology. Instead, the client may obliquely capture a printed material in which product information is embedded in the form of a one- or two-dimensional barcode. In this case, the electronic watermark extraction unit of the present invention is replaced with a one- or two-dimensional barcode reader.

[0374] An information database apparatus may also be provided, comprising: a distortion detection unit for detecting image distortion from imaging data obtained by an imaging device; an information data storing unit for storing

Samsung Exhibit 1002, Page 298 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

information data; and a selector unit for selecting information data stored in the information data storing unit based on the image distortion detected by the distortion detection unit.

INDUSTRIAL APPLICABILITY

[0375] The present invention is applicable to the field of image processing.

1. An image correction apparatus comprising:

a lens distortion calculation unit which acquires information on zoom magnifications contained in data of known images captured at respective different zoom magnifications, and calculates lens distortion correction information with respect to each zoom magnification; and

a storing unit which stores the lens distortion correction information in association with the zoom magnifications.

2. An image correction apparatus comprising:

a storing unit which contains lens distortion correction information in association with zoom magnifications of a lens;

a selection unit which acquires from data of an input captured image, information on a zoom magnification employed at the time of capturing of the captured image, and selects lens distortion correction information corresponding to the zoom magnification from the storing unit; and

a distortion correction unit which corrects distortion of the captured image ascribable to capturing based on the lens distortion correction information selected.

3. The image correction apparatus according to claim 2, wherein

the selection unit selects from the storing unit a plurality of candidate pieces of lens distortion correction information in accordance with the zoom magnification employed at the time of capturing, and correct a row of sample points forming a known shape in the captured image by using each of the plurality of pieces of lens distortion correction information for error pre-evaluation, and thereby selects one piece of lens distortion correction information from among the plurality of pieces of lens distortion correction information.

4. An image correction apparatus comprising:

a lens distortion calculation unit which acquires information on zoom magnifications contained in data of known images captured at respective different zoom magnifications, and calculates a lens distortion correction function for mapping points in a lens-distorted image onto points in an image having no lens distortion and a lens distortion function, or an approximate inverse function of the lens distortion correction function, with respect to each lens magnification; and

a storing unit which stores the pairs of lens distortion correction functions and lens distortion functions in association with the zoom magnifications.

5. An image correction apparatus comprising:

a storing unit which contains pairs of lens distortion correction functions for mapping points in a lens-distorted image onto points in an image having no lens distortion and lens distortion functions, that are approximate inverse functions of the lens distortion correction functions, in association with respective zoom magnifications of a lens;

a selection unit which acquires from data of an input captured image, information on a zoom magnification employed at the time of capturing of the captured image, and selects from the storing unit the lens distortion function corresponding to the zoom magnification; and

a distortion correction unit which corrects distortion of the captured image ascribable to capturing based on the lens distortion function selected.

6. The image correction apparatus according to claim 5, wherein

the selector unit selects from the memory unit a plurality of candidate lens distortion correction functions in accordance with the zoom magnification employed at the time of capturing, and corrects a sequence of sample points forming a known shape in the captured image by using each of the plurality of lens distortion correction functions for error pre-evaluation, and thereby selects one of the plurality of lens distortion functions.

7. An image correction apparatus comprising:

a storing unit which contains lens distortion functions for mapping points in an image having no lens distortion onto points in a lens-distorted image in association with respective zoom magnifications of a lens;

a selection unit which acquires from data of an input captured image, information on a zoom magnification employed at the time of capturing of the captured image, and selects the lens distortion function corresponding to the zoom magnification from the storing unit;

a perspective distortion calculation unit which calculates a perspective distortion function for mapping points in an image having no perspective distortion onto points on a perspective-distorted image, by using an image whose lens distortion is corrected by the lens distortion function selected; and

a distortion correction unit which corrects distortion of the captured image ascribable to capturing based on the perspective distortion function calculated by the perspective distortion calculation unit.

8. The image correction apparatus according to claim 7, wherein

the selector unit selects from the memory unit a plurality of candidate lens distortion correction functions in accordance with the zoom magnification employed at the time of capturing, and corrects a sequence of sample points forming a known shape in the captured image by using each of the plurality of lens distortion correction functions for error pre-evaluation, and thereby selects one of the plurality of lens distortion functions.

9. An image correction database creating method comprising:

acquiring information on zoom magnifications contained in data of known images captured at the respective

Samsung Exhibit 1002, Page 299 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

different zoom magnifications, and calculating a lens distortion correction function for mapping points on a lens-distorted image onto points on an image having no lens distortion and a lens distortion function, or an approximate inverse function of the lens distortion correction function, with respect to each lens magnification; and

registering the pairs of lens distortion correction functions and lens distortion functions into a database in association with the zoom magnifications.

10. An image correction method comprising:

consulting a database in which pairs of lens distortion correction functions for mapping points in a lens-distorted image onto points in an image having no lens distortion and lens distortion functions, that are approximate inverse functions of the lens distortion correction functions, are registered in association with respective zoom magnifications of a lens, acquiring from data of an input captured image, information on a zoom magnification employed at the time of capturing of the captured image, and selecting the lens distortion function corresponding to the zoom magnification; and

correcting distortion of the captured image ascribable to capturing based on the lens distortion function selected.

11. The image correction method according to claim 10, wherein

the correcting of the distortion includes:

mapping a point in a target image having no distortion ascribable to capturing onto a point in a lens-distorted captured image by using the lens distortion function selected which was selected from the image correction database; and

determining a pixel value at the point in the target image by interpolating pixel values near the mapped point in the captured image.

12. The image correction method according to claim 10 or 11, wherein

the selecting of the lens distortion function includes: selecting a plurality of lens distortion correction functions as candidates in accordance with the zoom magnification employed at the time of capturing; correcting a row of sample points having a known shape in the captured image by each of the plurality of lens distortion correction functions for error pre-evaluation; and selecting one from among the plurality of lens distortion functions.

13. An image correction method comprising:

consulting a database in which lens distortion functions for mapping points in an image having no lens distortion onto points in a lens-distorted image are registered in association with respective zoom magnifications of a lens, and acquiring from data of an input captured image, a zoom magnification employed at the time of capturing of the captured image and selecting the lens distortion function corresponding to the zoom magnification;

calculating a perspective distortion function for mapping points in an image having no perspective distortion onto points in a perspective-distorted image, by using an image whose lens distortion is corrected by the lens distortion function selected; and

correcting distortion of the captured image ascribable to capturing based on the perspective distortion function calculated.

14. The image correction method according to claim 13, wherein

the correcting of the distortion includes:

mapping a point in a target image having no distortion ascribable to capturing onto a point in a perspective-distorted captured image by using the perspective distortion function calculated; and

determining a pixel value at the point in the target image by interpolating pixel values near the mapped point in the captured image.

15. The image correction method according to claim 13 or 14, wherein

the selecting of the lens distortion function includes: selecting a plurality of lens distortion correction functions as candidates in accordance with the zoom magnification employed at the time of capturing; correcting a row of sample points having a known shape in the captured image by each of the plurality of lens distortion correction functions for error pre-evaluation; and thereby selecting one from among the plurality of lens distortion functions.

16-24. (canceled)

* * * * *

US 20050089241A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2005/0089241 A1

Kawanishi et al. (43) Pub. Date: Apr. 28, 2005

(54) IMAGE PROCESSING APPARATUS AND METHOD, RECORDING MEDIUM, AND PROGRAM

(75) Inventors: Isao Kawanishi, Kanagawa (JP); Miyuki Okada, Kanagawa (JP); Nobuyuki Sato, Tokyo (JP); Ken Nakajima, Tokyo (JP)

Correspondence Address:
OBLON, SPIVAK, MCCLELLAND, MAIER & NEUSTADT, P.C.
1940 DUKE STREET
ALEXANDRIA, VA 22314 (US)

(73) Assignee: Sony Corporation, Tokyo (JP)

(21) Appl. No.: 10/921,284

(22) Filed: Aug. 19, 2004

(30) Foreign Application Priority Data

Sep. 5, 2003 (JP) 2003-313521
Apr. 23, 2004 (JP) 2004-128251

Publication Classification

(51) Int. Cl.[7] G06T 5/00; H04N 1/40; H04N 1/409

(52) U.S. Cl. 382/274; 348/241; 358/461; 382/286; 358/3.26

(57) ABSTRACT

For each pixel read from an imaging device, a horizontal counter value and a vertical counter value corresponding to the pixel are supplied from a signal generator to a distance computation section via an optical-axis-center coordinate setting section and an up-and-down and right-and-left weighting section. In the distance computation section, the distance to the optical-axis center is computed, and correction coefficients for the zoom wide end and for the zoom tele end, which correspond to the distance, are obtained by look-up tables. The two obtained correction coefficients are blended at a mixture ratio determined by a blend ratio setting section. The blended shading correction coefficients are gain adjusted by a gain adjustment section, after which they are supplied to a correction section. As a result, a correction corresponding to the distance to the optical-axis-center position is performed on the signal of each pixel supplied from an imaging section.

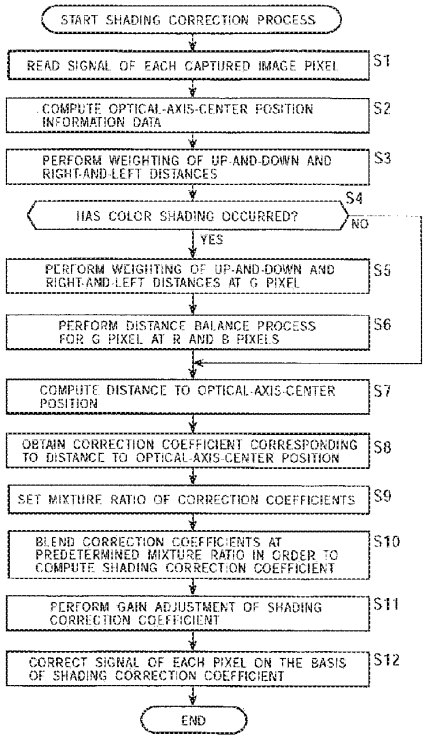


FIG. 1

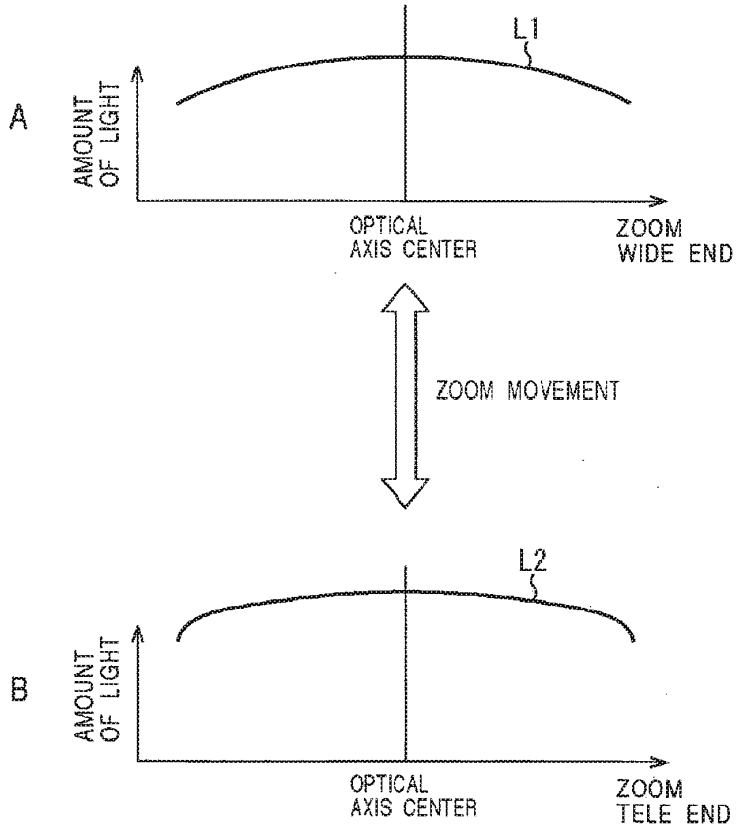

A
AMOUNT OF LIGHT
L1
OPTICAL AXIS CENTER
ZOOM WIDE END
ZOOM MOVEMENT
B
AMOUNT OF LIGHT
L2
OPTICAL AXIS CENTER
ZOOM TELE END

FIG. 2

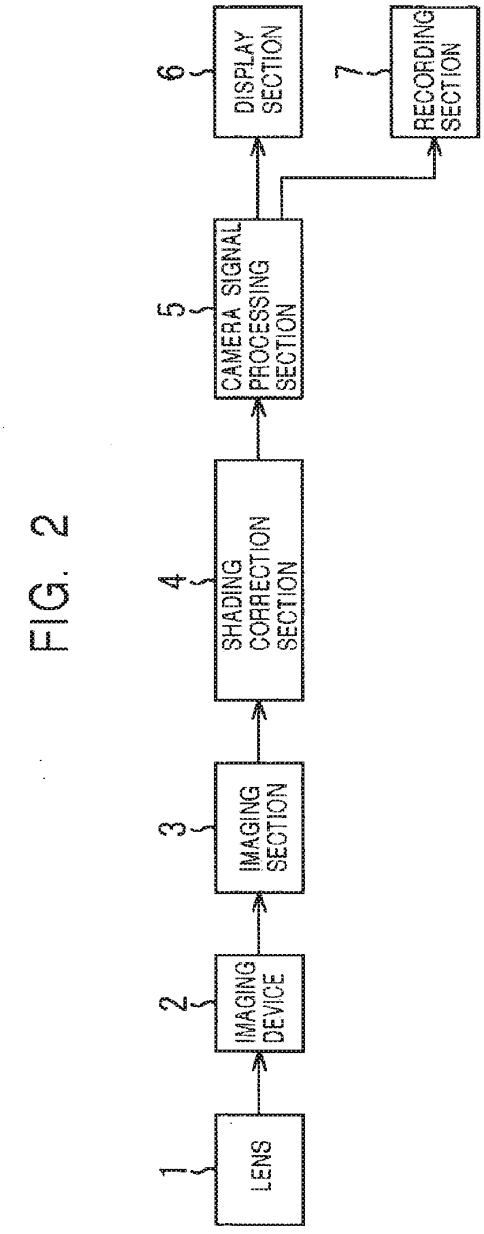

1
LENS
2
IMAGING DEVICE
3
IMAGING SECTION
4
SHADING CORRECTION SECTION
5
CAMERA SIGNAL PROCESSING SECTION
6
DISPLAY SECTION
7
RECORDING SECTION

FIG. 3

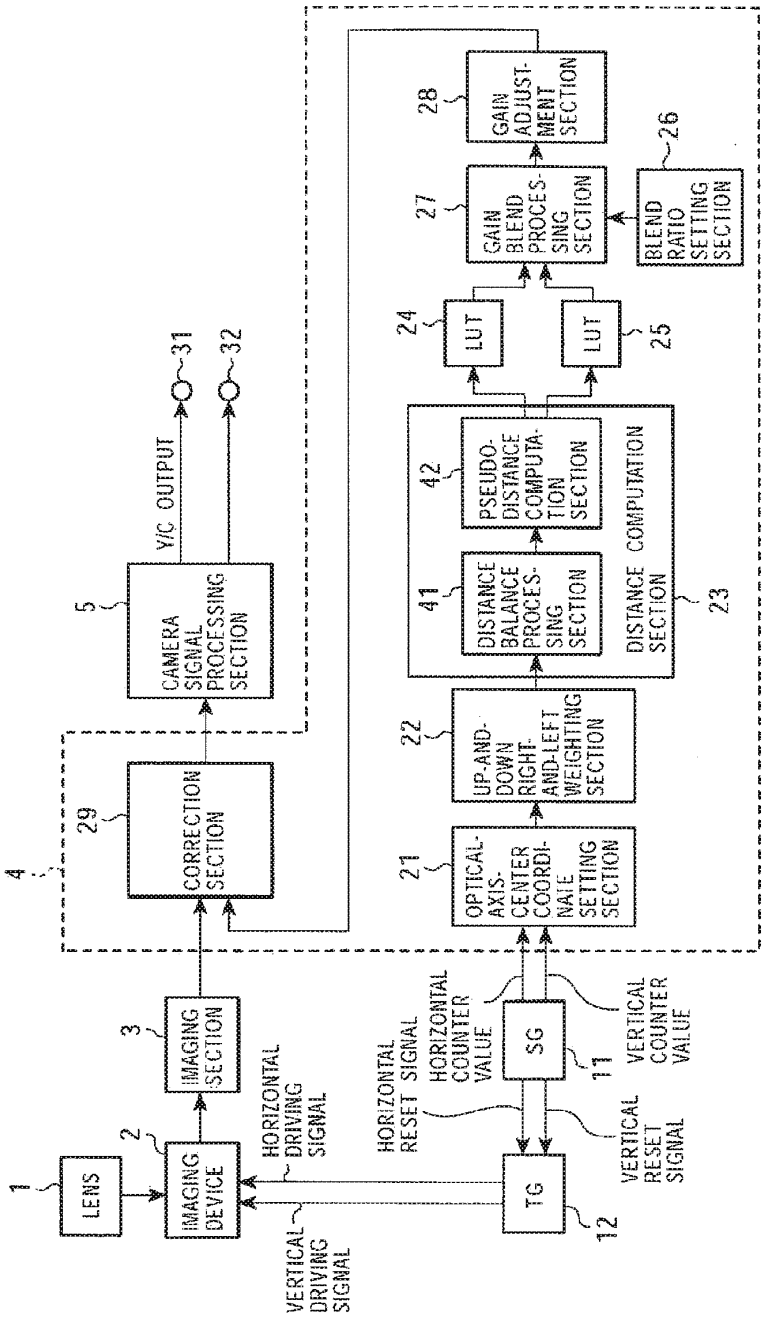

1
LENS
2
IMAGING DEVICE
3
IMAGING SECTION
4
5
CAMERA SIGNAL PROCESSING SECTION
Y/C OUTPUT
31
32
29
CORRECTION SECTION
21
OPTICAL-AXIS-CENTER COORDINATE SETTING SECTION
22
UP-AND-DOWN RIGHT-AND-LEFT WEIGHTING SECTION
23
DISTANCE COMPUTATION SECTION
41
DISTANCE BALANCE PROCESSING SECTION
42
PSEUDO-DISTANCE COMPUTATION SECTION
24
LUT
25
LUT
26
BLEND RATIO SETTING SECTION
27
GAIN BLEND PROCESSING SECTION
28
GAIN ADJUSTMENT SECTION
HORIZONTAL DRIVING SIGNAL
VERTICAL DRIVING SIGNAL
HORIZONTAL RESET SIGNAL
HORIZONTAL COUNTER VALUE
VERTICAL RESET SIGNAL
VERTICAL COUNTER VALUE
SG
11
TG
12

FIG. 4

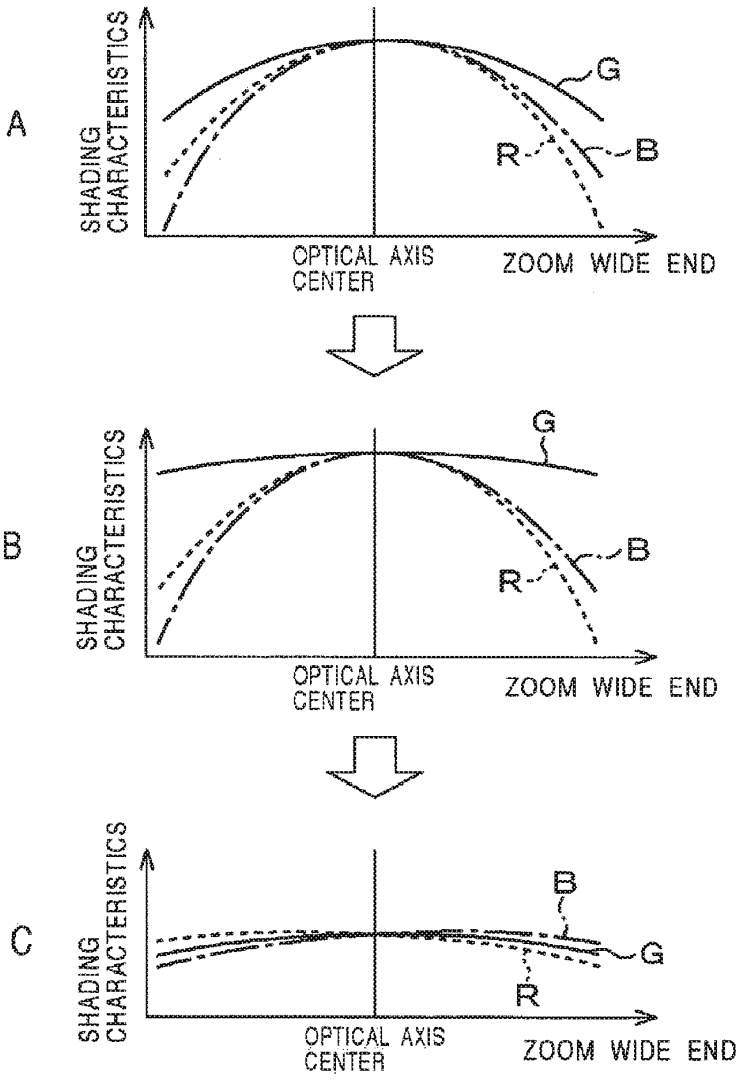

A
SHADING CHARACTERISTICS
G
R
B
OPTICAL AXIS CENTER
ZOOM WIDE END
B
SHADING CHARACTERISTICS
G
B
R
OPTICAL AXIS CENTER
ZOOM WIDE END
C
SHADING CHARACTERISTICS
B
G
R
OPTICAL AXIS CENTER
ZOOM WIDE END

FIG. 5

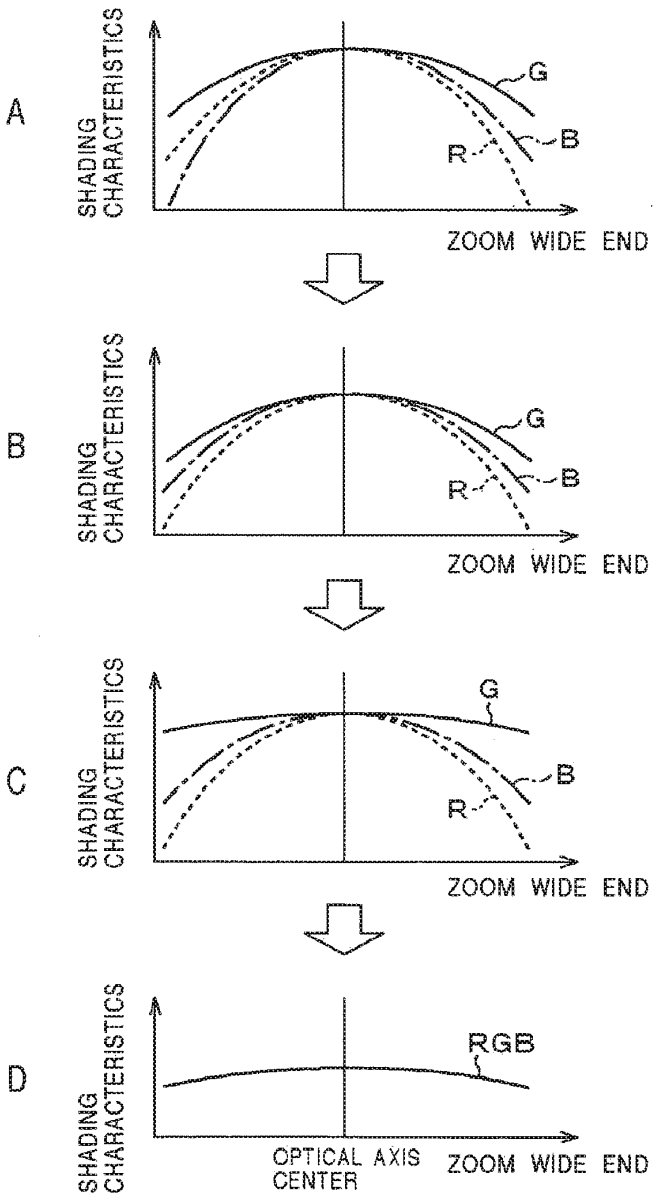

A
SHADING CHARACTERISTICS
G
B
R
ZOOM WIDE END
B
SHADING CHARACTERISTICS
G
B
R
ZOOM WIDE END
C
SHADING CHARACTERISTICS
G
B
R
ZOOM WIDE END
D
SHADING CHARACTERISTICS
RGB
OPTICAL AXIS CENTER
ZOOM WIDE END

FIG. 6

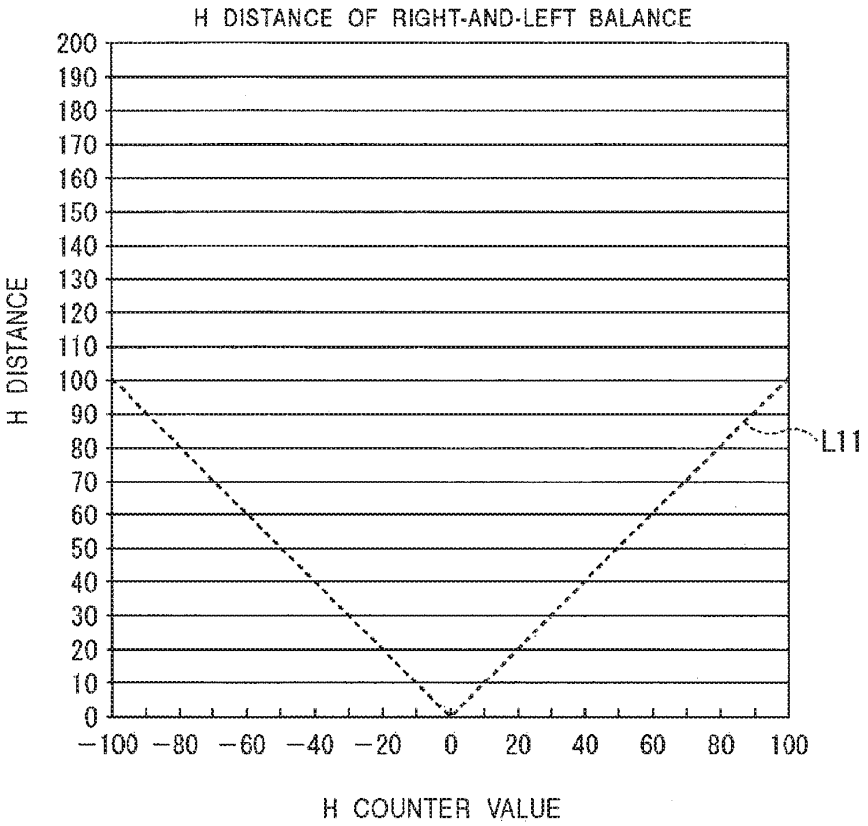

H DISTANCE OF RIGHT-AND-LEFT BALANCE
H DISTANCE
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−100 −80 −60 −40 −20 0 20 40 60 80 100
H COUNTER VALUE
L11

FIG. 7

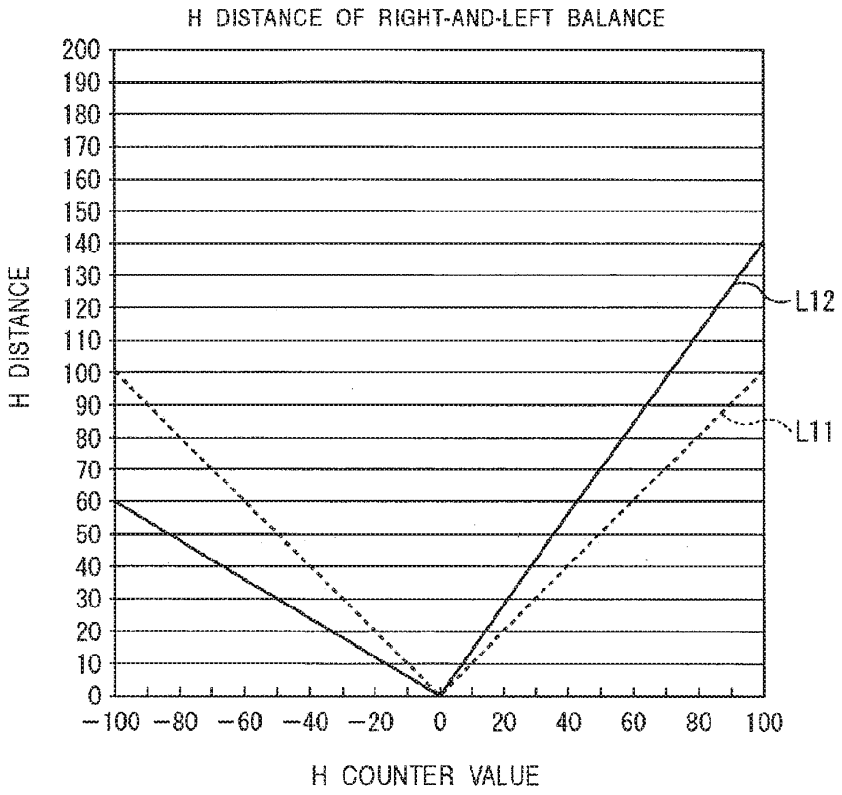

H DISTANCE OF RIGHT-AND-LEFT BALANCE
H DISTANCE
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−100 −80 −60 −40 −20 0 20 40 60 80 100
H COUNTER VALUE
L12
L11

FIG. 8

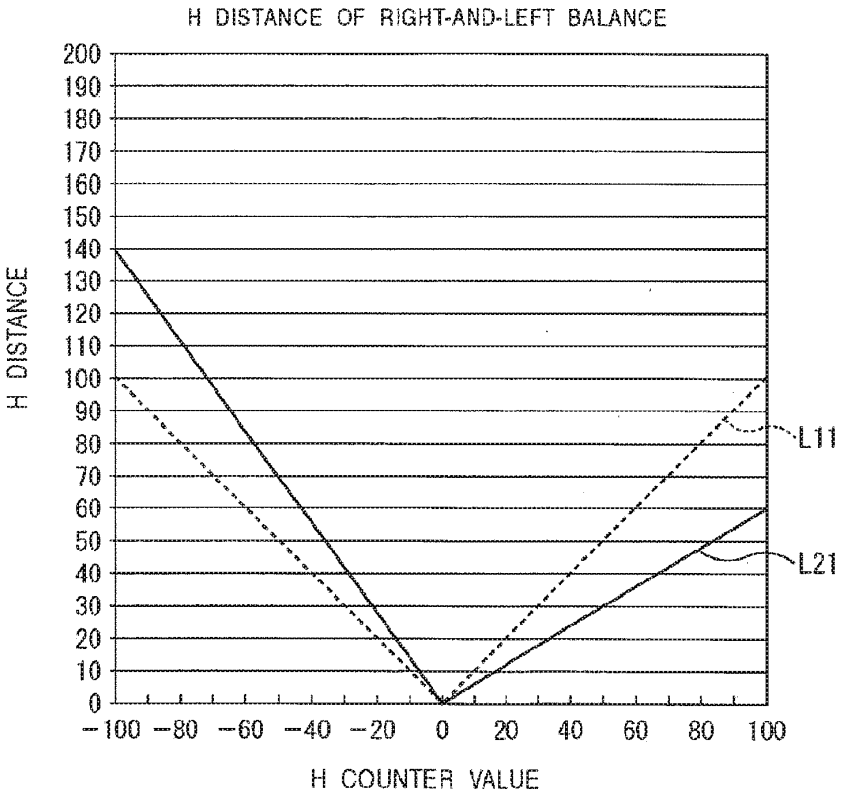

H DISTANCE OF RIGHT-AND-LEFT BALANCE
H DISTANCE
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−100 −80 −60 −40 −20 0 20 40 60 80 100
H COUNTER VALUE
L11
L21

FIG. 9

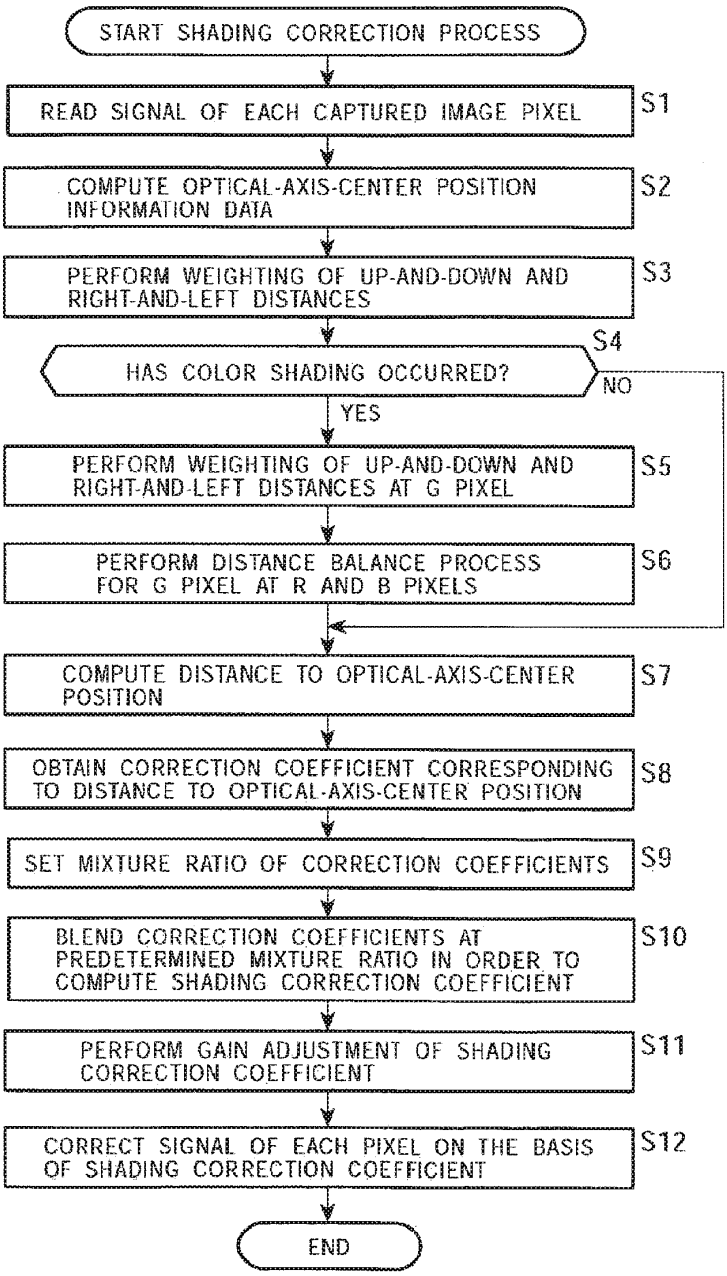

START SHADING CORRECTION PROCESS
READ SIGNAL OF EACH CAPTURED IMAGE PIXEL
S1
COMPUTE OPTICAL-AXIS-CENTER POSITION INFORMATION DATA
S2
PERFORM WEIGHTING OF UP-AND-DOWN AND RIGHT-AND-LEFT DISTANCES
S3
HAS COLOR SHADING OCCURRED?
S4
NO
YES
PERFORM WEIGHTING OF UP-AND-DOWN AND RIGHT-AND-LEFT DISTANCES AT G PIXEL
S5
PERFORM DISTANCE BALANCE PROCESS FOR G PIXEL AT R AND B PIXELS
S6
COMPUTE DISTANCE TO OPTICAL-AXIS-CENTER POSITION
S7
OBTAIN CORRECTION COEFFICIENT CORRESPONDING TO DISTANCE TO OPTICAL-AXIS-CENTER POSITION
S8
SET MIXTURE RATIO OF CORRECTION COEFFICIENTS
S9
BLEND CORRECTION COEFFICIENTS AT PREDETERMINED MIXTURE RATIO IN ORDER TO COMPUTE SHADING CORRECTION COEFFICIENT
S10
PERFORM GAIN ADJUSTMENT OF SHADING CORRECTION COEFFICIENT
S11
CORRECT SIGNAL OF EACH PIXEL ON THE BASIS OF SHADING CORRECTION COEFFICIENT
S12
END

FIG. 10

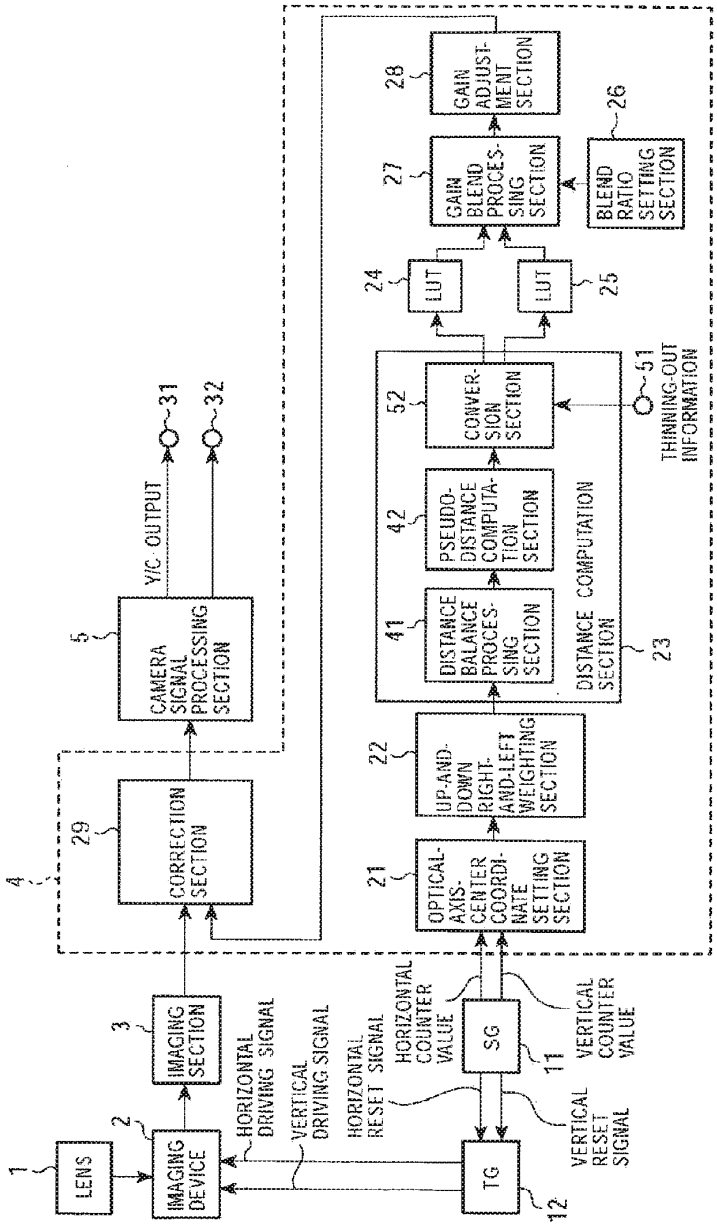

1
LENS
2
IMAGING DEVICE
3
IMAGING SECTION
HORIZONTAL DRIVING SIGNAL
VERTICAL DRIVING SIGNAL
HORIZONTAL RESET SIGNAL
VERTICAL RESET SIGNAL
TG
12
SG
11
HORIZONTAL COUNTER VALUE
VERTICAL COUNTER VALUE
4
29
CORRECTION SECTION
5
CAMERA SIGNAL PROCESSING SECTION
Y/C OUTPUT
31
32
21
OPTICAL-AXIS-CENTER COORDINATE SETTING SECTION
22
UP-AND-DOWN RIGHT-AND-LEFT WEIGHTING SECTION
DISTANCE COMPUTATION SECTION
23
41
DISTANCE BALANCE PROCESSING SECTION
42
PSEUDO-DISTANCE COMPUTATION SECTION
52
CONVERSION SECTION
51
THINNING-OUT INFORMATION
24
LUT
25
LUT
27
GAIN BLEND PROCESSING SECTION
26
BLEND RATIO SETTING SECTION
28
GAIN ADJUSTMENT SECTION

FIG. 11

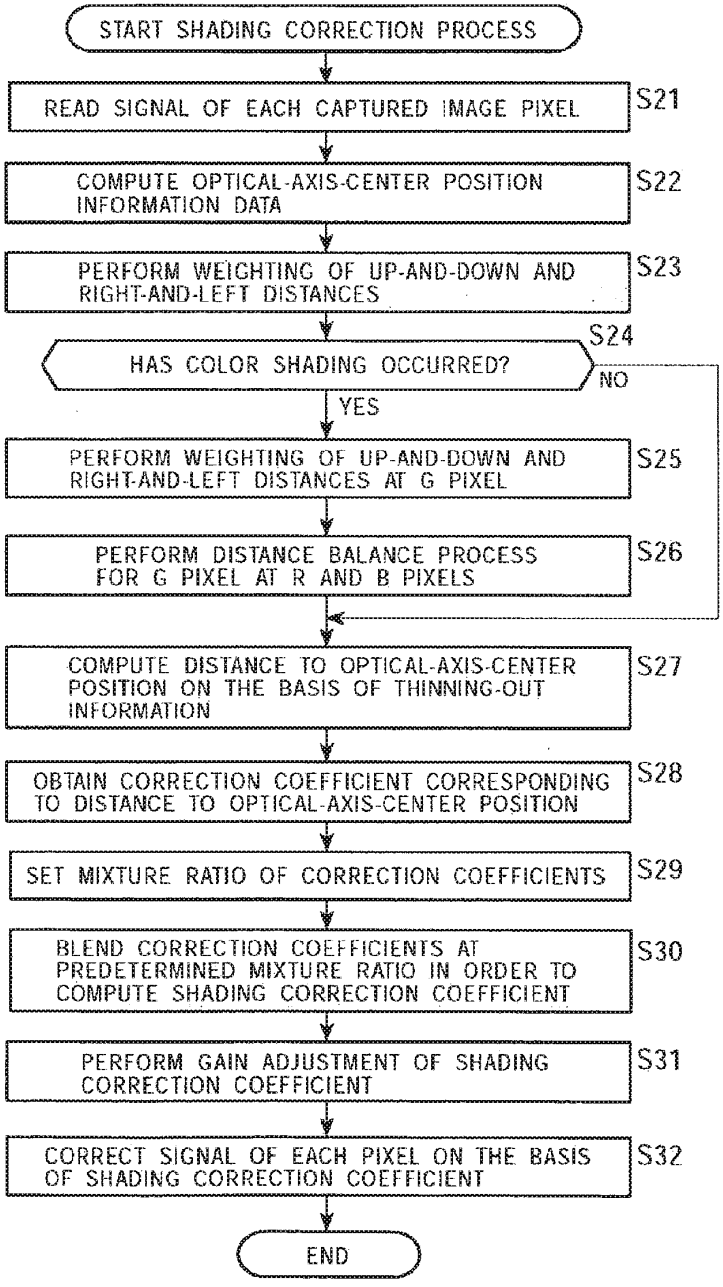

START SHADING CORRECTION PROCESS
READ SIGNAL OF EACH CAPTURED IMAGE PIXEL
S21
COMPUTE OPTICAL-AXIS-CENTER POSITION INFORMATION DATA
S22
PERFORM WEIGHTING OF UP-AND-DOWN AND RIGHT-AND-LEFT DISTANCES
S23
S24
HAS COLOR SHADING OCCURRED?
NO
YES
PERFORM WEIGHTING OF UP-AND-DOWN AND RIGHT-AND-LEFT DISTANCES AT G PIXEL
S25
PERFORM DISTANCE BALANCE PROCESS FOR G PIXEL AT R AND B PIXELS
S26
COMPUTE DISTANCE TO OPTICAL-AXIS-CENTER POSITION ON THE BASIS OF THINNING-OUT INFORMATION
S27
OBTAIN CORRECTION COEFFICIENT CORRESPONDING TO DISTANCE TO OPTICAL-AXIS-CENTER POSITION
S28
SET MIXTURE RATIO OF CORRECTION COEFFICIENTS
S29
BLEND CORRECTION COEFFICIENTS AT PREDETERMINED MIXTURE RATIO IN ORDER TO COMPUTE SHADING CORRECTION COEFFICIENT
S30
PERFORM GAIN ADJUSTMENT OF SHADING CORRECTION COEFFICIENT
S31
CORRECT SIGNAL OF EACH PIXEL ON THE BASIS OF SHADING CORRECTION COEFFICIENT
S32
END

FIG. 12

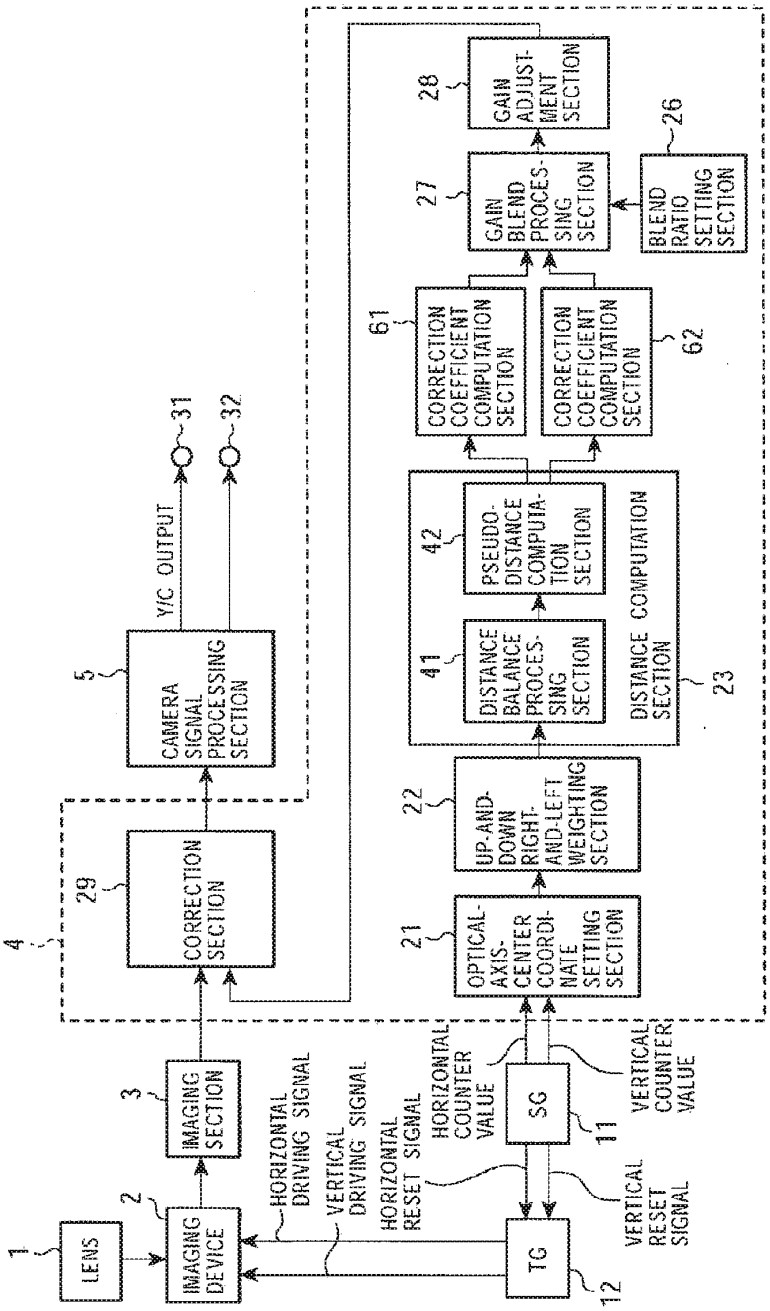

1
LENS
2
IMAGING DEVICE
3
IMAGING SECTION
4
5
CAMERA SIGNAL PROCESSING SECTION
Y/C OUTPUT
31
32
29
CORRECTION SECTION
21
OPTICAL-AXIS-CENTER COORDINATE SETTING SECTION
22
UP-AND-DOWN RIGHT-AND-LEFT WEIGHTING SECTION
23
DISTANCE COMPUTATION SECTION
41
DISTANCE BALANCE PROCESSING SECTION
42
PSEUDO-DISTANCE COMPUTATION SECTION
61
CORRECTION COEFFICIENT COMPUTATION SECTION
62
CORRECTION COEFFICIENT COMPUTATION SECTION
27
GAIN BLEND PROCESSING SECTION
28
GAIN ADJUSTMENT SECTION
26
BLEND RATIO SETTING SECTION
HORIZONTAL DRIVING SIGNAL
VERTICAL DRIVING SIGNAL
HORIZONTAL RESET SIGNAL
HORIZONTAL COUNTER VALUE
VERTICAL COUNTER VALUE
SG
11
TG
12
VERTICAL RESET SIGNAL

FIG. 13

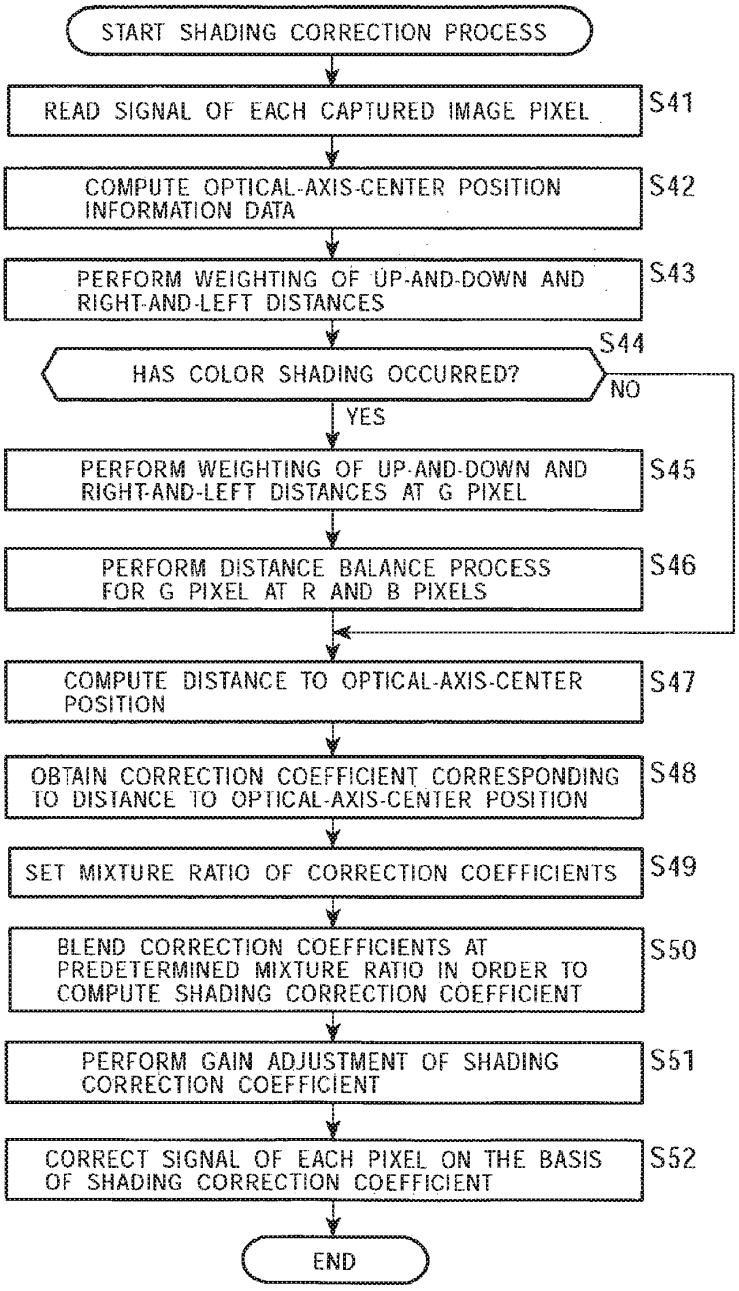

START SHADING CORRECTION PROCESS
READ SIGNAL OF EACH CAPTURED IMAGE PIXEL
S41
COMPUTE OPTICAL-AXIS-CENTER POSITION INFORMATION DATA
S42
PERFORM WEIGHTING OF UP-AND-DOWN AND RIGHT-AND-LEFT DISTANCES
S43
S44
HAS COLOR SHADING OCCURRED?
NO
YES
PERFORM WEIGHTING OF UP-AND-DOWN AND RIGHT-AND-LEFT DISTANCES AT G PIXEL
S45
PERFORM DISTANCE BALANCE PROCESS FOR G PIXEL AT R AND B PIXELS
S46
COMPUTE DISTANCE TO OPTICAL-AXIS-CENTER POSITION
S47
OBTAIN CORRECTION COEFFICIENT CORRESPONDING TO DISTANCE TO OPTICAL-AXIS-CENTER POSITION
S48
SET MIXTURE RATIO OF CORRECTION COEFFICIENTS
S49
BLEND CORRECTION COEFFICIENTS AT PREDETERMINED MIXTURE RATIO IN ORDER TO COMPUTE SHADING CORRECTION COEFFICIENT
S50
PERFORM GAIN ADJUSTMENT OF SHADING CORRECTION COEFFICIENT
S51
CORRECT SIGNAL OF EACH PIXEL ON THE BASIS OF SHADING CORRECTION COEFFICIENT
S52
END

FIG. 14

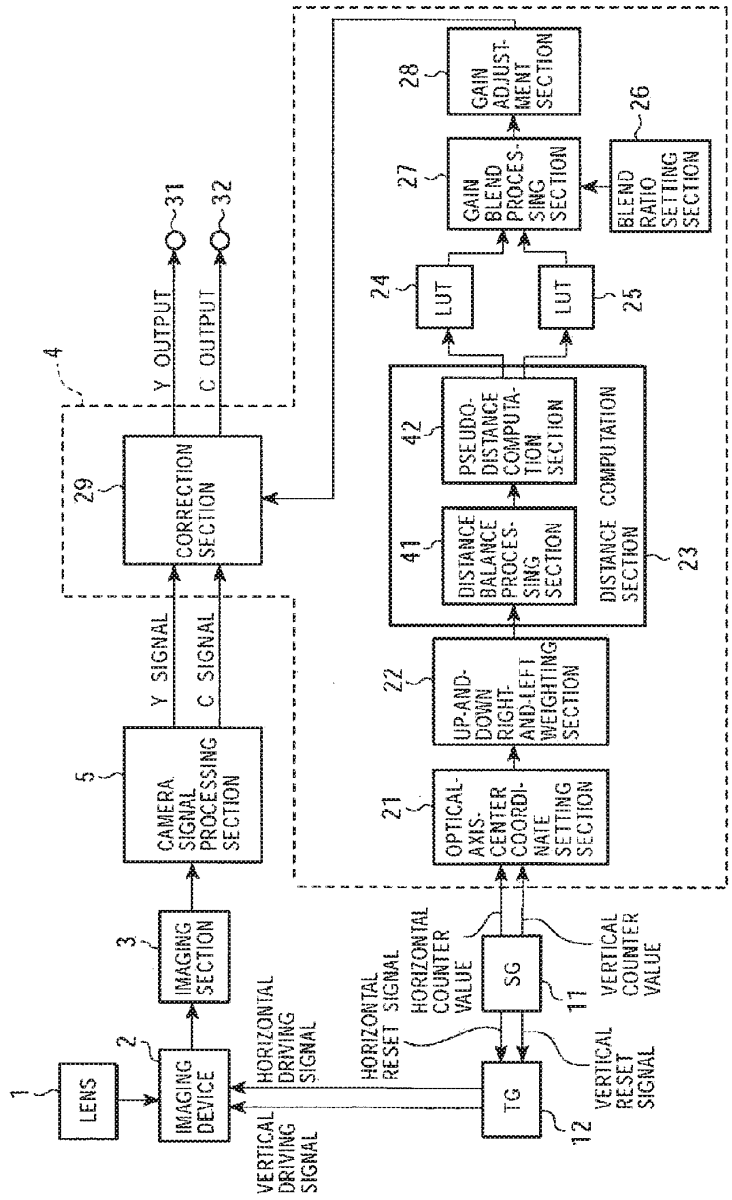

1
LENS
2
IMAGING DEVICE
3
IMAGING SECTION
5
CAMERA SIGNAL PROCESSING SECTION
Y SIGNAL
C SIGNAL
4
29
CORRECTION SECTION
Y OUTPUT
C OUTPUT
31
32
VERTICAL DRIVING SIGNAL
HORIZONTAL DRIVING SIGNAL
HORIZONTAL RESET SIGNAL
TG
12
SG
11
HORIZONTAL COUNTER VALUE
VERTICAL COUNTER VALUE
VERTICAL RESET SIGNAL
21
OPTICAL-AXIS-CENTER COORDINATE SETTING SECTION
22
UP-AND-DOWN RIGHT-AND-LEFT WEIGHTING SECTION
23
DISTANCE COMPUTATION SECTION
41
DISTANCE BALANCE PROCESSING SECTION
42
PSEUDO-DISTANCE COMPUTATION SECTION
24
LUT
25
LUT
27
GAIN BLEND PROCESSING SECTION
26
BLEND RATIO SETTING SECTION
28
GAIN ADJUSTMENT SECTION

FIG. 15

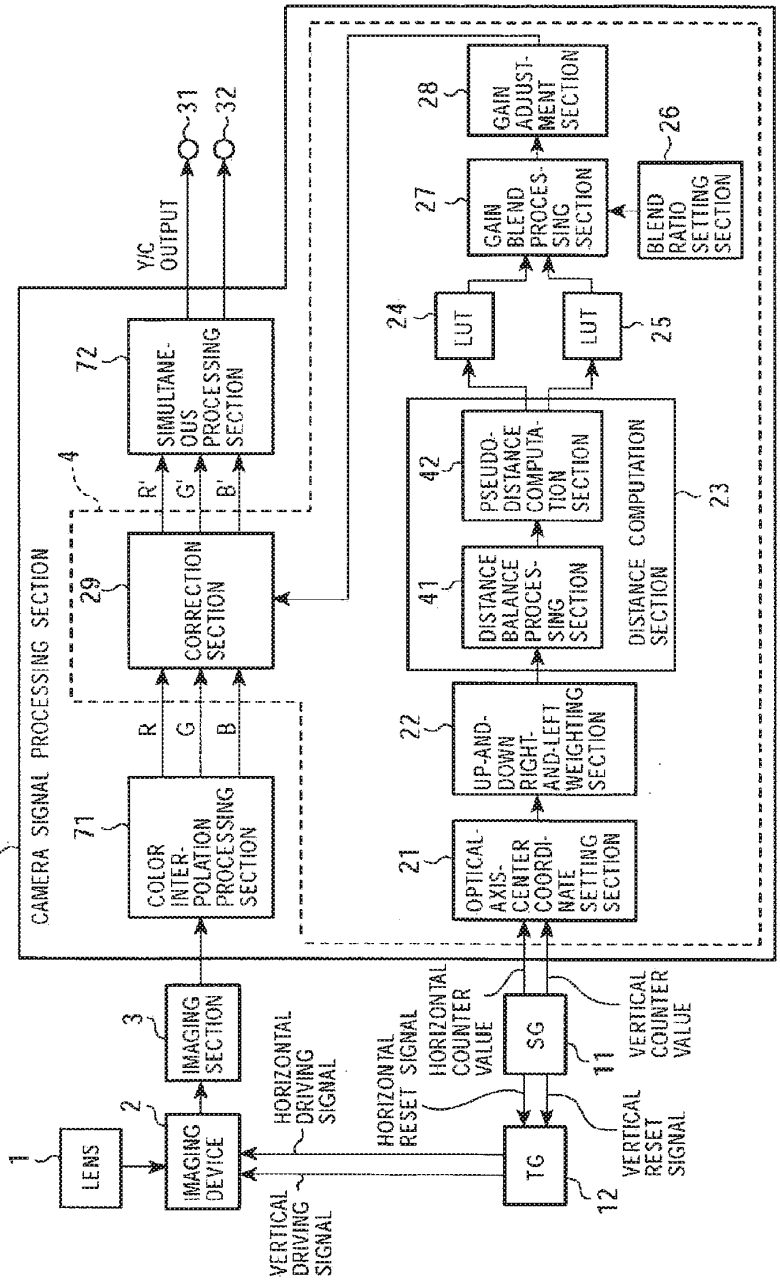

1
LENS
2
IMAGING DEVICE
3
IMAGING SECTION
HORIZONTAL DRIVING SIGNAL
VERTICAL DRIVING SIGNAL
HORIZONTAL RESET SIGNAL
VERTICAL RESET SIGNAL
HORIZONTAL COUNTER VALUE
VERTICAL COUNTER VALUE
SG
11
TG
12
5
CAMERA SIGNAL PROCESSING SECTION
71
COLOR INTER-POLATION PROCESSING SECTION
R
G
B
29
CORRECTION SECTION
4
R'
G'
B'
72
SIMULTANE-OUS PROCESSING SECTION
Y/C OUTPUT
31
32
21
OPTICAL-AXIS-CENTER COORDI-NATE SETTING SECTION
22
UP-AND-DOWN RIGHT-AND-LEFT WEIGHTING SECTION
41
DISTANCE BALANCE PROCESS-SING SECTION
42
PSEUDO-DISTANCE COMPUTA-TION SECTION
DISTANCE COMPUTATION SECTION
23
24
LUT
25
LUT
27
GAIN BLEND PROCES-SING SECTION
26
BLEND RATIO SETTING SECTION
28
GAIN ADJUST-MENT SECTION

FIG. 16

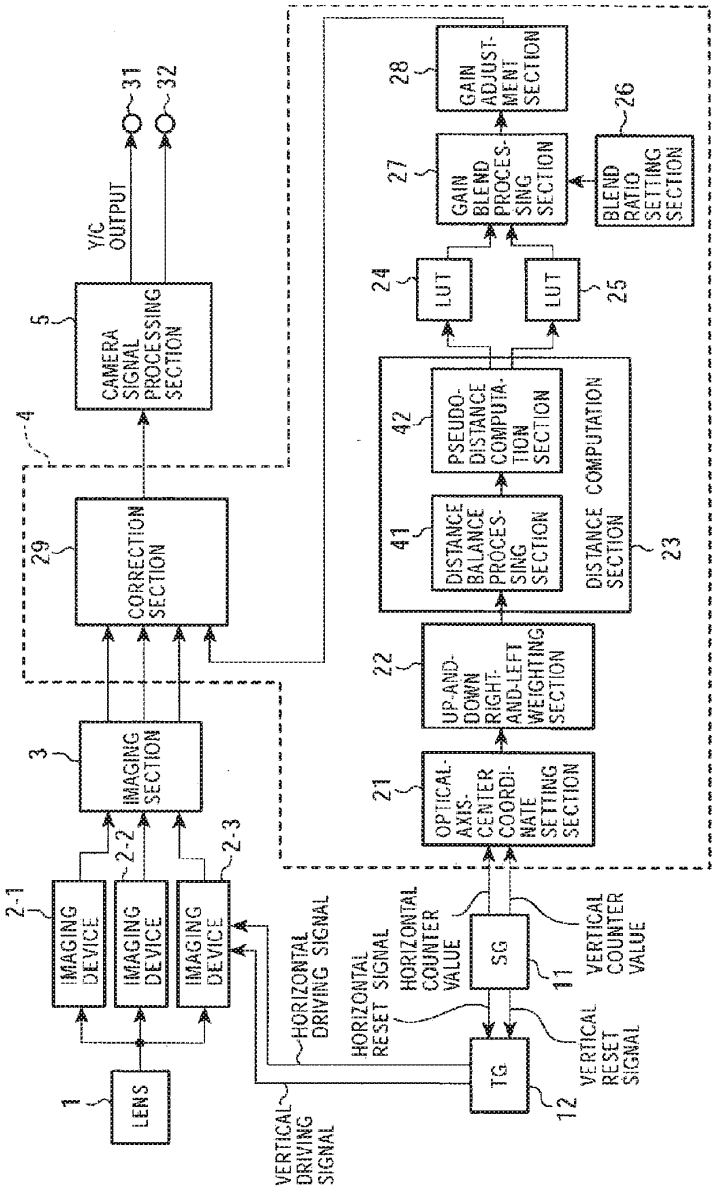

1
LENS
2-1
IMAGING DEVICE
2-2
IMAGING DEVICE
2-3
IMAGING DEVICE
3
IMAGING SECTION
4
29
CORRECTION SECTION
5
CAMERA SIGNAL PROCESSING SECTION
Y/C OUTPUT
31
32
VERTICAL DRIVING SIGNAL
HORIZONTAL DRIVING SIGNAL
HORIZONTAL RESET SIGNAL
HORIZONTAL COUNTER VALUE
VERTICAL RESET SIGNAL
VERTICAL COUNTER VALUE
TG
12
SG
11
21
OPTICAL-AXIS-CENTER COORDINATE SETTING SECTION
22
UP-AND-DOWN RIGHT-AND-LEFT WEIGHTING SECTION
23
DISTANCE COMPUTATION SECTION
41
DISTANCE BALANCE PROCESSING SECTION
42
PSEUDO-DISTANCE COMPUTATION SECTION
24
LUT
25
LUT
26
BLEND RATIO SETTING SECTION
27
GAIN BLEND PROCESSING SECTION
28
GAIN ADJUSTMENT SECTION

FIG. 17

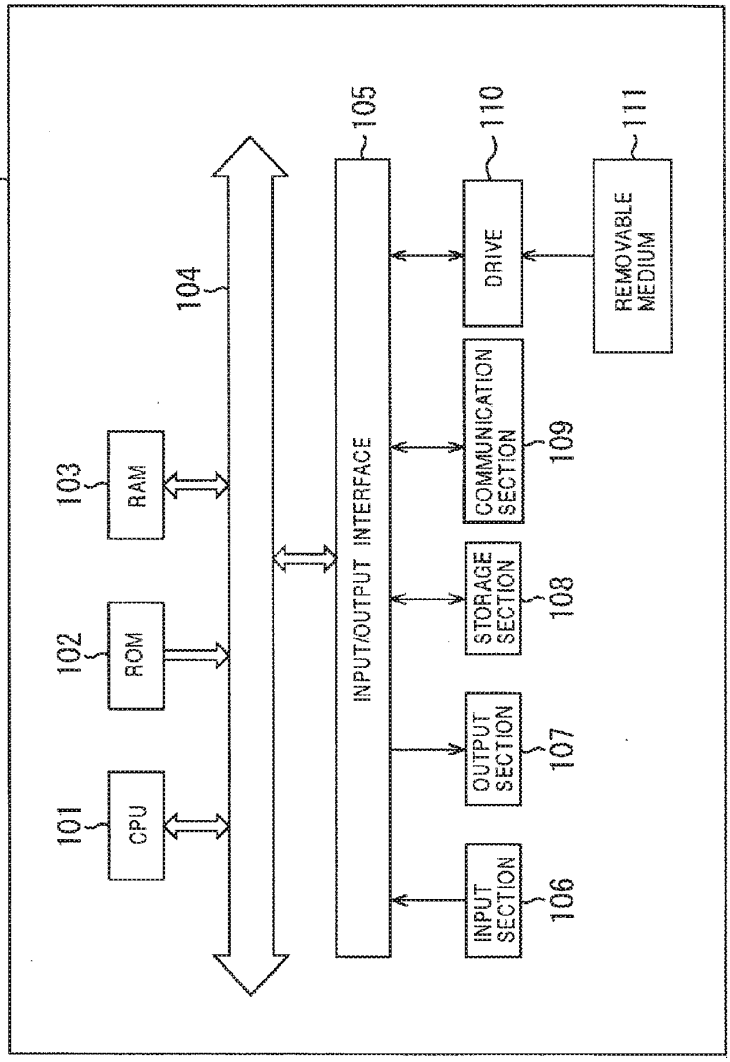

100
101
CPU
102
ROM
103
RAM
104
105
INPUT/OUTPUT INTERFACE
106
INPUT SECTION
107
OUTPUT SECTION
108
STORAGE SECTION
109
COMMUNICATION SECTION
110
DRIVE
111
REMOVABLE MEDIUM

IMAGE PROCESSING APPARATUS AND METHOD, RECORDING MEDIUM, AND PROGRAM

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an image processing apparatus and method, a recording medium, and a program. More particularly, the present invention relates to an image processing apparatus and method capable of correcting shading (sensitivity nonuniformity) of a captured image in a case where, for example, a subject is recorded by a video camera having a digital still camera function, a PDA (Personal Digital Assistant), a cellular phone, a PHS (Personal Handyphone System) or the like, to a recording medium therefor, and to a program therefor.

[0003] 2. Description of the Related Art

[0004] In an imaging apparatus having a lens system and an imaging section, in general, it is known that shading (sensitivity nonuniformity) occurs in a captured image due to, for example, a reduction in the amount of peripheral light due to a lens system.

[0005] In recent years, as the cell size of imaging devices has been minimized, the construction in the height direction of wiring of imaging devices has been relatively minimized, and the pupil distance has been shortened as a result of a size reduction of lenses, causing shading to likely occur in a captured image.

[0006] The principles of this shading are described in, for example, Japanese Unexamined Patent Application Publication No. 2002-218298 as follows. In the imaging device, in order to improve light sensitivity for each pixel, a microlens is provided for each photosensitive pixel portion of the imaging device. When light beams passing through an image-capturing lens nearly vertically enter the photosensitive section of the imaging device, the incident light beams are collected on the photosensitive section of the imaging device almost without any problems. On the other hand, when the light beams passing through an image-capturing lens obliquely enter the imaging device, due to the optical relation between the image-capturing lens and the microlens, only some of the original incident light beams enter each photosensitive section of an area away from the optical axis of the image-capturing lens (i.e., peripheral portions of the imaging device), and shading occurs.

[0007] This phenomenon becomes more intense as the pixel position on the imaging device becomes further away from the optical axis of the image-capturing lens. Furthermore, in the case of an imaging device of a large size, in some of the image-capturing lenses, the angle of the incidence of the light beams to the peripheral portion of the imaging device becomes larger. In this case, shading in which the sensitivity decreases occurs in the peripheral portion of the imaging device, where the incidence angle becomes larger, due to the position of the microlens, manufacture variations of on-chip color filters, the device structure of the imaging device, and the like.

[0008] As a method of preventing the occurrence of such shading, for example, the lens system may be designed with a large number of lenses. Such a lens system designed with a large number of lenses is expensive, and application in so-called consumer products is often difficult.

[0009] On the other hand, for example, when extraction of signals is performed in accordance with the XY coordinates as in devices incorporating semiconductor imaging devices, the image can be corrected by a digital process on the extracted signal. Accordingly, in the field of scanners, etc., hitherto, various technologies for digitally correcting lens shading, such as distortion which occurs because photo-taking is performed by an inexpensive lens system, reduction of the amount of peripheral light, or color blur, have been proposed (see, for example, Japanese Unexamined Patent Application Publication Nos. 11-355511 and 2000-41183).

[0010] However, all of these conventional technologies are performed by being restricted to the field of scanners, etc. (for example, a considerable time can be taken for correction processing), and correction processing in real time is not required as in a digital still camera.

[0011] In comparison, various technologies relating to an imaging apparatus and a shading correction method for eliminating sensitivity nonuniformity on the plane of the imaging device, and an imaging apparatus and a shading correction method for correcting color shading which occurs in specific color channels of the imaging device (see, for example, Japanese Unexamined Patent Application Publication Nos. 2002-218298 and 2000-41179) have been proposed.

[0012] According to Japanese Unexamined Patent Application Publication No. 2002-218298, shading correction coefficients corresponding to pixels which are arranged two-dimensionally on the plane of the imaging device are stored in storage means, so that the correction coefficient is corrected so as to correspond to at least one of the zoom position of the image-capturing lens, the focus position, the image height, the aperture stop value, the exit pupil position, and the amount of strobe light emission.

[0013] According to Japanese Unexamined Patent Application Publication No. 2000-41179, shading correction data is calculated by a CPU (Central Processing Unit), the data is written into rewritable recording means (for example, RAM (Random Access Memory)), shading correction data is read in accordance with a captured image signal read from a CCD (Charge-Coupled Device), and shading correction is performed by multiplying the captured image signal by the digital signal after the photographic signal is converted from analog into digital form, thus making it possible to perform high-speed and accurate shading correction. Furthermore, as a result of being configured in such a manner that a program used for computations by the CPU can be changed externally, an image input device capable of performing shading correction of photo-taking corresponding to the scene of a subject (for example, corresponding to reverse optical correction and illumination) can be provided.

[0014] According to the technology of Japanese Unexamined Patent Application Publication No. 2000-41179, the number of types of the step of storing a shading correction coefficient corresponding to each of the pixels arranged two-dimensionally on the plane of the imaging device is one. For example, when the zoom position of the lens is moved from the wide end to the tele end, the correction coefficient

needs to be corrected in such a manner as to correspond to each continuous zoom position.

[0015] Part A of **FIG. 1** shows shading characteristics in the relationship between the amount of light (the vertical axis) and the position of the zoom wide end (the horizontal direction). Part B of **FIG. 1** shows shading characteristics in the relationship between the amount of light (the vertical axis) and the position of the zoom tele end (the horizontal direction). As shown in part A of **FIG. 1**, shading characteristics L1 at the zoom wide end are gradual reduction of the amount of light, whereas, as shown in part B of **FIG. 1**, shading characteristics L2 at the tele wide end often have characteristics such that the amount of light decreases sharply at the peripheral portion of the image plane. As a result, problems arise in that it is difficult to correct the correction coefficient while moving the zoom position and to maintain the correction accuracy, and also in that the circuit scale and the correction program become larger.

[0016] The same applies to the focus position of the image-capturing lens, the image height, the aperture stop value, the exit pupil position, and the amount of strobe light emission.

SUMMARY OF THE INVENTION

[0017] The present invention has been made in view of such circumstances. The present invention aims to correct shading without increasing the circuit scale and the program scale even if one of the zoom position of an image-capturing lens, the focus position, the image height, the aperture stop value, the exit pupil position, and the amount of strobe light emission is at a position between two ends.

[0018] In one aspect, the present invention provides an image processing apparatus for correcting shading of a captured image, the image processing apparatus including: a first distance computation section for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain; an obtaining section for obtaining a correction value for correcting the shading of the image on the basis of the distance computed by the first distance computation section; and a correction section for correcting the signal of each of the pixels on the basis of the correction value obtained by the obtaining section.

[0019] The obtaining section may obtain a plurality of the correction values.

[0020] The image processing apparatus may further include: a mixture-ratio setting section for setting the mixture ratio of the plurality of correction values obtained by the obtaining section; and a mixing section for mixing the plurality of correction values on the basis of the mixture ratio set by the mixture-ratio setting section, wherein the correction section may correct the signal of each of the pixels on the basis of the correction value mixed by the mixing section.

[0021] The mixture-ratio setting section may set the mixture ratio on the basis of the lens zoom position, the focus position, the image height, the aperture stop value, the exit pupil position, and the amount of strobe light emission.

[0022] The image processing apparatus may further include a gain adjustment section for adjusting the gain of the correction value obtained by the obtaining section.

[0023] The image processing apparatus may further include, when the image is composed of three colors of a G pixel, an R pixel, and a B pixel: a second distance computation section for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with the G pixel; a first distance balance gain correction section for multiplying the distance gain in which the G pixel is used as a reference by the distance balance gain of the R pixel; and a second distance balance gain correction section for multiplying the distance gain in which the G pixel is used as a reference by the distance balance gain of the B pixel.

[0024] The image processing apparatus may further include, when the image is composed of four colors of a Gr pixel, an R pixel, a B pixel, and a Gb pixel, or four colors of an E pixel, an R pixel, a B pixel, and a G pixel: a second distance computation section for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with the Gb pixel or the G pixel; a first balance gain correction section for multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the distance balance gain of the R pixel; a second balance gain correction section for multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the distance balance gain of the B pixel; and a third balance gain correction section for multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the distance balance gain of the Gr pixel or the E pixel.

[0025] In another aspect, the present invention provides an image processing method for use with an image processing apparatus for correcting shading of a captured image, the image processing method including: a first distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain; an obtaining step of obtaining a correction value for correcting the shading of the image on the basis of the distance computed in the first distance computation step; and a correction step of correcting the signal of each of the pixels on the basis of the correction value obtained in the obtaining step.

[0026] In another aspect, the present invention provides a recording medium having recorded thereon a computer-readable program executable to perform image processing for correcting shading of a captured image, the program including: a first distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain; an obtaining step of obtaining a correction value for correcting the shading of the image on the basis of the distance computed in the first distance computation step; and a correction step of correcting the signal of each of the pixels on the basis of the correction value obtained in the obtaining step.

[0027] In another aspect, the present invention provides a program for allowing a computer to execute image processing of an image processing apparatus for correcting shading of a captured image, the program including: a first distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain; an obtaining step of obtaining a correction value for correcting the shading of the image on the basis of the distance computed in the first distance computation step;

Samsung Exhibit 1002, Page 320 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

and a correction step of correcting the signal of each of the pixels on the basis of the correction value obtained in the obtaining step.

[0028] In the present invention, the distance from the image-plane center to each pixel is computed by multiplying the distance by a distance gain by dividing into an up-and-down portion and a right-to-left portion of the image plane.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] **FIG. 1** shows shading characteristics;

[0030] **FIG. 2** is a block diagram showing an example of the basic configuration of a camera system to which the present invention is applied;

[0031] **FIG. 3** shows an example of the configuration of an imaging system of a digital still camera;

[0032] **FIG. 4** shows a state in which an image whose right-to-left balance is degraded at a degree which is different for each color due to color shading is subjected to shading correction;

[0033] **FIG. 5** shows a state in which an image whose right-to-left balance is degraded at a degree different for each color due to color shading is corrected by performing color shading balance;

[0034] **FIG. 6** shows a default H distance of right-to-left balance in the computation of the distance from the optical axis center;

[0035] **FIG. 7** shows an unbalance H distance upward from right to the left;

[0036] **FIG. 8** shows an unbalance H distance upward from left to the right;

[0037] **FIG. 9** is a flowchart illustrating a shading correction process performed by the digital still camera shown in **FIG. 3**;

[0038] **FIG. 10** shows another example of the configuration of an imaging system of a digital still camera;

[0039] **FIG. 11** is a flowchart illustrating a shading correction process performed by the digital still camera shown in **FIG. 10**;

[0040] **FIG. 12** shows another example of the configuration of an imaging system of a digital still camera;

[0041] **FIG. 13** is a flowchart illustrating a shading correction process performed by the digital still camera shown in **FIG. 12**;

[0042] **FIG. 14** shows another example of the configuration of an imaging system of a digital still camera;

[0043] **FIG. 15** shows another example of the configuration of an imaging system of a digital still camera;

[0044] **FIG. 16** shows another example of the configuration of an imaging system of a digital still camera; and

[0045] **FIG. 17** is a block diagram showing an example of the configuration of a personal computer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0046] The best mode for practicing the present invention will now be described below. Before that, the corresponding relationship between the invention described in the specification and the embodiments will be described with examples as follows. Even if there is an embodiment which is not described here as an embodiment corresponding to the invention although described in another specification, this fact does not mean that the embodiment does not correspond to the invention. Conversely, even if the embodiment is described here as that corresponding to the invention, this fact does not mean that the embodiment does not correspond to the invention other than that invention.

[0047] Furthermore, this description does not mean that all the aspects of the invention corresponding to the embodiments described in the specification are described. In other words, this description does not deny the existence of another invention described in another specification, that is, the existence of an invention, which will be divisionally applied for patent, or will appear or will be added by amendments in the future.

[0048] An image processing apparatus (for example, a digital still camera of **FIG. 3**) as set forth in the first aspect of the present invention is an image processing apparatus for correcting the shading of a captured image, the image processing apparatus including a first distance computation section (for example, an up-and-down and right-and-left weighting section **22** of **FIG. 3** for performing processing of step **S3** in **FIG. 9**, and a pseudo-distance computation section **42** of a distance computation section **23** of **FIG. 3** for performing processing of step S7) for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain; an obtaining section (for example, look-up tables **24** and **25** of **FIG. 3** for performing processing of step **S8** in **FIG. 9**) for obtaining a correction value for correcting the shading of an image on the basis of the distance computed by the first distance computation section; and a correction section (for example, a correction section **29** of **FIG. 3** for performing processing of step S12 in **FIG. 9**) for correcting the signal of each pixel on the basis of the correction value obtained by the obtaining section.

[0049] The obtaining section of the image processing apparatus obtains a plurality of correction values (for example, a correction coefficient for a zoom wide end, and a correction coefficient for a zoom tele end).

[0050] The image processing apparatus of the present invention further includes mixture-ratio setting means (for example, a blend ratio setting section **26** of **FIG. 3** for performing processing of step **S9** in **FIG. 9**) for setting the mixture ratio of the plurality of correction values obtained by the obtaining section; and a mixing section (for example, a gain blend processing section **27** of **FIG. 3** for performing processing of step **S10** in **FIG. 9**) for mixing the plurality of correction values on the basis of the mixture ratio set by the mixture-ratio setting means, wherein the correction section corrects the signal of each pixel on the basis of the correction value mixed by the mixing section.

[0051] The mixture-ratio setting means of the image processing apparatus of the present invention sets the mixture ratio on the basis of the lens zoom position, the aperture stop value, the focus position, the image height, the exit pupil position, or the amount of strobe light emission (for example, in accordance with a predetermined position between the minimum side and the maximum side).

[0052] The image processing apparatus of the present invention further includes a gain adjustment section (for example, a gain adjustment section **28** of **FIG. 3** for performing processing of step S11 in **FIG. 9**) for adjusting the gain of the correction value obtained by the obtaining section.

[0053] The image processing apparatus of the present invention further includes, when the image is composed of three colors of a G pixel, an R pixel, and a B pixel: a second distance computation section (for example, an up-and-down and right-and-left weighting section **22** of **FIG. 3** for performing processing of step S5 in **FIG. 9**) for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with the G pixel; a first distance balance gain correction section (for example, a distance balance processing section **41** of **FIG. 3** for performing processing of step S6 in **FIG. 9**) for multiplying the distance gain in which the G pixel is used as a reference by the distance balance gain of the R pixel; and a second distance balance gain correction section (for example, the distance balance processing section **41** of **FIG. 3** for performing processing of step S6 in **FIG. 9**) for multiplying the distance gain in which the G pixel is used as a reference by the distance balance gain of the B pixel.

[0054] The image processing apparatus of the present invention further includes, when the image is composed of four colors of a Gr pixel, an R pixel, a B pixel, and a Gb pixel, or four colors of an E pixel, an R pixel, a B pixel, and a G pixel: a second distance computation section (the up-and-down and right-and-left weighting section **22** of **FIG. 3** for performing processing of step S5 in **FIG. 9**) for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with the Gb pixel or the G pixel; a first distance balance gain correction section (the distance balance processing section **41** of **FIG. 3** for performing processing of step S6 in **FIG. 9**) for multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the up-and-down and right-to-left distance balance gain of the R pixel; a second distance balance gain correction section (the distance balance processing section **41** of **FIG. 3** for performing processing of step S6 in **FIG. 9**) for multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the distance balance gain of the B pixel; and a third distance balance gain correction section (the distance balance processing section **41** of **FIG. 3** for performing processing of step S6 in **FIG. 9**) for multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the distance balance gain of the Gr pixel or the E pixel.

[0055] The image processing method for use with an image processing apparatus (for example, the digital still camera of **FIG. 3**) for correcting shading of a captured image as set forth in the second aspect of the present invention includes: a first distance computation step (for example, steps S3 and S7 in **FIG. 9**) of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain; an obtaining step (for example, step S8 in **FIG. 9**) of obtaining a correction value for correcting the shading of the image on the basis of the distance computed in the process of the first distance computation step; and a correction step (for example, step S12 in **FIG. 9**) of correcting the signal of each of the pixels on the basis of the correction value obtained in the process of the obtaining step.

[0056] The image processing method of the present invention further includes, when the image is composed of three colors of a G pixel, an R pixel, and a B pixel: a second distance computation step (for example, step S5 in **FIG. 9**) of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain by using the G pixel as a reference; a first distance balance gain correction step (for example, step S6 in **FIG. 9**) of multiplying the distance gain in which the G pixel is used as a reference by the distance balance gain of the R pixel; and a second distance balance gain correction step (for example, step S6 in **FIG. 9**) of multiplying the distance gain in which the G pixel is used as a reference by the distance balance gain of the B pixel.

[0057] The image processing method of the present invention further includes, when the image is composed of four colors of a Gr pixel, an R pixel, a B pixel, and a Gb pixel, or four colors of an E pixel, an R pixel, a B pixel, and a G pixel: a second distance computation step (for example, step S5 of **FIG. 9**) of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with the Gb pixel or the G pixel; a first distance balance gain correction step (for example, step S6 of **FIG. 9**) of multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the distance balance gain of the R pixel; a second distance balance gain correction step (for example, step S6 of **FIG. 9**) of multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the distance balance gain of the B pixel; and a third distance balance gain correction step (for example, step S6 of **FIG. 9**) of multiplying the distance gain in which the Gb pixel or the G pixel is used as a reference by the distance balance gain of the Gr pixel or the E pixel.

[0058] In the program recorded on the recording medium as set forth in the third aspect of the present invention, and the program as set forth in the fourth aspect of the present invention, an embodiment (one example) to which each step corresponds is identical to that of the image processing method as set forth in the second aspect of the present invention.

[0059] Embodiments of the present invention will now be described below with reference to the drawings.

[0060] **FIG. 2** is a block diagram showing an example of the basic configuration of a camera system to which the present invention is applied. In this example of the configuration, the camera system is broadly divided into three blocks of (i) an imaging system including a lens **1**, an imaging device **2**, an imaging section **3** having a CDS (Correlated Double Sampling) circuit; an AGC (Automatic Gain Control) circuit; and an A/D (Analog to Digital) converter, a shading correction section **4**, and a camera signal processing section **5**; (ii) a display system including a display section **6**; and (iii) a recording system including a recording section **7**.

[0061] The lens **1** allows light (i.e., a video image of a subject) to enter the imaging device **2**. The imaging device **2** is, for example, such that photoelectric conversion devices for performing photoelectric conversion, including CCD

(Charge Coupled Devices) imagers and C-MOS (Complementary Metal Oxide Semiconductor) imagers, are arranged two-dimensionally, with R, G, and B primary-color filters (not shown) arranged in a mosaic form being disposed in front of the photoelectric conversion devices. That is, the imaging device **2** photoelectrically converts an optical image of a subject, which enters via the lens **1** and the primary-color filters, in order to generate a captured image signal (charge), and outputs the generated captured signal to the imaging section **3** by a raster scanning method. For the primary-color filters, complementary-color-system filters in which Ye, Cy, Mg, and G filters are arranged in a mosaic form may be used.

[**0062**] In the imaging section **3**, noise reduction is performed on the captured image signal output from the imaging device **2** at the CDS circuit, and gain adjustment is performed on the signal at the AGC circuit, the signal is converted from an analog signal into a digital signal at the A/D converter, after which the signal is supplied to the shading correction section **4**.

[**0063**] The shading correction section **4** corrects the reduction of the amount of peripheral light of the image-capturing plane due to lens shading with respect to the captured image data supplied from the imaging section **3**, and thereafter, supplies the data to the camera signal processing section **5**.

[**0064**] The camera signal processing section **5** performs signal processing, such as gamma processing, color separation processing, and YUV conversion at a ratio of 4:2:2, on the captured image data supplied from the shading correction section **4** so as to generate image data composed of luminance signal data and chroma signal data. The camera signal processing section **5** supplies the generated image data to the display section **6**, whereby the corresponding image is displayed, or supplies the generated image data to the recording section **7**, whereby the image data is recorded.

[**0065**] The display section **6** includes, for example, an LCD (Liquid-Crystal Display), and displays the image of a subject supplied from the camera signal processing section **5**. The recording section **7** controls, for example, a removable medium such as a magnetic disk, an optical disk, a magneto-optical disk, or a semiconductor memory, and records image data supplied from the camera signal processing section **5** on the removable medium.

[**0066**] Next, a description will be given of the operation of correcting shading of the camera system configured as described above.

[**0067**] An optical image of a subject enters the imaging device **2** via the lens **1**, and as a result of being photoelectrically converted thereby, a captured image signal is generated. The captured image signal is subjected to noise reduction, gain adjustment, and A/D conversion in the imaging section **3**, and is output as captured image data (a digital video signal) to the shading correction section **4**. Here, since shading is considered to occur in proportion to the distance from the optical-axis center, the distance from the optical-axis center is computed by the shading correction section **4**, a shading correction coefficient corresponding to the distance is read from the correction coefficient table, and the shading is corrected by multiplying the captured image data by the correction coefficient. Then, the camera signal processing section **5** performs signal processing, such as gamma processing, color separation processing, and YUV conversion on the captured image data in which shading is corrected, thereby generating image data composed of luminance signal data and chroma signal data. The camera signal processing section **5** outputs the generated image data to the display section **6** or the recording section **7**.

[**0068**] Next, a description will be given below of a specific example of the camera system shown in **FIG. 2**.

[**0069**] **FIG. 3** shows an example of the configuration of an imaging system of a digital still camera provided with a function for correcting, for example, the reduction of the amount of peripheral light in real time by reading the correction table based on the distance to the optical-axis center. Components in **FIG. 3**, which correspond to those of **FIG. 2**, are designated with the corresponding reference numerals, and descriptions thereof are omitted where appropriate.

[**0070**] A signal generator (SG) **11** generates a horizontal reset signal and a vertical reset signal, and supplies these signals to a timing generator (TG) **12**. Also, the signal generator **11** generates a horizontal counter value and a vertical counter value, and supplies these signals to an optical-axis-center coordinate setting section **21** of the shading correction section **4**.

[**0071**] Based on the horizontal reset signal and the vertical reset signal supplied from the signal generator **11**, the timing generator **12** generates a horizontal driving signal and a vertical driving signal, and supplies these signals to the imaging device **2**. As a result, the signal of each pixel at which an image is captured is read from the imaging device **2** in accordance with the horizontal driving signal and the vertical driving signal generated at the timing generator **12**.

[**0072**] Based on the horizontal counter value and the vertical counter value supplied from the signal generator **11**, the optical-axis-center coordinate setting section **21** computes optical-axis-center position information data. For example, when the pixel length in the horizontal direction of 5 million pixels is 2560 pixels, in order that the value of the optical-axis center becomes zero, this is achieved by subtracting the value of ½ of the pixel length, that is, the value of 1280, from the horizontal counter value. Furthermore, when the line length in the vertical direction of 5 million pixels is 1920 lines, in order that the value of the optical-axis center becomes zero, this is achieved by subtracting the value of ½ of the line length, that is, the value of 960, from the vertical counter value.

[**0073**] The up-and-down and right-and-left weighting section **22** multiplies the horizontal counter value by the horizontal distance gain on the right side or the horizontal distance gain on the left side, the distance gain being used as a weight, when viewed from the optical-axis-center position based on the optical-axis-center position information data computed by the optical-axis-center coordinate setting section **21**. For example, in a case where the pixel length in the horizontal direction of 5 million pixels is 2560 pixels, if the value of ½ of the pixel length, that is, the value of 1280, is subtracted from the horizontal counter value, the value of zero is computed in a portion in the optical-axis center, a negative value is computed in a portion to the left of the optical-axis center, and a positive value is computed

in a portion to the right of the optical-axis center. In this manner, in the up-and-down and right-and-left weighting section **22**, a determination is made as to which is the left side or the right side when viewed from the optical-axis-center position, and the right-side horizontal distance gain or the left-side vertical distance gain, which is used as a weight, is multiplied to the horizontal counter value.

[**0074**] Furthermore, the up-and-down and right-and-left weighting section **22** multiplies the vertical counter value by the vertical distance gain on the upper side or the vertical distance gain on the lower side, the distance gain being used as a weight, when viewed from the optical-axis-center position based on the optical-axis-center position information data computed by the optical-axis-center coordinate setting section **21**. For example, when the line length in the vertical direction of 5 million pixels is 1920 lines, if the value of ½ of the line length, that is, the value of 960, is subtracted from the vertical counter value, the value of zero is computed in the optical-axis center, a negative value is computed above the optical-axis center, and a positive value is computed below the optical-axis center. In this manner, in the up-and-down and right-and-left weighting section **22**, a determination is made as to which is the upper side or the lower side when viewed from the optical-axis-center position, and the horizontal distance gain on the upper side or the vertical distance gain on the lower side, the distance gain being used as a weight, is multiplied to the vertical counter value.

[**0075**] Furthermore, in order to perform weighting to the horizontal counter value and the vertical counter value, the up-and-down and right-and-left weighting section **22** performs up-and-down and right-to-left weighting commonly to the G pixel, the R pixel, and the B pixel in the case of the state as is. Furthermore, when the degrees of the up-and-down and right-to-left unbalance of the G pixel, the R pixel, and the B pixel are the same, the up-and-down and right-and-left weighting section **22** performs weighting so that the up-and-down and right-to-left balance is achieved.

[**0076**] However, when the degrees of the up-and-down and right-to-left unbalance of the G pixel, the R pixel, and the B pixel differ from one another, even if a common up-and-down and right-to-left weighting process is performed, unbalance for each color cannot be corrected.

[**0077**] Referring now to **FIG. 4**, a description will be given of an example of a case where the degrees of the up-and-down and right-to-left unbalance of the G pixel, the R pixel, and the B pixel differ from one another.

[**0078**] Parts A to C of **FIG. 4** show states in which an image whose right-to-left balance is degraded at a degree which is different for each color due to color shading is subjected to shading correction. In **FIG. 4**, the vertical axis indicates shading characteristics, and the horizontal axis indicates the position at the zoom wide end.

[**0079**] Part A of **FIG. 4** shows a waveform in which single shading which differs for each of RGB occurs, and right-to-left balance is degraded at a degree which is different for each color. In this state, a state in which, for example, the G pixel is taken note of, and the up-and-down and right-and-left weighting section **22** performs right-to-left weighting in accordance with the G pixel, and the gain adjustment section **28** multiplies a correction gain is shown in Part B of **FIG. 4**. Here, weighting and a correction gain are not yet performed to the R pixel and the B pixel.

[**0080**] Part C of **FIG. 4** shows that, since the R pixel and the B pixel are in the state of single shading, the single shading is not removed even if the up-and-down and right-and-left weighting section **22** performs right-to-left weighting in accordance with the G pixel, or the gain adjustment section **28** makes a correction by a color-by-color gain.

[**0081**] The reason for this is that, after the up-and-down and right-and-left weighting section **22** performs right-to-left weighting in accordance with the G pixel, the gain adjustment section **28** uniformly multiplies a color-by-color gain with respect to the up-and-down and right-to-left of the image plane. That is, if a gain is multiplied while being kept in the state of single shading, in the case of the single shading upward from left to right, the single shading remains while the left-side shading is not corrected, and in the case of the single shading upward from right to left, the single shading remains while the right-side shading is not corrected.

[**0082**] In the case of an image whose up-and-down balance is degraded at a degree which is different for each color, also, in the manner described above, shading cannot be corrected similarly to the case of an image whose right-to-left balance is degraded at a degree which is different for each color.

[**0083**] Therefore, in order to correct that the right-to-left or up-and-down balance is degraded at a degree which is different for each color due to color shading, the distance balance processing section **41** is provided inside the distance computation section **23** of **FIG. 3**.

[**0084**] Referring now to **FIG. 5**, a description will be given below of an example of a case where the degradation of right-to-left or up-and-down balance at a degree which is different for each color due to color shading is corrected.

[**0085**] Parts A to D of **FIG. 5** show states in which an image whose right-to-left or up-and-down balance is degraded at a degree which is different for each color due to color shading is corrected by performing color shading balance. In **FIG. 5**, the vertical axis indicates shading characteristics, and the horizontal axis indicates the position at the zoom wide end.

[**0086**] Part A of **FIG. 5** shows a waveform in which single shading which differs for each of RGB occurs, and right-to-left balance is degraded at a degree which is different for each color. In this state, for example, the G pixel is taken note of, and the up-and-down and right-and-left weighting section **22** performs weighting of up-and-down and right-to-left distances in accordance with the G pixel. That is, the up-and-down and right-and-left weighting section **22** multiplies the horizontal or vertical counter value by a gain corresponding to the up-and-down and right-to-left distance from the optical-axis center, the gain being used as a weight, in accordance with the shading of the G pixel. Thereafter, the distance balance processing section **41** performs a distance balance process for achieving balance of the distance for the G pixel on each of the R pixel and the B pixel. That is, the distance balance processing section **41** achieves balance of the length of the distance from the optical-axis center on the left side and the length of the distance from the optical-axis

center on the right side by dividing into the R pixel and the B pixel. The same applies to the upper side and the lower side.

[0087] The result is shown in part B of **FIG. 5**. Each single shading of the R pixel and the B pixel is removed by the distance balance process. This makes it possible to converge the intensity of the correction gain and to obtain a flat level in which the correction result is the same as that of the G pixel.

[0088] **FIG. 6** shows a default H distance of right-to-left balance (the right-to-left distance gain is lx) in the computation of the distance from the optical-axis center. In **FIG. 6**, the vertical axis indicates the H distance of right-to-left balance, and the horizontal axis indicates the H counter value. The H counter value is calculated in such a manner that the horizontal counter value supplied from the signal generator **11** is obtained, the optical-axis center takes a value of zero, the left side takes a negative value, and the right side takes a positive value. In the default, the absolute value of the H counter value becomes the H distance (the default distance **L11**) as is (in the case where the right-to-left distance gain is lx). In this manner, the distance balance processing section **41** corrects the reduction of the amount of peripheral light in accordance with the H distance.

[0089] A description will now be given below of a basic method of adjusting a right-to-left distance balance. Here, an example of a balance distance in a case where, as names of variables, Default_dist is set as the default distance, and BAL_dist is set as a balance distance (distance for adjusting unbalance) is shown in the following equations (1) and (2). It is assumed here that equation (1) is used for a case in which the H distance is negative, equation (2) is used for a case in which the H distance is positive, and the coefficient is from 0.0 to 1.998046875 (u,1,9).

$$BAL\_dist=Default\_dist\times coefficient \quad (1)$$

$$BAL\_dist=2.0\times Default\_dist-(Default\_dist\times coefficient) \quad (2)$$

[0090] Of course, in addition to the above-described equations, other equations of calculating the balance distance can be used as long as they satisfy the achievement of the distance balance.

[0091] Furthermore, as shown in **FIG. 7**, in the case of an unbalance H distance upward from right to left (a balance distance L12 in the case of an example of **FIG. 7**), the distance balance is achieved so that, since the distance on the left side is shorter, the distance on the right side is increased correspondingly. Furthermore, as shown in **FIG. 8**, in the case of an unbalance H distance (a balance distance L21 in the case of an example of **FIG. 8**) upward from left to right, the distance balance is achieved so that, since the distance on the left side is longer, the distance on the right side is decreased correspondingly.

[0092] In this manner, as a result of adjusting the color-by-color unbalance before the shading correction operation is performed, if a color-by-color gain in which the gain is uniform is adjusted, it is possible to make the waveform to become closer to a flat waveform. Part C of **FIG. 5** shows a state in which, as shown in part B of **FIG. 5**, after the unbalance is adjusted color by color, the up-and-down and right-and-left weighting section **22** performs right-to-left weighting in accordance with the G pixel, and the gain adjustment section **28** multiplies a correction gain. Part D of **FIG. 5** shows a state in which, after the up-and-down and right-and-left weighting section **22** performs right-to-left weighting in accordance with the G pixel with respect to the R pixel and the B pixel, the gain adjustment section **28** adjusts the gain in accordance with the G pixel by a color-by-color gain.

[0093] The above processing makes it possible to solve color shading in which the right-to-left balance is degraded at a degree different for each color.

[0094] In the foregoing, a description is given of three-color data of green, red, and blue. The present invention can also be applied to four-color data of Gr/R/B/Gb, E/R/B/G, etc. In this case, taking note of the Gb pixel or the G pixel, the up-and-down and right-and-left weighting section **22** multiplies the horizontal or vertical counter value by a gain corresponding to the distance from each of the up-and-down and right-to-left distance from the optical-axis center in accordance with the shading of the Gb pixel or the G pixel, the gain being used as a weight.

[0095] Thereafter, the distance balance processing section **41** performs a distance balance process for achieving balance of the distance for the Gb pixel or the G pixel with respect to each of the Gr pixel, the R pixel, and the B pixel, or each of the E pixel, the R pixel, and the B pixel. That is, the balance of the length of the distance from the optical-axis center on the left side and the length of the distance from the optical-axis center on the right side is achieved. The same applies to the upper side and the lower side.

[0096] In the manner described above, regarding the four-color data of Gr/R/B/Gb, E/R/B/G, etc., color shading in which right-to-left balance is degraded at a degree different for each color can be solved.

[0097] A pseudo-distance computation section **42** of the distance computation section **23** is formed of a 16-sided polygon (hexadecagon) pseudo-distance calculation circuit for computing the distance d by an approximation using a polygon for the purpose of reducing the circuit scale. In the up-and-down and right-and-left weighting section **22**, the weighting of the up-and-down and right-to-left distances is performed, and in the distance balance processing section **41**, based on the data in which distance balance is achieved, the distance d to the optical-axis-center position is computed on the basis of the following equation (3). Here, the coordinates from the optical-axis center are denoted as (x, y), and the absolute values thereof are denoted as X and Y.

$$d=(X+Y)+3/8\times\{|X-Y|+3/8\times\{|X-2Y|+|2X+Y|\}\} \quad (3)$$

[0098] The details of the hexadecagon pseudo-distance calculation are disclosed in Japanese Unexamined Patent Application Publication Nos. 2002-216136 and 2002-237998.

[0099] If the hexadecagon pseudo-distance calculation is simply calculated, a nearly regular 16-sided polygon is formed. However, here, since weights of up-and-down and right-to-left distances are multiplied, it is not always that the shape is formed closer to a regular 16-sided polygon.

[0100] In the look-up tables **24** and **25**, for example, a correction coefficient table for correcting, for example, the reduction of the amount of peripheral light at the zoom wide end and a correction coefficient table for correcting, for example, the reduction of the amount of peripheral light at the zoom tele end are generated in advance and stored. The look-up tables **24** and **25** obtain a correction coefficient at the zoom wide end and a correction coefficient at the zoom tele end, which correspond to the distance data to the optical-axis-center position, which is computed by the distance

Samsung Exhibit 1002, Page 325 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

computation section **23**, and supply the correction coefficients to the gain blend processing section **27**

[**0101**] In the look-up tables **24** and **25**, two correction coefficients for the zoom wide end and for the zoom tele end are stored. In addition, for example, two correction coefficients in which the aperture stop is open and the aperture stop is closed may be stored. Furthermore, two correction coefficients between the minimum side and the maximum side of the focus position, the image height, the exit pupil position, and the amount of strobe light emission may be stored.

[**0102**] The blend ratio setting section **26** sets the mixture (blend) ratio of two correction coefficients (the correction coefficient at the zoom wide end and the correction coefficient at the zoom tele end) according to each zoom position between the zoom wide end and the zoom tele end. More specifically, when the mixture ratio is set to 0, only the correction coefficient obtained from one of the look-up tables **24** and **25** (for example, the look-up table **24**) is used. Then, as the value of the mixture ratio is set to be greater, the ratio of the correction coefficient obtained from the other table (for example, the look-up table **25**) becomes greater.

[**0103**] Furthermore, the blend ratio setting section **26** sets the mixture ratio of two correction coefficients according to a predetermined position between the minimum side and the maximum side of the aperture stop value, the focus position, the image height, the exit pupil position, or the amount of strobe light emission.

[**0104**] When the two correction coefficients which are read from the look-up tables **24** and **25** correspondingly are, for example, subjected to shading correction at the zoom position, the gain blend processing section **27** mixes them at a mixture ratio determined by the blend ratio setting section **26** according to the zoom position in order to compute the shading correction coefficient. Furthermore, when shading is to be corrected, for example, by one of the aperture stop value of the image-capturing lens, the focus position, the image height, the exit pupil position, or the amount of strobe light emission, the gain blend processing section **27** mixes two correction coefficients read from the look-up tables **24** and **25** correspondingly at a mixture ratio determined according to a predetermined position between the minimum side and the maximum side in order to compute the shading correction coefficient.

[**0105**] For example, when the correction coefficient read from the look-up table **24** is denoted as A, the correction coefficient read from the look-up table **25** is denoted as B, and the mixture ratio set by the blend ratio setting section **26** is denoted as R, the blended shading correction coefficient C is computed on the basis of the following equation (4).

$$\begin{aligned} C &= (1-R)\cdot A + R\cdot B \\ &= A - R\cdot A + R\cdot B \\ &= A - R\cdot(A-B) \end{aligned} \tag{4}$$

[**0106**] The gain adjustment section **28** identifies a color information signal of Gr/R/B/Gb, G/R/B/E, etc., and multiplies the shading correction coefficient blended at the gain blend processing section **27** by a color-by-color gain for each of the four colors. This color-by-color gain also serves the function of the degree of influence of shading correction, and the degree of influence of correction means that the intensity of correction is set for each photo-taking scene.

[**0107**] Based on the shading correction coefficient which is gain adjusted at the gain adjustment section **28**, the correction section **29** corrects the reduction of the amount of peripheral light according to the distance to the optical-axis-center position with respect to the signal of each pixel, which is supplied from the imaging section **3**. This correction section **29** is generally formed of a multiplier for multiplying a correction coefficient, but may be an adder in a case where a correction is made by adding an offset.

[**0108**] The camera signal processing section **5** performs an interpolation process and a simultaneous process on an image signal whose shading is corrected at the correction section **29**, and forms output image signals (Y/C signals) to be output to terminals **31** and **32**.

[**0109**] Referring now to the flowchart in **FIG. 9**, a description will be given of a shading correction process performed by the digital still camera having an imaging system shown in **FIG. 3**. In this process, a description is given of three-color data of green, red, and blue, but this process can also be applied to four-color data of Gr/R/B/Gb, E/R/B/G, etc., in a similar manner.

[**0110**] In step **S1**, the imaging device **2** reads the signal of each pixel at which an image is captured in accordance with the horizontal driving signal and the vertical driving signal generated at the timing generator **12**. In step **S2**, based on the horizontal counter value and the vertical counter value generated at the signal generator **11**, the optical-axis-center coordinate setting section **21** subtracts the value of ½ of the pixel length of the imaging device **2** from the horizontal counter value and subtracts the value of ½ of the line length from the vertical counter value in order to compute the optical-axis-center position information data.

[**0111**] In step **S3**, the up-and-down and right-and-left weighting section **22** multiplies the horizontal counter value by a horizontal distance gain on the right side or a horizontal distance gain on the left side, when viewed from the optical-axis-center position based on the optical-axis-center position information data computed in the process of step **S2**, the horizontal distance gain being used as a weight, and multiplies the vertical counter value by a vertical distance gain on the upper side or a vertical distance gain on the lower side, the gain being used as a weight.

[**0112**] In step **S4**, the up-and-down and right-and-left weighting section **22** determines whether or not the image is an image in which the right-to-left or up-and-down balance is degraded at a degree which is different for each color, that is, color shading has occurred. When it is determined that color shading has occurred, the process proceeds to step **S5**. In step **S5**, the up-and-down and right-and-left weighting section **22** performs a distance computation process for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain by dividing into the upper side, the lower side, the left side, and the right side of the image plane in accordance with the green pixel. In step **S6**, the distance balance processing section **41** of the distance computation section **23** performs a red distance balance computation for multiplying the

distance gain in which the green pixel is used as a reference by up-and-down and right-to-left balance gains of the red pixel, and a blue distance balance computation for multiplying the distance gain in which the green pixel is used as a reference by up-and-down and right-to-left balance gains of the blue pixel.

[0113] After the process of step S6, or when it is determined in step S4 that color shading has not occurred, the process proceeds to step S7. In this step, based on the data to which weights of up-and-down and right-to-left distances are assigned in the process of step S3 and based on the data in which distance balance is achieved when the processing of steps S5 and S6 is completed, the pseudo-distance computation section 42 of the distance computation section 23 computes the distance d to the optical-axis-center position on the basis of equation (3) described above.

[0114] As a result of the processing up to this point, for each pixel read from the imaging device 2, the horizontal counter value and the vertical counter value, corresponding to the pixel, is supplied from the signal generator 11 via the optical-axis-center coordinate setting section 21 and the up-and-down and right-and-left weighting section 22 to the distance computation section 23, whereby the distance to the optical-axis-center position is computed.

[0115] In step S8, the look-up tables 24 and 25 obtain the correction coefficient for the zoom wide end and the correction coefficient for the zoom tele end, which correspond to the distance to the optical-axis-center position for each pixel, the distance being computed in the process of step S7, respectively. In step S9, the blend ratio setting section 26 sets the mixture ratio of two correction coefficients obtained in the process of step S8 in accordance with each zoom position between the zoom wide end and the zoom tele end. In step S10, based on the equation (4) described above, the gain blend processing section 27 mixes the correction coefficient for the zoom wide end and the correction coefficient for the zoom tele end, obtained in the process of step S8, at a predetermined mixture ratio set in the process of step S9, in order to compute the shading correction coefficient C.

[0116] As a result of processing up to this point, even if shading characteristics differ greatly at both ends of the wide end and the tele end of the zoom position of the image-capturing lens, by mixing the two types of correction coefficients of the two ends at a mixture ratio which is determined according to a predetermined zoom position between the wide end and the tele end, the shading correction coefficient can be easily computed without degrading the correction accuracy.

[0117] Similarly, even if the shading characteristics differ greatly between two ends of the aperture stop value, the focus position, the image height, the exit pupil position, and the amount of strobe light emission on the minimum side and those on the maximum side, by mixing the correction coefficients at the two ends at a mixture ratio determined according to a predetermined position between the minimum side and the maximum side, also, the shading correction coefficient can easily be computed without degrading the correction accuracy.

[0118] In step S11, the gain adjustment section 28 multiplies the shading correction coefficient computed in the process of step S10 by a color-by-color gain for each of the three colors. In step S12, the correction section 29 makes a correction of, for example, the reduction of the amount of peripheral light corresponding to the distance to the optical-axis-center position with respect to the signal of each pixel read from the imaging device 2 in the process of step S1 on the basis of the shading correction coefficient which is gain adjusted in the process of step S11.

[0119] As described above, even if the shading characteristics are inclined to the up-and-down or right-to-left of the image plane, by performing up-and-down and right-to-left weighting of the distance from optical-axis-center position, the up-and-down and right-to-left balance of the image signal is achieved, the distance is computed using equation (3) which is approximated by a polygon, and the correction coefficients corresponding to the computed distance values are obtained from the two look-up tables 24 and 25, correspondingly. Then, the two obtained correction coefficients are blended at the mixture ratio which is determined according to a predetermined position between two ends, that is, the wide end and the tele end of the zoom position of the image-capturing lens, thus computing the target shading correction coefficient. As a result, even if the zoom position of the image-capturing lens is at any position between the wide end and the tele end, the shading correction coefficient can easily be computed without degrading the correction accuracy. Therefore, satisfactory lens shading correction can be performed with simple hardware configuration.

[0120] The look-up tables 24 and 25 are each formed of one block. In addition, for example, values corresponding to the three primary-color signals (R, G, B), a luminance signal (Y signal), or color-difference signals (Cb and Cr signals) may be stored.

[0121] In the foregoing, by reading two correction coefficients based on the distance to the optical-axis-center position, shading correction is performed in real time. In addition, when the image is thinned out in one of the vertical direction and the horizontal direction or in both directions, shading correction can similarly be performed in real time.

[0122] FIG. 10 shows an example of the configuration of an imaging system of a digital still camera provided with a function for correcting reduction of the amount of peripheral light in real time by reading a correction table based on the direction to the optical-axis-center position in a case where an image is thinned out in one of the vertical direction and the horizontal direction or in both directions. Components in FIG. 10, which correspond to those of FIG. 3, are designated with the corresponding reference numerals, and descriptions thereof are omitted where appropriate. The case of the configuration shown in FIG. 10 is identical to that of FIG. 3 except that a conversion section 52 is newly provided inside the distance computation section 23.

[0123] The distance computation section 23 computed the distance d to the optical-axis-center position on the basis of equation (3) described above from the data in which weighting of up-and-down and right-to-left distances is performed at the up-and-down and right-and-left weighting section 22 and the distance balance is achieved at the distance balance processing section 41. Thereafter, the distance computation section 23 causes the conversion section 52 to convert the value of the distance d in accordance with the thinning-out information (the reciprocal of the thinning-out rate) supplied from a terminal 51.

Samsung Exhibit 1002, Page 327 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

[0124] Referring now to the flowchart in **FIG. 11**, a description is given of a shading correction process performed by the digital still camera having an imaging system shown in **FIG. 10**.

[0125] The processing of steps S21 to S26 is identical to the above-described processing of steps S1 to S6 of **FIG. 9**, and accordingly, a description thereof is omitted. That is, the signal of each pixel at which an image is captured is read, the optical-axis-center position information data is computed on the basis of the horizontal counter value and the vertical counter value corresponding to each pixel, weighting of up-and-down and right-to-left distances, when viewed from the optical-axis-center position, is performed, and distance balance is achieved when color shading has occurred.

[0126] In step S27, the distance computation section **23** computes the distance d to the optical-axis-center position on the basis of equation (3) described above from the data in which weighting of up-and-down and right-to-left distances is performed in the process of step S23 and the data in which distance balance is achieved when the processing of steps S25 and S26 is completed. The conversion section **52** converts the computed value of the distance d on the basis of the thinning-out information supplied from the terminal **51**.

[0127] The processing of steps S28 to S31 is identical to the above-described processing of steps S9 to S12 of **FIG. 9**, and accordingly, a description thereof is omitted. That is, the correction coefficient for the zoom wide end and the correction coefficient for the zoom tele end are obtained on the basis of the distance to the optical-axis-center position for each pixel, which is converted in the process of step S27, and these coefficients are blended at a predetermined mixture ratio, thereby computing the shading correction coefficient. Then, the gain of the shading correction coefficient is adjusted, and based on the shading correction coefficient, correction of, for example, the reduction of the amount of peripheral light, corresponding to the distance to the optical-axis-center position, is made with respect to the read signal of each pixel.

[0128] As described above, even if the thinning-out of the image has been performed, the conversion section **52** converts the count value into a count value in the state in which thinning out is not performed, and the distance from the optical-axis-center position can be determined correctly. As a result, a satisfactory correction of, for example, lens shading, can be performed.

[0129] In the look-up tables **24** and **25** shown in **FIGS. 3 and 10**, a correction coefficient table for correcting, for example, the reduction of the amount of peripheral light at the zoom wide end and a correction coefficient table for correcting, for example, the reduction of the amount of peripheral light at the zoom tele end are prestored. Alternatively, for example, a correction coefficient for correcting, for example, the reduction of the amount of peripheral light can also be computed in accordance with the value of the distance to the optical-axis-center position.

[0130] **FIG. 12** shows an example of the configuration of the imaging system of a digital still camera provided with a function for correcting, for example, the reduction of the amount of peripheral light in real time by computing a correction coefficient in accordance with the value of the distance to the optical-axis-center position. Components in **FIG. 12**, which correspond to those of **FIG. 3**, are designated with the corresponding reference numerals, and descriptions thereof are omitted where appropriate. The case of the configuration shown in **FIG. 12** is identical to that of **FIG. 3** except that correction function computation sections **61** and **62** are provided in place of the look-up tables **24** and **25**.

[0131] The correction function computation sections **61** and **62** compute a correction coefficient for correcting, for example, the reduction of the amount of peripheral light at the zoom wide end and a correction coefficient for correcting, for example, the reduction of the amount of peripheral light at the zoom tele end, respectively, in accordance with the distance data to the optical-axis-center position computed by the distance computation section **23**.

[0132] Referring now to the flowchart in **FIG. 13**, a description is given of a shading correction process performed by the digital still camera having an imaging system shown in **FIG. 12**.

[0133] The processing of steps S41 to S47 is identical to the above-described processing of steps S1 to S7 of **FIG. 9**, and accordingly, a description thereof is omitted. That is, the signal of each pixel at which an image is captured is read, the optical-axis-center position information data is computed on the basis of the horizontal counter value and the vertical counter value corresponding to each pixel, weighting of up-and-down and right-to-left distances is performed, the distance balance is achieved when color shading has occurred, and the distance to the optical-axis-center position for each pixel is computed.

[0134] In step S48, the correction function computation sections **61** and **62** compute a correction coefficient for the zoom wide end and a correction coefficient for the zoom tele end, which correspond to the distance to the optical-axis-center position for each pixel, the distance being computed in the process of step S47.

[0135] The processing of steps S49 to S52 is identical to the above-described processing of steps S9 to S12 of **FIG. 9**, and accordingly, a description thereof is omitted. That is, as a result of the correction coefficient for the zoom wide end and the correction coefficient for the zoom tele end, which are computed in the process of step S48, being blended at a predetermined mixture ratio, the shading correction coefficient is computed. Then, the gain of the shading correction coefficient is adjusted, and based on the shading correction coefficient, a correction of, for example, the reduction of the amount of peripheral light, corresponding to the distance to the optical-axis-center position, is performed on the read signal of each pixel.

[0136] As described above, even if the correction coefficient table is not stored, the correction function computation sections **61** and **62** compute the correction coefficient for the zoom wide end and the correction coefficient for the zoom tele end, respectively. As a result, a satisfactory correction of, for example, lens shading can be made using the computed correction coefficients.

[0137] In the foregoing, the shading correction section **4** is provided at a stage prior to the camera signal processing section **5**. Alternatively, for example, as shown in **FIG. 14**,

the shading correction section **4** may be provided at a stage subsequent to the camera signal processing section **5**. In this case, shading correction is performed after the image signal is separated into a luminance signal (Y signal) and color-difference signals (Cb and Cr signals) in the camera signal processing section **5**. Therefore, independent processing can be performed on the luminance signal and the color-difference signals. for example, the correction of the reduction of the amount of peripheral light is performed on the luminance signal and color blur correction is performed on the color-difference signals.

[**0138**] The shading correction section **4** can also be provided at a stage subsequent to the color interpolation processing section **71** inside the camera signal processing section **5**, as shown in, for example, **FIG. 15**. In this case, when the three primary-color signals (R, G, B) for all the pixels are collected by the interpolation process by the color interpolation processing section **71**, a shading correction process is performed. Then, the three primary-color signals (R', G', B') on which the shading correction process is performed are processed so as to become simultaneous by the simultaneous processing section **72**, and output image signals (Y/C signals) are formed.

[**0139**] Furthermore, as shown in **FIG. 16**, in the device provided with a plurality of imaging devices **2-1** to **2-3**, a shading correction process may be performed for each signal of each pixel, which is read from each of the imaging devices **2-1** to **2-3**.

[**0140**] In the foregoing, even if the shading characteristics are inclined either up and down or right to left of the image plane, up-and-down and right-to-left unbalance of the shading characteristics can be corrected with simple hardware configuration.

[**0141**] Regarding one of the zoom position of the image-capturing lens, the aperture stop value, the focus position, the image height, the exit pupil position, and the amount of strobe light emission, the shading characteristics curve greatly differs between the two ends on the minimum side and on the maximum side, by obtaining or computing two types of correction coefficients, that is, a correction coefficient on the minimum side and a correction coefficient on the maximum side and by computing a target shading correction coefficient by mixing those correction coefficients at a mixture ratio determined according to a predetermined position between the minimum side and the maximum side, the correction coefficient can easily be computed without degrading correction accuracy with simple hardware configuration.

[**0142**] In the foregoing, a description is given by using as an example a digital still camera for capturing a still image. Of course, by utilizing features such that computation of a distance in real time is possible, the present invention can also be applied to a digital video camera for capturing moving images.

[**0143**] As described above, although these series of processes can be performed by hardware, the processes can also be performed by software. In this case, for example, the digital still camera having an imaging system of **FIGS. 3, 10, 12**, and **14** to **16** is realized by a personal computer **100** shown in **FIG. 17**.

[**0144**] In **FIG. 17**, a CPU (Central Processing Unit) **101** executes various processing in accordance with a program stored in a ROM (Read Only Memory) **102** or a program loaded from a storage section **108** to a RAM (Random Access Memory) **103**. In the RAM **103**, furthermore, for example, data required for the CPU **101** to execute various processing is stored as appropriate.

[**0145**] The CPU **101**, the ROM **102**, and the RAM **103** are interconnected with one another via a bus **104**. Also, an input/output interface **105** is connected to the bus **104**.

[**0146**] Connected to the input/output interface **105** are an input section **106** including a keyboard, a mouse, etc.; an output section **107** including a display unit; the storage section **108**; and a communication section **109**. The communication section **109** performs a communication process via a network.

[**0147**] Also, a drive **110** is connected to the input/output interface **105** as required. A removable medium **111**, such as a magnetic disk, an optical disk, a magneto-optical disk, or a semiconductor memory, is loaded into the drive **110** as necessary, and a computer program read therefrom is installed into the storage section **108** as necessary.

[**0148**] The recording medium for recording a computer-executable program, which is installed into the computer, is formed of a removable medium **111** composed of a magnetic disk (including a flexible disk), an optical disk (including a CD-ROM (Compact Disk-Read Only Memory) or a DVD (Digital Versatile Disk)), a magneto-optical disk (including an MD (Mini-Disk) (registered trademark)), or a semiconductor memory, the recording medium being distributed to provide a program to the user separately to the main unit of the device, as shown in **FIG. 17**. Furthermore, the recording medium is formed of the ROM **103**, a hard disk contained in the storage section **108**, in which a program is recorded, which are provided to the user by being preincorporated into the main unit of the device.

[**0149**] In this specification, the steps for writing the program stored in a recording medium may be executed chronologically according to the written orders. However, they do not have to be executed chronologically, and they may be executed concurrently or individually.

[**0150**] Furthermore, in this specification, the system designates the entire apparatus formed of a plurality of devices.

[**0151**] According to the present invention, shading can be corrected. In particular, shading can be corrected without increasing the circuit scale and the program scale and without degrading correction accuracy.

What is claimed is:

1. An image processing apparatus for correcting shading of a captured image, said image processing apparatus comprising:

a first distance computation section for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain;

an obtaining section for obtaining a correction value for correcting the shading of said image on the basis of said distance computed by said first distance computation section; and

a correction section for correcting the signal of each of said pixels on the basis of said correction value obtained by said obtaining section.

Samsung Exhibit 1002, Page 329 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

2. The image processing apparatus according to claim 1, wherein said obtaining section obtains a plurality of said correction values.

3. The image processing apparatus according to claim 2, further comprising:

a mixture-ratio setting section for setting the mixture ratio of said plurality of correction values obtained by said obtaining section; and

a mixing section for mixing said plurality of correction values on the basis of said mixture ratio set by said mixture-ratio setting section,

wherein said correction section corrects the signal of each of said pixels on the basis of said correction value mixed by said mixing section.

4. The image processing apparatus according to claim 3, wherein said mixture-ratio setting section sets said mixture ratio on the basis of the lens zoom position, the focus position, the image height, the aperture stop value, the exit pupil position, and the amount of strobe light emission.

5. The image processing apparatus according to claim 1, further comprising a gain adjustment section for adjusting the gain of said correction value obtained by said obtaining section.

6. The image processing apparatus according to claim 1, further comprising, when said image is composed of three colors of a G pixel, an R pixel, and a B pixel:

a second distance computation section for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with said G pixel;

a first distance balance gain correction section for multiplying the distance gain in which said G pixel is used as a reference by the distance balance gain of said R pixel; and

a second distance balance gain correction section for multiplying the distance gain in which said G pixel is used as a reference by the distance balance gain of said B pixel.

7. The image processing apparatus according to claim 1, further comprising, when said image is composed of four colors of a Gr pixel, an R pixel, a B pixel, and a Gb pixel, or four colors of an E pixel, an R pixel, a B pixel, and a G pixel:

a second distance computation section for computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with said Gb pixel or said G pixel;

a first balance gain correction section for multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said R pixel;

a second balance gain correction section for multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said B pixel; and

a third balance gain correction section for multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said Gr pixel or said E pixel.

8. An image processing method for use with an image processing apparatus for correcting shading of a captured image, said image processing method comprising:

a first distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain;

an obtaining step of obtaining a correction value for correcting the shading of said image on the basis of said distance computed in said first distance computation step; and

a correction step of correcting the signal of each of said pixels on the basis of said correction value obtained in said obtaining step.

9. The image processing method according to claim 8, further comprising, when said image is composed of three colors of a G pixel, an R pixel, and a B pixel:

a second distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with said G pixel;

a first distance balance gain correction step of multiplying the distance gain in which said G pixel is used as a reference by the distance balance gain of said R pixel; and

a second distance balance gain correction step of multiplying the distance gain in which said G pixel is used as a reference by the distance balance gain of said B pixel.

10. The image processing method according to claim 8, further comprising, when said image is composed of four colors of a Gr pixel, an R pixel, a B pixel, and a Gb pixel, or four colors of an E pixel, an R pixel, a B pixel, and a G pixel:

a second distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with said Gb pixel or said G pixel;

a first distance balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said R pixel;

a second distance balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said B pixel; and

a third distance balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said Gr pixel or said E pixel.

11. A recording medium having recorded thereon a computer-readable program executable to perform image processing of an image processing apparatus for correcting shading of a captured image, the program comprising:

a first distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain;

an obtaining step of obtaining a correction value for correcting the shading of said image on the basis of said distance computed in said first distance computation step; and

a correction step of correcting the signal of each of said pixels on the basis of said correction value obtained in said obtaining step.

12. The recording medium having recorded thereon a computer-readable program according to claim 11, said program further comprising, when said image is composed of three colors of a G pixel, an R pixel, and a B pixel:

a second distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with said G pixel;

a first distance balance gain correction step of multiplying the distance gain in which said G pixel is used as a reference by the distance balance gain of said R pixel; and

a second distance balance gain correction step of multiplying the distance gain in which said G pixel is used as a reference by the distance balance gain of said B pixel.

13. The recording medium having recorded thereon a computer-readable program according to claim 11, said program further comprising, when said image is composed of four colors of a Gr pixel, an R pixel, a B pixel, and a Gb pixel, or four colors of an E pixel, an R pixel, a B pixel, and a G pixel:

a second distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with said Gb pixel or said G pixel;

a first balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said R pixel;

a second balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said B pixel; and

a third balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said Gr pixel or said E pixel.

14. A program for allowing a computer to execute image processing of an image processing apparatus for correcting shading of a captured image, the program comprising:

a first distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain;

an obtaining step of obtaining a correction value for correcting the shading of said image on the basis of said distance computed in said first distance computation step; and

a correction step of correcting the signal of each of said pixels on the basis of said correction value obtained in said obtaining step.

15. The program according to claim 14, further comprising, when said image is composed of three colors of a G pixel, an R pixel, and a B pixel:

a second distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with said G pixel;

a first distance balance gain correction step of multiplying the distance gain in which said G pixel is used as a reference by the distance balance gain of said R pixel; and

a second distance balance gain correction step of multiplying the distance gain in which said G pixel is used as a reference by the distance balance gain of said B pixel.

16. The program according to claim 14, further comprising, when said image is composed of four colors of a Gr pixel, an R pixel, a B pixel, and a Gb pixel, or four colors of an E pixel, an R pixel, a B pixel, and a G pixel:

a second distance computation step of computing the distance from the image-plane center to each pixel by multiplying the distance by a distance gain in accordance with said Gb pixel or said G pixel;

a first balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said R pixel;

a second balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said B pixel; and

a third balance gain correction step of multiplying the distance gain in which said Gb pixel or said G pixel is used as a reference by the distance balance gain of said Gr pixel or said E pixel.

17. The image processing apparatus according to claim 1, further comprising a conversion section for performing a conversion, corresponding to thinning-out information of the image, on the distance computed by said distance computation section.

18. The image processing apparatus according to claim 1, wherein said obtaining section obtains said correction value by referring to a look-up table.

19. The image processing apparatus according to claim 1, wherein said obtaining section computes said correction value by computations.

* * * * *

US007609297B2

(12) **United States Patent**
Master et al.

(10) **Patent No.: US 7,609,297 B2**
(45) **Date of Patent: Oct. 27, 2009**

(54) **CONFIGURABLE HARDWARE BASED DIGITAL IMAGING APPARATUS**

(75) Inventors: **Paul L. Master**, Sunnyvale, CA (US); **John Watson**, Edgewood, WA (US)

(73) Assignee: **QST Holdings, Inc.**, San Jose, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 893 days.

(21) Appl. No.: **10/606,031**

(22) Filed: **Jun. 25, 2003**

(65) **Prior Publication Data**

US 2004/0268096 A1 Dec. 30, 2004

(51) **Int. Cl.**
H04N 5/228 (2006.01)

(52) **U.S. Cl.** **348/222.1**; 702/29

(58) **Field of Classification Search** 712/29, 712/28, 11, 15; 348/222.1

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,409,175	A	11/1968	Byrne
3,666,143	A	5/1972	Weston
3,938,639	A	2/1976	Birrell
3,949,903	A	4/1976	Benasutti et al.
3,960,298	A	6/1976	Birrell
3,967,062	A	6/1976	Dobias
3,991,911	A	11/1976	Shannon et al.
3,995,441	A	12/1976	McMillin
4,076,145	A	2/1978	Zygiel
4,143,793	A	3/1979	McMillin et al.
4,172,669	A	10/1979	Edelbach
4,174,872	A	11/1979	Fessler
4,181,242	A	1/1980	Zygiel et al.
RE30,301	E	6/1980	Zygiel
4,218,014	A	8/1980	Tracy
4,222,972	A	9/1980	Caldwell
4,237,536	A	12/1980	Enelow et al.
4,252,253	A	2/1981	Shannon
4,302,775	A	11/1981	Widergren et al.
4,333,587	A	6/1982	Fessler et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE	100 18 374	A1	10/2001

(Continued)

OTHER PUBLICATIONS

Abnous et al., "Ultra-Low-Power Domain-Specific Multimedia Processors," VLSI Signal Processing, IX, 1998, IEEE Workshop in San Francisco, CA, USA, Oct. 30—Nov. 1, 1998, pp. 461-470 (Oct. 30, 1998).

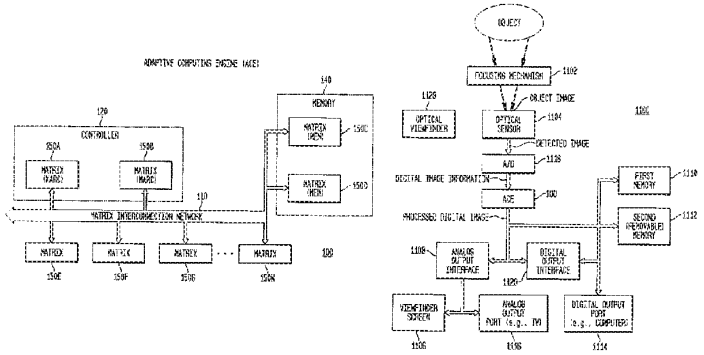
(Continued)

Primary Examiner—Lin Ye
Assistant Examiner Nelson D. Hernández Hernández
(74) *Attorney, Agent, or Firm*—Nixon Peabody LLP

(57) **ABSTRACT**

The present invention provides a digital imaging apparatus having an optical sensor, an analog-to-digital converter, a plurality of computational elements, and an interconnection network. The optical sensor converts an object image into a detected image, which is then converted to digital image information by the analog-to-digital converter. The plurality of computational elements includes a first computational element having a first fixed architecture and a second computational element having a second, different fixed architecture. The interconnection network is capable of providing a processed digital image from the digital image information by configuring and reconfiguring the plurality of computational elements for performance of a plurality of different imaging functions. The invention may be embodied, for example, as a digital camera, a scanner, a printer, or a dry copier.

35 Claims, 25 Drawing Sheets



U.S. PATENT DOCUMENTS

4,354,613	A	10/1982	Desai et al.
4,377,246	A	3/1983	McMillin et al.
4,380,046	A	4/1983	Frosch et al.
4,393,468	A	7/1983	New
4,413,752	A	11/1983	McMillin et al.
4,458,584	A	7/1984	Annese et al.
4,466,342	A	8/1984	Basile et al.
4,475,448	A	10/1984	Shoaf et al.
4,509,690	A	4/1985	Austin et al.
4,520,950	A	6/1985	Jeans
4,549,675	A	10/1985	Austin
4,553,573	A	11/1985	McGarrah
4,560,089	A	12/1985	McMillin et al.
4,577,782	A	3/1986	Fessler
4,578,799	A	3/1986	Scholl et al.
RE32,179	E	6/1986	Sedam et al.
4,633,386	A	12/1986	Terepin
4,649,512	A	3/1987	Nukiyama
4,658,988	A	4/1987	Hassell
4,694,416	A	9/1987	Wheeler et al.
4,711,374	A	12/1987	Gaunt et al.
4,713,755	A	12/1987	Worley, Jr. et al.
4,719,056	A	1/1988	Scott
4,726,494	A	2/1988	Scott
4,747,516	A	5/1988	Baker
4,748,585	A	5/1988	Chiarulli et al.
4,758,985	A	7/1988	Carter
4,760,525	A	7/1988	Webb
4,760,544	A	7/1988	Lamb
4,765,513	A	8/1988	McMillin et al.
4,766,548	A	8/1988	Cedrone et al
4,781,309	A	11/1988	Vogel
4,800,492	A	1/1989	Johnson et al.
4,811,214	A	3/1989	Nosenchuck et al.
4,824,075	A	4/1989	Holzboog
4,827,426	A	5/1989	Patton et al.
4,850,269	A	7/1989	Hancock et al.
4,856,684	A	8/1989	Gerstung
4,870,302	A	9/1989	Freeman
4,899,149	A	2/1990	Kahan
4,901,887	A	2/1990	Burton
4,905,231	A	2/1990	Leung et al.
4,921,315	A	5/1990	Metcalfe et al.
4,930,666	A	6/1990	Rudick
4,932,564	A	6/1990	Austin et al.
4,936,488	A	6/1990	Austin
4,937,019	A	6/1990	Scott
4,960,261	A	10/1990	Scott et al.
4,961,533	A	10/1990	Teller et al.
4,967,340	A	10/1990	Dawes
4,974,643	A	12/1990	Bennett et al.
4,982,876	A	1/1991	Scott
4,993,604	A	2/1991	Gaunt et al.
5,007,560	A	4/1991	Sassak
5,021,947	A	6/1991	Campbell et al.
5,040,106	A	8/1991	Maag
5,044,171	A	9/1991	Farkas
5,090,615	A	2/1992	Dabbish et al.
5,099,418	A	3/1992	Pian et al.
5,129,549	A	7/1992	Austin
5,139,708	A	8/1992	Scott
5,144,166	A	9/1992	Camarota et al.
5,156,301	A	10/1992	Hassell et al.
5,156,871	A	10/1992	Goulet et al.
5,165,023	A	11/1992	Gifford
5,165,575	A	11/1992	Scott
5,190,083	A	3/1993	Gupta et al.
5,190,189	A	3/1993	Zimmer et al.
5,193,151	A	3/1993	Jain
5,193,718	A	3/1993	Hassell et al.
5,202,993	A	4/1993	Tarsy et al.
5,203,474	A	4/1993	Haynes
5,218,240	A	6/1993	Camarota et al.
5,240,144	A	8/1993	Feldman
5,245,227	A	9/1993	Furtek et al.
5,253,192	A	10/1993	Tufts
5,261,099	A	11/1993	Bigo et al.
5,263,509	A	11/1993	Cherry et al.
5,269,442	A	12/1993	Vogel
5,280,711	A	1/1994	Motta et al.
5,297,400	A	3/1994	Benton et al.
5,301,100	A	4/1994	Wagner
5,303,846	A	4/1994	Shannon
5,335,276	A	8/1994	Thompson et al.
5,336,950	A	8/1994	Popli et al.
5,339,428	A	8/1994	Burmeister et al.
5,343,716	A	9/1994	Swanson et al.
5,361,362	A	11/1994	Benkeser et al.
5,368,198	A	11/1994	Goulet
5,379,343	A	1/1995	Grube et al
5,381,546	A	1/1995	Servi et al.
5,381,550	A	1/1995	Jourdenais et al.
5,388,062	A	2/1995	Knutson
5,388,212	A	2/1995	Grube et al.
5,392,960	A	2/1995	Kendt et al.
5,428,754	A	6/1995	Baldwin
5,437,395	A	8/1995	Bull et al.
5,450,557	A	9/1995	Kopp et al.
5,454,406	A	10/1995	Rejret et al.
5,465,368	A	11/1995	Davidson et al.
5,475,856	A	12/1995	Kogge
5,479,055	A	12/1995	Eccles
5,490,165	A	2/1996	Blakeney, II et al.
5,491,823	A	2/1996	Ruttenberg
5,507,009	A	4/1996	Grube et al.
5,515,519	A	5/1996	Yoshioka et al.
5,517,600	A	5/1996	Shimokawa
5,519,694	A	5/1996	Brewer et al
5,522,070	A	5/1996	Sumimoto
5,530,964	A	6/1996	Alpert et al.
5,534,796	A	7/1996	Edwards
5,542,265	A	8/1996	Rutland
5,553,755	A	9/1996	Boncwald et al.
5,555,417	A	9/1996	Odnert et al.
5,560,028	A	9/1996	Sachs et al.
5,560,038	A	9/1996	Haddock
5,570,587	A	11/1996	Kim
5,572,572	A	11/1996	Kawan et al.
5,590,353	A	12/1996	Sakakibara et al.
5,594,657	A	1/1997	Cantone et al.
5,600,810	A	2/1997	Ohkami
5,600,844	A	2/1997	Shaw et al.
5,602,833	A	2/1997	Zehavi
5,603,043	A	2/1997	Taylor et al.
5,607,083	A	3/1997	Vogel et al.
5,608,643	A	3/1997	Wichter et al.
5,611,867	A	3/1997	Cooper et al.
5,623,423	A	4/1997	Lipovski
5,623,545	A	4/1997	Childs et al.
5,625,669	A	4/1997	McGregor et al.
5,626,407	A	5/1997	Westcott
5,630,206	A	5/1997	Urban et al.
5,635,940	A	6/1997	Hickman et al.
5,646,544	A	7/1997	Iadanza
5,646,545	A	7/1997	Trimberger et al.
5,647,512	A	7/1997	Assis Mascarenhas de Oliveira et al.
5,667,110	A	9/1997	McCann et al.
5,684,793	A	11/1997	Kierna et al.
5,684,980	A	11/1997	Casselman
5,687,236	A	11/1997	Moskowitz et al.
5,694,613	A	12/1997	Suzuki
5,694,794	A	12/1997	Jerg et al.
5,699,328	A	12/1997	Ishizaki et al.

5,701,398	A		12/1997	Glier et al.	5,931,918	A	8/1999	Row et al.
5,701,482	A		12/1997	Harrison et al.	5,933,642	A	8/1999	Greenbaum et al.
5,704,053	A		12/1997	Santhanam	5,940,438	A	8/1999	Poon et al.
5,706,191	A		1/1998	Bassett et al.	5,949,356	A	9/1999	Kim et al.
5,706,976	A		1/1998	Purkey	5,949,415	A	9/1999	Lin et al.
5,712,996	A		1/1998	Schepers	5,950,011	A	9/1999	Albrecht et al.
5,720,002	A		2/1998	Wang	5,950,131	A	9/1999	Vilmur
5,721,693	A		2/1998	Song	5,951,674	A	9/1999	Moreno
5,721,854	A		2/1998	Ebcioglu et al.	5,953,322	A	9/1999	Kimball
5,729,754	A		3/1998	Estes	5,956,518	A	9/1999	DeHon et al.
5,732,563	A		3/1998	Bethuy et al.	5,956,967	A	9/1999	Kim
5,734,808	A		3/1998	Takeda	5,959,811	A	9/1999	Richardson
5,737,631	A		4/1998	Trimberger	5,959,881	A	9/1999	Trimberger et al.
5,742,180	A		4/1998	DeHon et al.	5,963,048	A	10/1999	Harrison et al.
5,742,821	A		4/1998	Prasanna	5,966,534	A	10/1999	Cooke et al.
5,745,366	A		4/1998	Higham et al.	5,970,254	A	10/1999	Cooke et al.
RE35,780	E		5/1998	Hassell et al.	5,987,105	A	11/1999	Jenkins et al.
5,748,688	A		5/1998	Kim et al.	5,987,611	A	11/1999	Freund
5,748,790	A		5/1998	Golin	5,987,637	A	11/1999	Thomas
5,751,295	A		5/1998	Becklund et al.	5,991,302	A	11/1999	Berl et al.
5,754,227	A	*	5/1998	Fukuoka 348/231.6	5,991,308	A	11/1999	Fuhrmann et al.
5,758,261	A		5/1998	Wiedeman	5,993,739	A	11/1999	Lyon
5,768,561	A		6/1998	Wise	5,999,734	A	12/1999	Willis et al.
5,771,362	A		6/1998	Bartkowiak et al.	6,005,943	A	12/1999	Cohen et al.
5,778,439	A		7/1998	Trimberger et al.	6,006,249	A	12/1999	Leong
5,781,135	A		7/1998	Kim et al.	6,016,395	A	1/2000	Mohamed
5,784,636	A		7/1998	Rupp	6,018,783	A	1/2000	Chiang
5,784,699	A		7/1998	McMahon et al.	6,021,186	A	2/2000	Suzuki et al.
5,787,237	A		7/1998	Reilly	6,021,492	A	2/2000	May
5,790,817	A		8/1998	Asghar et al.	6,023,742	A	2/2000	Ebeling et al.
5,791,517	A		8/1998	Avital	6,023,755	A	2/2000	Casselman
5,791,523	A		8/1998	Oh	6,028,610	A	2/2000	Deering
5,794,062	A		8/1998	Baxter	6,036,166	A	3/2000	Olson
5,794,067	A		8/1998	Kadowaki	6,039,219	A	3/2000	Bach et al.
5,796,957	A		8/1998	Yamamoto et al.	6,041,322	A	3/2000	Meng et al.
5,802,055	A		9/1998	Krein et al.	6,041,970	A	3/2000	Vogel
5,802,278	A		9/1998	Isfeld et al.	6,046,603	A	4/2000	New
5,808,570	A		9/1998	Bakhmutsky	6,047,115	A	4/2000	Mohan et al.
5,818,603	A		10/1998	Motoyama	6,052,600	A	4/2000	Fette et al.
5,821,886	A		10/1998	Son	6,055,314	A	4/2000	Spies et al.
5,822,308	A		10/1998	Weigand et al.	6,056,194	A	5/2000	Kolls
5,822,313	A		10/1998	Malek et al.	6,059,840	A	5/2000	Click, Jr.
5,822,360	A		10/1998	Lee et al.	6,061,580	A	5/2000	Altschul et al.
5,828,858	A		10/1998	Athanas et al.	6,073,132	A	6/2000	Gehman
5,829,085	A		11/1998	Jerg et al.	6,076,174	A	6/2000	Freund
5,835,753	A		11/1998	Witt	6,078,736	A	6/2000	Guccione
5,838,165	A		11/1998	Chatter	6,085,740	A	7/2000	Ivri et al.
5,838,894	A		11/1998	Horst	6,088,043	A	7/2000	Kelleher et al.
5,845,815	A		12/1998	Vogel	6,091,263	A	7/2000	New et al.
5,860,021	A		1/1999	Klingman	6,091,765	A	7/2000	Pietzold, III et al.
5,862,961	A		1/1999	Motta et al.	6,094,065	A	7/2000	Tavana et al.
5,870,427	A		2/1999	Tiedemann, Jr. et al.	6,094,726	A	7/2000	Gonion et al.
5,873,045	A		2/1999	Lee et al.	6,094,739	A	7/2000	Miller et al.
5,881,106	A		3/1999	Cartier	6,111,893	A	8/2000	Volftsun et al.
5,884,284	A		3/1999	Peters et al.	6,111,935	A	8/2000	Hughes-Hartogs
5,886,537	A		3/1999	Macias et al.	6,115,751	A	9/2000	Tam et al.
5,887,174	A		3/1999	Simons et al.	6,119,178	A	9/2000	Martin et al.
5,889,816	A		3/1999	Agrawal et al.	6,120,551	A	9/2000	Law et al.
5,890,014	A		3/1999	Long	6,122,670	A	9/2000	Bennett et al.
5,892,900	A		4/1999	Ginter et al.	6,128,307	A	10/2000	Brown
5,892,961	A		4/1999	Trimberger	6,134,605	A	10/2000	Hudson et al.
5,892,962	A		4/1999	Cloutier	6,134,629	A	10/2000	L'Ecuyer
5,894,473	A		4/1999	Dent	6,138,693	A	10/2000	Matz
5,901,884	A		5/1999	Goulet et al.	6,141,283	A	10/2000	Bogin et al.
5,903,674	A		5/1999	Ooi	6,150,838	A	11/2000	Wittig et al.
5,903,886	A		5/1999	Heimlich et al.	6,154,492	A	11/2000	Araki et al.
5,907,285	A		5/1999	Toms et al.	6,154,494	A	11/2000	Sugahara et al.
5,907,580	A		5/1999	Cummings	6,157,997	A	12/2000	Oowaki et al.
5,910,733	A	*	6/1999	Bertolet et al. 326/41	6,173,389	B1	1/2001	Pechanek et al.
5,912,572	A		6/1999	Graf, III	6,175,854	B1	1/2001	Bretscher
5,913,172	A		6/1999	McCabe et al.	6,175,892	B1	1/2001	Sazzad et al.
5,917,852	A		6/1999	Butterfield et al.	6,181,981	B1	1/2001	Varga et al.
5,920,801	A		7/1999	Thomas et al.	6,185,418	B1	2/2001	MacLellan et al.

6,192,070	B1	2/2001	Poon et al.	6,507,947	B1	1/2003	Schreiber et al.
6,192,255	B1	2/2001	Lewis et al.	6,510,138	B1	1/2003	Pannell
6,192,388	B1	2/2001	Cajolet	6,510,510	B1	1/2003	Garde
6,195,788	B1	2/2001	Leaver et al.	6,538,470	B1 *	3/2003	Langhammer et al. 326/41
6,198,924	B1	3/2001	Ishii et al.	6,556,044	B2	4/2003	Langhammer et al.
6,199,181	B1	3/2001	Rechef et al.	6,563,891	B1	5/2003	Eriksson et al.
6,202,130	B1	3/2001	Scales, III et al.	6,570,877	B1	5/2003	Kloth et al.
6,202,189	B1	3/2001	Hinedi et al.	6,577,678	B2	6/2003	Scheuermann
6,219,697	B1	4/2001	Lawande et al.	6,587,590	B1	7/2003	Pan
6,219,756	B1	4/2001	Kasamizugami	6,587,684	B1	7/2003	Hsu et al.
6,219,780	B1	4/2001	Lipasti	6,590,415	B2	7/2003	Agrawal et al.
6,223,222	B1	4/2001	Fijolek et al.	6,601,086	B1	7/2003	Howard et al.
6,226,387	B1	5/2001	Tewfik et al.	6,601,158	B1	7/2003	Abbott et al.
6,230,307	B1	5/2001	Davis et al.	6,604,085	B1	8/2003	Kolls
6,237,029	B1	5/2001	Master et al.	6,604,189	B1	8/2003	Zemlyak et al.
6,246,883	B1	6/2001	Lee	6,606,529	B1	8/2003	Crowder, Jr. et al.
6,247,125	B1	6/2001	Noel-Baron et al.	6,611,906	B1	8/2003	McAllister et al.
6,249,251	B1	6/2001	Chang et al.	6,615,333	B1	9/2003	Hoogerbrugge et al.
6,258,725	B1	7/2001	Lee et al.	6,618,434	B2	9/2003	Heidari-Bateni et al.
6,263,057	B1	7/2001	Silverman	6,618,777	B1	9/2003	Greenfield
6,266,760	B1	7/2001	DeHon et al.	6,640,304	B2	10/2003	Ginter et al.
6,272,579	B1	8/2001	Lentz et al.	6,647,429	B1	11/2003	Semal
6,272,616	B1	8/2001	Fernando et al.	6,653,859	B2	11/2003	Sihlbom et al.
6,281,703	B1	8/2001	Furuta et al.	6,675,265	B2	1/2004	Barroso et al.
6,282,627	B1	8/2001	Wong et al.	6,675,284	B1	1/2004	Warren
6,289,375	B1	9/2001	Knight et al.	6,684,319	B1	1/2004	Mohamed et al.
6,289,434	B1	9/2001	Roy	6,691,148	B1	2/2004	Zinky et al.
6,289,488	B1	9/2001	Dave et al.	6,694,380	B1	2/2004	Wolrich et al.
6,292,822	B1	9/2001	Hardwick	6,711,617	B1	3/2004	Bantz et al.
6,292,827	B1	9/2001	Raz	6,718,182	B1	4/2004	Kung
6,292,830	B1	9/2001	Taylor et al.	6,721,286	B1	4/2004	Williams et al.
6,295,089	B1	9/2001	Hoang	6,721,884	B1	4/2004	De Oliveira Kastrup Pereira et al.
6,301,653	B1	10/2001	Mohamed et al.	6,732,354	B2	5/2004	Eberling et al.
6,305,014	B1	10/2001	Roediger et al.	6,735,621	B1	5/2004	Yoakum et al.
6,311,149	B1	10/2001	Ryan et al.	6,738,744	B2	5/2004	Kirovski et al.
6,321,985	B1	11/2001	Kolls	6,748,360	B2	6/2004	Pitman et al.
6,326,806	B1	12/2001	Fallside et al.	6,751,723	B1	6/2004	Kundu et al.
6,346,824	B1	2/2002	New	6,754,470	B2	6/2004	Hendrickson et al.
6,347,346	B1	2/2002	Taylor	6,760,587	B2	7/2004	Holtzman et al.
6,349,394	B1	2/2002	Brock et al.	6,760,833	B1	7/2004	Dowling
6,353,841	B1	3/2002	Marshall et al.	6,766,165	B2	7/2004	Sharma et al.
6,356,994	B1	3/2002	Barry et al.	6,778,212	B1 *	8/2004	Deng et al. 348/222.1
6,359,248	B1	3/2002	Mardi	6,785,341	B2	8/2004	Walton et al.
6,360,256	B1	3/2002	Lim	6,807,590	B1	10/2004	Carlson et al.
6,360,259	B1	3/2002	Bradley	6,819,140	B2	11/2004	Yamanaka et al.
6,360,263	B1	3/2002	Kurtzberg et al.	6,823,448	B2	11/2004	Roth et al.
6,363,411	B1	3/2002	Dugan et al.	6,829,633	B2	12/2004	Gelfer et al.
6,366,999	B1	4/2002	Drabenstott et al.	6,832,250	B1	12/2004	Coons et al.
6,377,983	B1	4/2002	Cohen et al.	6,836,839	B2	12/2004	Master et al.
6,378,072	B1	4/2002	Collins et al.	6,859,434	B2	2/2005	Segal et al.
6,381,293	B1	4/2002	Lee et al.	6,865,664	B2	3/2005	Budrovic et al.
6,381,735	B1	4/2002	Hunt	6,871,236	B2	3/2005	Fishman et al.
6,385,751	B1	5/2002	Wolf	6,883,074	B2	4/2005	Lee et al.
6,404,815	B1	6/2002	Sekiguchi et al.	6,883,084	B1	4/2005	Donohoe
6,405,214	B1	6/2002	Meade, II	6,894,996	B2	5/2005	Lee
6,408,039	B1	6/2002	Ito	6,901,118	B2	5/2005	Hocevar et al.
6,410,941	B1	6/2002	Taylor et al.	6,901,440	B1	5/2005	Bimm et al.
6,411,612	B1	6/2002	Halford et al.	6,907,598	B2	6/2005	Fraser
6,421,372	B1	7/2002	Bierly et al.	6,912,515	B2	6/2005	Jackson et al.
6,421,809	B1	7/2002	Wuytack et al.	6,941,336	B1	9/2005	Mar
6,426,649	B1	7/2002	Fu et al.	6,980,515	B1	12/2005	Schunk et al.
6,430,624	B1	8/2002	Jamtgaard et al.	6,985,517	B2	1/2006	Matsumoto et al.
6,433,578	B1 *	8/2002	Wasson 326/38	6,986,021	B2	1/2006	Master et al.
6,434,590	B1	8/2002	Blelloch et al.	6,986,142	B1	1/2006	Ehlig et al.
6,438,737	B1	8/2002	Morelli et al.	6,988,139	B1	1/2006	Jervis et al.
6,456,996	B1	9/2002	Crawford, Jr. et al.	7,032,229	B1	4/2006	Flores et al.
6,459,883	B2	10/2002	Subramaman et al.	7,035,356	B1	4/2006	Langhammer
6,467,009	B1	10/2002	Winegarden et al.	7,044,741	B2	5/2006	Leem
6,469,540	B2	10/2002	Nakaya	7,082,456	B2	7/2006	Mani-Meitav et al.
6,473,609	B1	10/2002	Schwartz et al.	7,103,226	B1	9/2006	Frank et al.
6,483,343	B1	11/2002	Faith et al.	7,139,910	B1	11/2006	Ainsworth et al.
6,487,574	B1	11/2002	Malvai	7,142,731	B1 *	11/2006	Toi 382/307
6,507,211	B1 *	1/2003	Schultz et al. 326/37	7,249,242	B2	7/2007	Ramchandran

2001/0003191 A1 6/2001 Kovacs et al.
2001/0023482 A1 9/2001 Wray
2001/0029515 A1 10/2001 Mirsky
2001/0034795 A1 10/2001 Moulton et al.
2001/0039654 A1 11/2001 Miyamoto
2001/0048713 A1 12/2001 Medlock et al.
2001/0048714 A1 12/2001 Jha
2001/0050948 A1 12/2001 Ramberg et al.
2002/0010848 A1 1/2002 Kamano et al.
2002/0013795 A1 1/2002 Blaker
2002/0013937 A1 1/2002 Ostanevich et al.
2002/0015435 A1 2/2002 Rieken
2002/0015439 A1 2/2002 Kohli et al.
2002/0023210 A1 2/2002 Tuomenoksa et al.
2002/0024942 A1 2/2002 Tsuneki et al.
2002/0024993 A1 2/2002 Subramanian et al.
2002/0031166 A1 3/2002 Subramanian et al.
2002/0032551 A1 3/2002 Zakiya
2002/0035623 A1 3/2002 Lawande et al.
2002/0041581 A1 4/2002 Aramaki
2002/0042907 A1 4/2002 Yamanaka et al.
2002/0061741 A1 5/2002 Leung et al.
2002/0069282 A1 6/2002 Reisman
2002/0072830 A1 6/2002 Hunt
2002/0078337 A1 6/2002 Moreau et al.
2002/0083305 A1 6/2002 Renard et al.
2002/0083423 A1 6/2002 Ostanevich et al.
2002/0087829 A1 7/2002 Snyder et al.
2002/0089348 A1 7/2002 Langhammer
2002/0101909 A1 8/2002 Chen et al.
2002/0107905 A1 8/2002 Roe et al.
2002/0107962 A1 8/2002 Richter et al.
2002/0119803 A1 8/2002 Bitterlich et al.
2002/0120672 A1 8/2002 Butt et al.
2002/0133688 A1 9/2002 Lee et al.
2002/0138716 A1 9/2002 Master et al.
2002/0141489 A1 10/2002 Imaizumi
2002/0147845 A1 10/2002 Sanchez-Herrero et al.
2002/0159503 A1 10/2002 Ramachandran
2002/0162026 A1 10/2002 Neuman et al.
2002/0168018 A1 11/2002 Scheuermann
2002/0181559 A1 12/2002 Heidari-Bateni et al.
2002/0184275 A1 12/2002 Dutta et al.
2002/0184291 A1 12/2002 Hogenauer
2002/0184498 A1 12/2002 Qi
2002/0191796 A1 12/2002 Anand et al.
2003/0007606 A1 1/2003 Suder et al.
2003/0012270 A1 1/2003 Zhou et al.
2003/0018446 A1 1/2003 Makowski et al.
2003/0018700 A1 1/2003 Giroti et al.
2003/0023830 A1 1/2003 Hogenauer
2003/0026242 A1 2/2003 Jokinen et al.
2003/0030004 A1 2/2003 Dixon et al.
2003/0046421 A1 3/2003 Horvitz et al.
2003/0061260 A1 3/2003 Rajkumar
2003/0061311 A1 3/2003 Lo
2003/0063656 A1 4/2003 Rao et al.
2003/0074473 A1 4/2003 Pham et al.
2003/0076815 A1 4/2003 Miller et al.
2003/0099223 A1 5/2003 Chang et al.
2003/0102889 A1 6/2003 Master et al.
2003/0105949 A1 6/2003 Master et al.
2003/0110485 A1 6/2003 Lu et al.
2003/0131162 A1 7/2003 Secatch et al.
2003/0142818 A1 7/2003 Raghunathan et al.
2003/0154357 A1 8/2003 Master et al.
2003/0163723 A1 8/2003 Kozuch et al.
2003/0172138 A1 9/2003 McCormack et al.
2003/0172139 A1 9/2003 Srinivasan et al.
2003/0200538 A1 10/2003 Ebeling et al.
2003/0212684 A1 11/2003 Meyer et al.
2003/0229864 A1 12/2003 Watkins
2004/0006584 A1 1/2004 Vandeweerd
2004/0010645 A1 1/2004 Scheuermann et al.
2004/0015970 A1 1/2004 Scheuermann
2004/0025159 A1 2/2004 Scheuermann et al.
2004/0057505 A1 3/2004 Valio
2004/0062300 A1 4/2004 McDonough et al.
2004/0064781 A1 4/2004 Kamada
2004/0081248 A1 4/2004 Parolari
2004/0093479 A1 5/2004 Ramchandran
2004/0133745 A1 7/2004 Ramchandran
2004/0168044 A1 8/2004 Ramchandran
2004/0243916 A1 12/2004 Kim et al.
2005/0044344 A1 2/2005 Stevens
2005/0166038 A1 7/2005 Wang et al.
2005/0166073 A1 7/2005 Lee
2005/0198199 A1 9/2005 Dowling
2006/0031660 A1 2/2006 Master et al.

FOREIGN PATENT DOCUMENTS

EP 0 301 169 A1 2/1989
EP 0 166 586 B1 1/1991
EP 0 236 633 B1 5/1991
EP 0 478 624 B1 4/1992
EP 0 479 102 A2 4/1992
EP 0 661 831 A2 7/1995
EP 0 690 588 A2 1/1996
EP 0 691 754 A2 1/1996
EP 0 768 602 A2 4/1997
EP 0 817 003 A2 1/1998
EP 0 821 495 A2 1/1998
EP 0 668 659 A2 9/1998
EP 0 866 210 A2 9/1998
EP 0 923 247 A2 6/1999
EP 0 926 596 A2 6/1999
EP 1 056 217 A2 11/2000
EP 1 061 437 A1 12/2000
EP 1 061 443 A2 12/2000
EP 1 126 368 A2 8/2001
EP 1 150 506 A2 10/2001
EP 1 189 358 A1 3/2002
GB 2 067 800 A 7/1981
GB 2 237 908 A 5/1991
JP 62-249456 10/1987
JP 63-147258 6/1988
JP 4-51546 2/1992
JP 7-064789 3/1995
JP 7066718 3/1995
JP 10233676 9/1998
JP 10254696 9/1998
JP 11296345 10/1999
JP 2000315731 11/2000
JP 2001-053703 2/2001
WO WO 89/05029 A1 6/1989
WO WO 89/11443 A2 11/1989
WO WO 91/00238 A1 1/1991
WO WO 93/13603 A1 7/1993
WO WO 95/11855 A1 5/1995
WO WO 96/33558 A1 10/1996
WO WO 98/32071 A3 7/1998
WO WO 99/03776 A1 1/1999
WO WO 99/21094 A2 4/1999
WO WO 99/26860 A1 6/1999
WO WO 99/65818 A1 12/1999
WO WO 00/19311 A1 4/2000
WO WO 00/65855 A1 11/2000
WO WO 00/69073 A1 11/2000
WO WO 01/11281 A1 2/2001
WO WO 01/22235 A1 3/2001

WO WO 01/76129 A2 10/2001
WO WO 02/12978 A2 2/2002

OTHER PUBLICATIONS

Aggarwal et al., "Efficient Huffman Decoding," International Conference on Image Processing IEEE 1:936-939 (Sep. 10-13, 2000).

Allan et al., "Software Pipelining," ACM Computing Surveys, 27(3):1-78 (Sep. 1995).

Alsolaim et al., "Architecture and Application of a Dynamically Reconfigurable Hardware Array for Future Mobile Communication Systems," Field Programmable Custom Computing Machines, 2000 IEEE Symposium, Napa Valley, Los Alamitos, CA. IEEE Comput. Soc. pp. 205-214 (Apr. 17-19, 2000).

Ashenden et al., "The VHDL Cookbook," Dept. Computer Science, University of Adelaide, South Australia. Downloaded from http://tams-www.informatik.uni-hamburg.de/vhdl/doc/cookbook/VHDL-Cookbook.pdf on Dec. 7, 2006 (Jul. 1990).

Bacon et al., "Compiler Transformations for High-Performance Computing," ACM Computing Surveys 26(4):368-373 (Dec. 1994).

Balasubramonian et al., "Reducing the Complexity of the Register File in Dynamic Superscalar Processors," Proceedings of the 34th Annual ACM/IEEE International Symposium on Microarchitecture, pp. 237-248 (Dec. 1, 2001).

Banerjee et al., "A Matlab Compiler for Distributed, Heterogeneous, Reconfigurable Computing Systems," 2000 IEEE Symposium, pp. 39-48, (Apr. 17-19, 2000).

Bapte et al., "Uniform Execution Environment for Dynamic Reconfiguration," Darpa Adaptive Computing Systems, http://isis.vanderbilt.edu/publications/archive/babty_T_#_0_1999_Uniform_Ex.pdf, pp. 1-7 (1999).

Baumgarte et al., "Pact XPP_A Self-Reconfigurable Data Processing Architecture," NN www.pactcorp.com/sneu/download/ersa01.pdf; retrieved on Nov. 25, 2005 (Jun. 25, 2001).

Becker et al., "An Application-Tailored Dynamically Reconfigurable Hardware Architecture for Digital Baseband Processing," IEEE Conference Proceedings Article pp. 341-346 (Sep. 18, 2000).

Becker et al., "Design and Implementation of a Coarse-Grained Dynamically Reconfigurable Hardware Architecture," VLSI 2001, Proceedings IEEE Computer Soc. Workshop, Piscataway, NJ, USA, pp. 41-46 (Apr. 19-20, 2001).

Bevstar, BevStar Bottled Water Model Advertisement *Automatic Merchandiser* at www.AMonline.com (2005).

Bevstar, BevStar Point of Use Water Model Advertisement *Automatic Merchandiser* at www.AMonline.com (2005).

Bishop & Loucks, "A Heterogeneous Environment for Hardware/Software Cosimulation," Proceedings of the 30th Annual Simulation Symposium, pp. 14-22 (Apr. 7-9, 1997).

Brakensiek et al., "Re-Configurable Multi-Standard Terminal for Heterogeneous Networks," Radio and Wireless Conference, Rawcon 2002 IEEE pp. 27-30 (2002).

Brown et al., "Quick PDA Data Exchange," PC Magazine pp. 1-3 (May 22, 2001).

Buck et al., "Ptolemy: A Framework for Simulating and Prototyping Heterogeneous Systems," International Journal of Computer Simulation 4:155-182 (Apr. 1994).

Burns et al., "A Dynamic Reconfiguration Run-Time System," Proceedings of the 5th Annual Symposium on Field-Programmable Custom Computing Machines, pp. 166-175 (Apr. 16, 1997).

Business Wire, "Whirlpool Internet-Enabled Appliances to Use Beeline Shopper Software Features," http://www.whirlpoocorp.com/news/releases/release.asp?rid=90 (Feb. 16, 2001).

Buttazzo et al., "Optimal Deadline Assignment for Scheduling Soft Aperiodic Tasks in Hard Real-Time Environments," Engineering of Complex Computer Systems, Proceedings of the Third IEEE International Conference on Como, pp. 39-48 (Sep. 8, 1997).

Callahan et al., "Adapting Software Pipelining for Reconfigurable Computing," in Proceedings of the International Conference on Compilers, Architectrue and Synthesis for Embedded Systems p. 8, ACM (Cases '00, San Jose, CA) (Nov. 17-18, 2000).

Chapman & Mehrotra, "OpenMP and HPF: Integrating Two Paradigms," Proceedings of the 4th International Euro-Par Conference (Euro-Par'98), Springer-Verlag Heidelberg, Lecture Notes in Computer Science 1470:650-658 (1998).

Chen et al., "A Reconfigurable Multiprocessor IC for Rapid Prototyping of Algorithmic-Specific High-Speed DSP Data Paths," IEEE Journal of Solid-State Circuits, IEEE 35:74-75 (Feb. 1, 2001).

Clarke, "Embedded Solutions Enters Development Pact with Marconi," EETimes Online (Jan. 26, 2000).

Compton & Hauck, "Reconfigurable Computing: A Survey of Systems and Software," ACM Press, ACM Computing Surveys (CSUR) 34(2):171-210 (Jun. 2002).

Compton et al., "Configuration Relocation and Defragmentation for Run-Time Reconfigurable Computing," Northwestern University, http://citeseer.nj.nec.com/compton00configuration.html, pp. 1-17 (2000).

Conte et al., "Dynamic Rescheduling: A Technique for Object Code Compatibility in VLIW Architectures," Proceedings of the 28th Annual International Symposium on Microarchitecture pp. 208-218 (Nov. 29, 1995).

Conte et al., "Instruction Fetch Mechanisms for VLIW Architectures with Compressed Encodings," Proceedings of the Annual IEEE/ACM International Symposium on Microarchitecture (MICRO) 29:201-211 (Dec. 2, 1996).

Cray Research Inc., "Cray T3E Fortran Optimization Guide," Ver. 004-2518-002, Section 4.5 (Jan. 1999).

Cummings et al., "FPGA in the Software Radio," IEEE Communications Magazine. 37(2):108-112 (Feb. 1999).

Dandalis et al., "An Adaptive Cryptograhic Engine for IPSec Architectures," IEEE pp. 132-141 (Jan. 2000).

David et al., "DART: A Dynamically Reconfigurable Architecture Dealing with Future Mobile Telecommunication Constraints," Proceedings of the International Parallel and Distributed Processing Symposium pp. 156-163 (Apr. 15, 2002).

Deepakumara et al., "FPGA Implementation of MD5 has Algorithm," Canadian Conference on Electrical and Computer Engineering, IEEE (2001).

Dehon et al., "Reconfigurable Computing: What, Why and Implications for Design Automation," Design Automation Conference Proceedings pp. 610-615 (1999).

Dipert, "Figuring Out Reconfigurable Logic," EDN 44(16):107-114 (Aug. 5, 1999).

Dominikus, "A Hardware Implementation of MD4-Family Hash Algorithms," 9th International Conference on Electronics, Circuits and Systems IEEE (2002).

Dorband, "aCe C Language Reference Guide," Online (Archived Mar. 2001), http://web.archive.org/web/20000616053819/http://newton.gsfc.nasa.gov/aCe/aCe_dir/aCe_cc_Ref.html (Mar. 2001)

Drozdowski, "Scheduling Multiprocessor Tasks—An Overview," Instytut Informatyki Politechnika, pp. 1-31 (Jan. 31, 1996).

Ebeling et al., "RaPiD Reconfigurable Pipelined Datapath," Springer-Verlag, 6th International Workshop on Field-Programmable Logic and Applications pp. 126-135 (1996).

Fawer et al., "A Multiprocessor Approach for Implementing a Time-Diversity Spread Specturm Receiver," Proceeding sof the 1990 International Zurich Seminal on Digital Communications, pp. 173-180 (Mar. 5-8, 1990).

Fisher, "Gone Flat," Forbes pp. 76-79 (Oct. 2001).

Fleischmann et al., "Prototyping Networked Embedded Systems," Integrated Engineering, pp. 116-119 (Feb. 1999).

Forbes " Best of the Web—Computer Networking/Consumer Durables," *The Forbes Magnetic 40* p. 80 (May 2001).

Gibson, "Fresh Technologies Will Create Myriad Functions," FT Information Technology Review; World Wide Web at http://technews.acm.org/articles/2000-2/0301w.html?searchterm=%22fresh+technologies%22 (Mar. 1, 2000).

Gluth, "Integrierte Signalprozessoren," Elektronik 35(18):112-118 Franzis Verlag GMBH. Munich, Germany (Sep. 5, 1986).

Gokhale & Schlesinger, "A Data Parallel C and Its Platforms," Proceedings of the Fifth Symposium on the Frontiers of Massively Parallel Computation pp. 194-202 (Frontiers '95) (Feb. 1995).

Grimm et al., "A System Architecture for Pervasive Computing," Washington University, pp. 1-6 (Sep. 2000).

Halbwachs et al., "The Synchronous Data Flow Programming Language LUSTRE," Proceedings of the IEEE 79(9):1305-1319 (Sep. 1991).
Hammes et al., "Cameron: High Level Language Compilation for Reconfigurable Systems," Proc. of the Intl. Conf. on Parallel Architectures and Compilation Techniques, pp. 236-244 (Oct. 1999).
Hartenstein, "Coarse Grain Reconfigurable Architectures," Design Automation Conference, 2001. Proceedings of the ASP-Dac 2001, Asian and South Pacific Jan. 30-Feb. 2, 2001, Piscataway, NJ, US, IEEE, pp. 564-569 (Jan. 30, 2001).
Heinz, "An Efficiently Compilable Extension of {M} odula-3 for Problem-Oriented Explicitly Parallel Programming," Proceedings of the Joint Symposium on Parallel Processing (May 1993).
Hinden et al., "The DARPA Internet Interconnecting Heterogeneous Computer Networks with Gateways," IEEE Computer Magazine pp. 38-48 (1983).
Horton, "Beginning Java 2: JDK 1.3 Edition," Wrox Press, Chapter 8, pp. 313-316 (Feb. 2001).
Huff et al, "Lifetime-Sensitive Modulo Scheduling," 6th Conference on Programming Language, Design and Implementation, pp. 258-267, ACM (1993).
IBM, "Multisequencing a Single Instruction Stream Scheduling with Space-time Trade-offs," IBM Technical Disclosure Bulletin 36(2):105-108 (Feb. 1, 1993).
IEEE, "IEEE Standard Verilog Hardware Description Language," downloaded from http://inst.eecs.berkeley.edu/~cs150/fa06/Labs/verilog-ieee.pdf on Dec. 7, 2006 (Sept. 2001).
Internet Wire, Sunbeam Joins Microsoft in University Plug and Play Forum to Establish A "Universal" Smart Appliance Technology Standard (Mar. 23, 2000).
Ishii et al., "Parallel Variable Length Decoding with Inverse Quantization for Software MPEG-2 Decoders," Workshop on Signal Processing Systems, Design and Implementation, IEEE pp. 500-509 (Nov. 3-5, 1997).
Isoworth, "Isoworth Beverage Dispensing Technology Worldwide Company," Brochure (May 22, 2000).
Jain et al., "An Alternative Approach Towards the Design of Control Units," Microelectronics and Reliability 24(6):1009-1012 (1984).
Jain, "Parallel Processing with the TMS320C40 Parallel Digital Signal Processor," Sonitech International Inc., pp. 13-46. Retrieved from: http://www-s.ti.com/sc/psheets/spra031/spra031.pdf retrieved on Apr. 14, 2004 (Feb. 1994).
Janssen et al., "Partitioned Register File for TTAs," Proceedings of the 28th Annual International Symposium on Microarchitecture, pp. 303-312 (Nov. 1995).
Jong-Pyng et al., "Real-Time Virtual Channel Flow Control," Proceedings of the Annual International Phoenix Conference on Computers and Communications, Conf. 13, pp. 97-103 (Apr. 12, 1994).
Jung et al., "Efficient Hardware Controller Synthesis for Synchronous Dataflow Graph in System Level Design," Proceedings of the 13th International Symposium on System Synthesis pp. 79-84 (ISSS'00) (Sep. 2000).
Kaufmann et al., "Digital Spread-Spectrum Multipath-Diversity Receiver for Indoor Communication," from Pioneers to the 21st Century; Denver, Proceedings of the Vehicular Technology Socity [sic] Conference, NY, IEEE, US 2(Conf. 42):1038-1041 (May 10-13, 1992).
Kneip et al., "An Algorithm Adapted Autonomous Controlling Concept for a Parallel Single-Chip Digital Signal Processor," Journal of VLSI Signal Processing Systems for Signal, Image, an dVideo Technology 16(1):31-40 (May 1, 1997).
Lee & Messerschmitt, "Pipeline Interleaved Programmable DSP's: Synchronous Data Flow Programming," IEEE Transactions on Acoustics, Speech, and Signal Processing ASSP-35(9):1334-1345 (Sep. 1987).
Lee & Messerschmitt, "Synchronous Data Flow," Proceedings of the IEEE 75(9):1235-1245 (Sep. 1987).
Lee & Parks, "Dataflow Process Networks," Proceedings of the IEEE 83(5):773-799 (May 1995).
Liu et al., "Scheduling Algorithms for Multiprogramming in a Hard-Real-Time Environment," *Journal of the Association for Computing* 20(1):46-61 (1973).
Liosa et al., "Lifetime-Sensitive Modulo Scheduling in a Production Environment," IEEE Trans. on Comps. 50(3):234-249 (Mar. 2001).
Lu et al., "The Morphosys Dynamically Reconfigurable System-On-Chip," Proceedings of the First NASA/DOD Workshop on Evolvable Hardware, pp. 152-160 (Jul. 19, 1999).
Mangione-Smith et al., "Seeking Solutions in Configurable Computing," *Computer* 30(12):38-43 (Dec. 1997).
Manion, "Network CPU Adds Spice," Electronic Engineering Times, Issue 1126 (Aug. 14, 2000).
Mascia & Ishii., "Neural Net Implementation on Single-Chip Digital Signal Processor," IEEE (1989).
McGraw, "Parallel Functional Programming in Sisal: Fictions, Facts, and Future," Lawrence Livermore National Laboratory pp. 1-40 (Jul. 1993).
Najjar et al., "High-Level Language Abstraction for Reconfigurable Computing," *Computer* 36(8):63-69 (Aug. 2003).
Nichols et al., "Data Management and Control-Flow Constructs in a SIMD/SPMD Parallel Language/Compiler," Proceedings of the 3rd Symposium on the Frontiers of Massively Parallel Computation pp. 397-406 (Oct. 1990).
Openmp Architecture Review Board, "OpenMP C and C++ Application Program Interface," pp. 7-16 (Oct. 1998).
Oracle Corporation, "Oracle8i JDBC Developer's Guide and Reference," Release 3, 8.1.7, pp. 10-8-10-10 (Jul. 2000).
Pauer et al., "Algorithm Analysis and Mapping Environment for Adaptive Computing Systems: Further Results," Proc. IEEE Symposium on FPGA's for Custom Computing Machines (FCCM), Napa CA (1999).
Pauer et al., "Algorithm Analysis and Mapping Environment for Adaptive Computing Systems," Presentation slides, Third Bi-annual Ptolemy Miniconference (1999).
Ramamritham et al., "On Scheduling Algorithms for Real-Time Multiprocessor Systems," Algorithms and Applications, Proceedings of the International conference on Parallel Processing 3:143-152 (Aug. 8, 1989).
Schneider, "A Parallel/Serial Trade-Off Methodology for Look-Up Table Based Decoders," Proceedings of the Design Automation Conference 34:498-503 (Jun. 9-13, 1997).
Sidhu et al., "A Self-Reconfigurable Gate Array Architecture," 10 International Workshop on Field Programmable Logic and Applications http:// /coblitz.codeen.org:3125/citeseer.ist.psu.edu/cache/papers/cs/17524/http:zSzzSzmaarcii.usc.eduzSzPublicationsZSzsidhu_fp100.pdf/sidhu00selfreconfigurable.pdf retrieved on Jun. 21, 2006 (Sep. 1, 2001).
Smith, "Intro to ASICs: ASIC Cell Libraries," at http:/ /iroi.seu.edu.cn/books/asics/Book2/CH01/CH01.5.htm, printed on Feb. 4, 2005 (Jun. 1997).
Souza, " Computing's New Face—Reconfigurable Devices Could Rattle Supply Chain," Electronic Buyers' News Issue 1205, p. P.1 (Apr. 3, 2000).
Souza, "Quicksilver Buys White Eagle," Electronic Buyers News, Issue 1220 (Jul. 17, 2000).
Sriram et al., "MPEG-2 Video Decoding on the TMS320C6X DSP Architecture," Conference Record of the 32nd Asilomar Conference on Signals, Systems, and Computers, IEEE pp. 1735-1739 (Nov. 1-4, 1998).
Steiner, "Coke Chief's Latest Daft Idea—A Cola Tap in Every House," Sunday Times (Mar. 2001).
Sun Microsystems, "Fortran 3.0.1 User's Guide, Revision A," pp. 57-68 (Aug. 1994).
Svensson, "Co's Join On Home Web Wiring Network," Associated Press Online printed on Apr. 30, 2008 (Jun. 2000).
Tang et al., "Thread Partitioning and Scheduling Based on Cost Model," Proceedings of the Ninth Annual ACM Symposium on Parallel Algorithms and Architectures, pp. 272-281 Retrieved from: http://doi.acm.org/10.1145/258492.2585 retrieved on Aug. 25, 2004 (1997).
Vaya, "VITURBO: A Reconfigurable Architecture for Ubiquitous Wireless Networks," A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree Master of Science; Rice University (Aug. 2002).

Wang et al., "Cell Search in W-CDMA," IEEE Journal on Selected Areas in Communications 18(8):1470-1482 (Aug. 2000).
Wardell, "Help for Hurried Cooks?," Popular Science, p. 32 (May 2000).
Whiting & Pascoe, "A History of Data-Flow Languages," IEEE Annals of the History of Computing 16(4):38-59 (1994).
Williamson & Lee, "Synthesis of Parallel Hardware Implementations from Synchronous Dataflow Graph Specifications," Conference Record of the Thirtieth Asilomar Conference on Signals, Systems and Computers 1340-1343 (Nov. 1996).
Wirthlin et al., "A Dynamic Instruction Set Computer," Proceedings of the IEEE Symposium on FPGA's for Custom Computing Machines, pp. 99-107 (Apr. 21, 1995).
WWW.APPLIANCEMAGAZINE.COM, World Wide Web at http://web.archive.org/web/20000511085402/http://www.appliancemagazine.com/ printed on Apr. 30, 2008.
WWW.BESTROM.COM, BreakMateTM from www.bestrom.com printed on Apr. 29, 2008.
WWW.BEVERAGEEXPRESS.COM, Beverage Express from www.beverageexpress.com printed on Apr. 30, 2008.
WWW.BEVSTAR.COM, Isoworth Beverage Dispensing Technology Worldwide from www.bevstar.com printed on Apr. 30, 2008.
WWW.BONATOR.COM, from the World Wide Web at http://web.archive.org/web/20000510102440/http://www.bonator.com/ printed on Apr. 30, 2008.
WWW.ECOMMERCE.DEWPOINTINC.COM, Swiss Mountain Coffees from www.ecommerce.dewpointinc.com printed on Apr. 30, 2008.
WWW.GATEWAY.COM, World Wide Web, http://web.archive.org/web/20000229192734/www.gateway.com/productpages/9300splash/index.shtml Available on Mar. 3, 2000, 1 page (Mar. 3, 2000).
WWW.ICL.COM, from the World Wide Web at http://www.icl.com printed on Apr. 30, 2008.
WWW.MARGHERITA2000.COM; from Margherita2000.com printed Apr. 30, 2008 (Jan. 26, 2001).
WWW.SODACLUBENTERPRISES.COM, Soda-Club Enterprises from www.sodaclubenterprises.com printed on Apr. 30, 2008.
WWW.SYMBOL.COM, Symbol from www.symbol.com printed on Apr. 30, 2008.
WWW.WUNDERBAR.COM, Wunder-Bar Dispensing Systems from www.wunderbar.com printed on Apr. 30, 2008.
XILINX, "Virtex-II Pro Platform FPGAs: Functional Description DS083-2 (v2.5)," Product Specification, pp. 13-46 (Jan. 20, 2003).
Young, "Architecture Powers up IPSec, SSL," EETimes, Los Gatos, CA, pp. 1-4 http://www.eetimes.com/story/OEG20011102S0065 (Nov. 2, 2001).
Yuan et al., "A Decomposition Approach to Non-Preemptive Real-Time Scheduling," Real Time Systems 6(1):7-35 (1994).
Zaino et al., "Algorithm Analysis and Mapping Environment for Adaptive Computing Systems," Final Technical Report, DARPA Contract F33615-97-C-1174 (Sep. 2001).
Zhang et al., "A 1V Heterogeneous Reconfigurable Processor IC for Baseband Wireless Applications," 2000 IEEE Solid.
Altera Apex 20K 1999.
Andraka Consulting Group, "Distributed Arithmetic." Obtained from: http://www.fpga-guru.com/distribu.htm (1998-2000).
Computer Organization and Design 2nd Edition, Hennessy, Morgan Kaufmann Publishers, pp. 569-570 (1998).
Free On-Line Dictionary of Computing, ©1995-2000 www.foldoc.org search terms: cache, operating system, Internet, DMA, interrupt.
Hanna et al., "A Normalized Backpropagation Learning Algorithm for Multilayer Feed-Forward Neural Adaptive Filters," *Neural Networks for Signal Processing XI*, Proceedings of the 2001 IEEE Signal Processing Society Workshop pp. 63-72 (Sep. 2001).
Janweijer et al., "A Compact Robin Using the SHarc (CRUSH)," Obtained from: http://www.nikhef.nl/~peterj/Crush/CRUSH-hw.pdf (Sep. 1998).
Rajagopalan et al., "A Flexible Multiplication Unit for an FPGA Logic Block," *Circuits and Systems* 4:546-9 (2001).
Xilinx Data Book 1998.
Xilinx Virtex 1.1 1998.
Xilinx Virtex 2.2 2000.

* cited by examiner

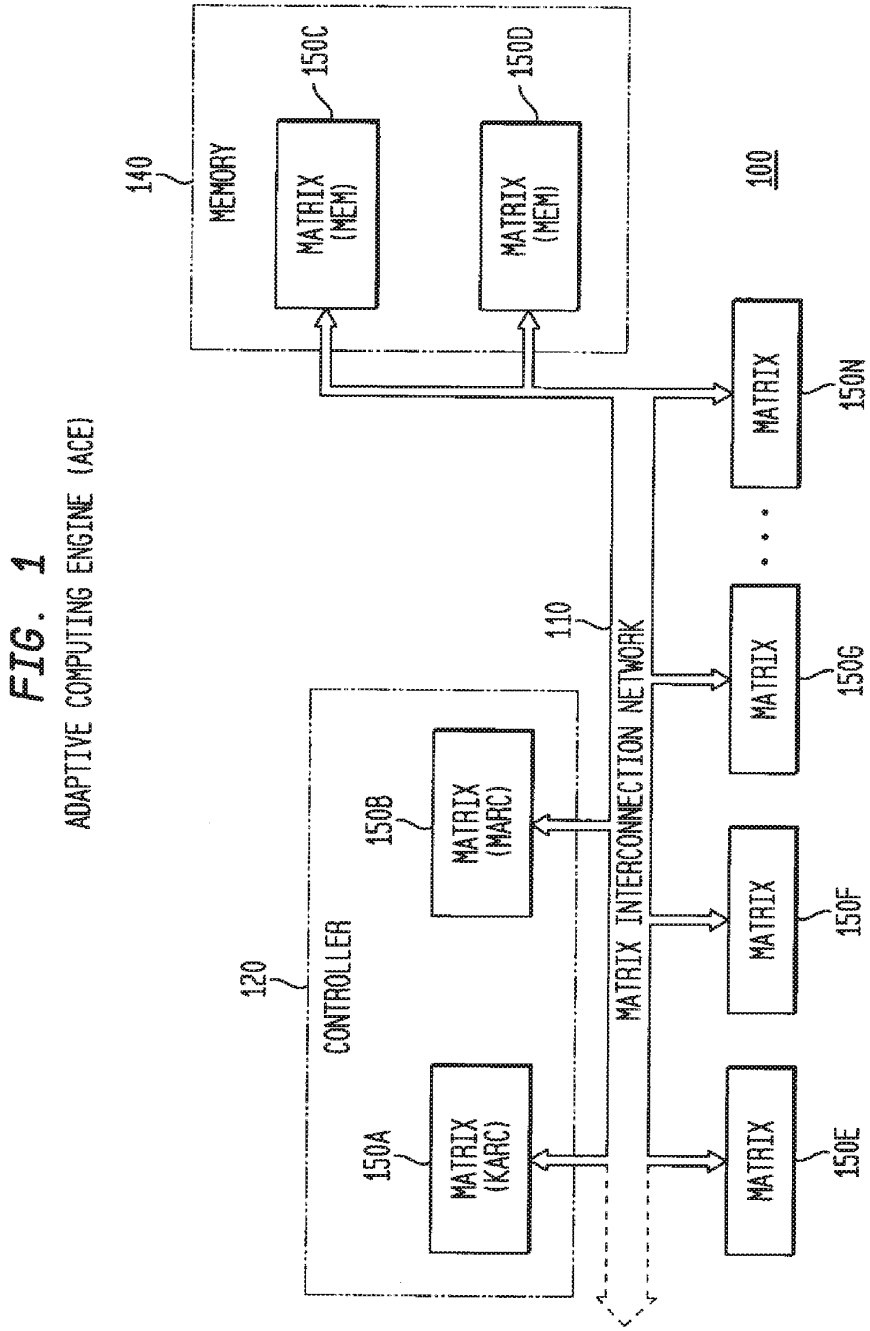

ADAPTIVE COMPUTING ENGINE (ACE)
100
140
MEMORY
150C
MATRIX (MEM)
150D
MATRIX (MEM)
MATRIX
150N
110
MATRIX INTERCONNECTION NETWORK
MATRIX
150G
MATRIX
150F
MATRIX
150E
120
CONTROLLER
150B
MATRIX (MARC)
150A
MATRIX (KARC)

FIG. 1

FIG. 2

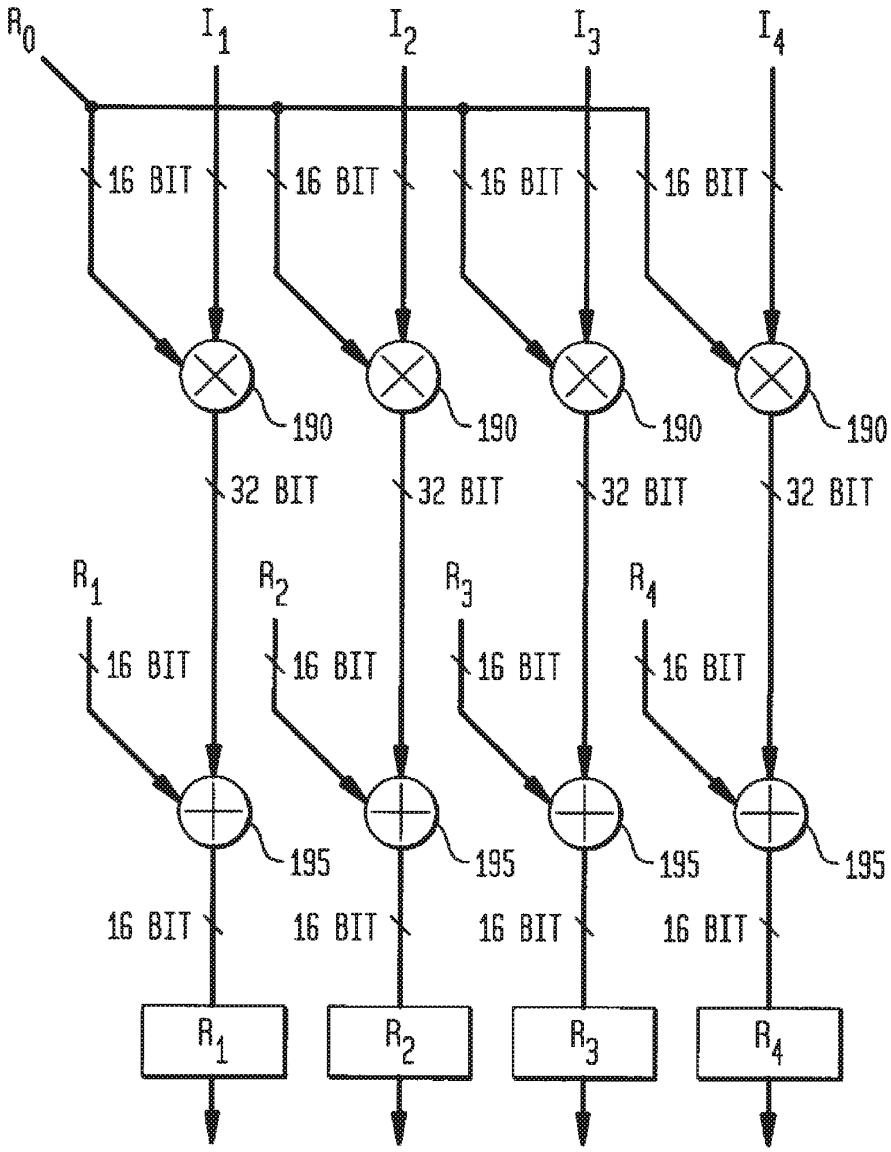

R0
I1
I2
I3
I4
16 BIT
16 BIT
16 BIT
16 BIT
190
190
190
190
32 BIT
32 BIT
32 BIT
32 BIT
R1
R2
R3
R4
16 BIT
16 BIT
16 BIT
16 BIT
195
195
195
195
16 BIT
16 BIT
16 BIT
16 BIT
R1
R2
R3
R4

FIG. 3

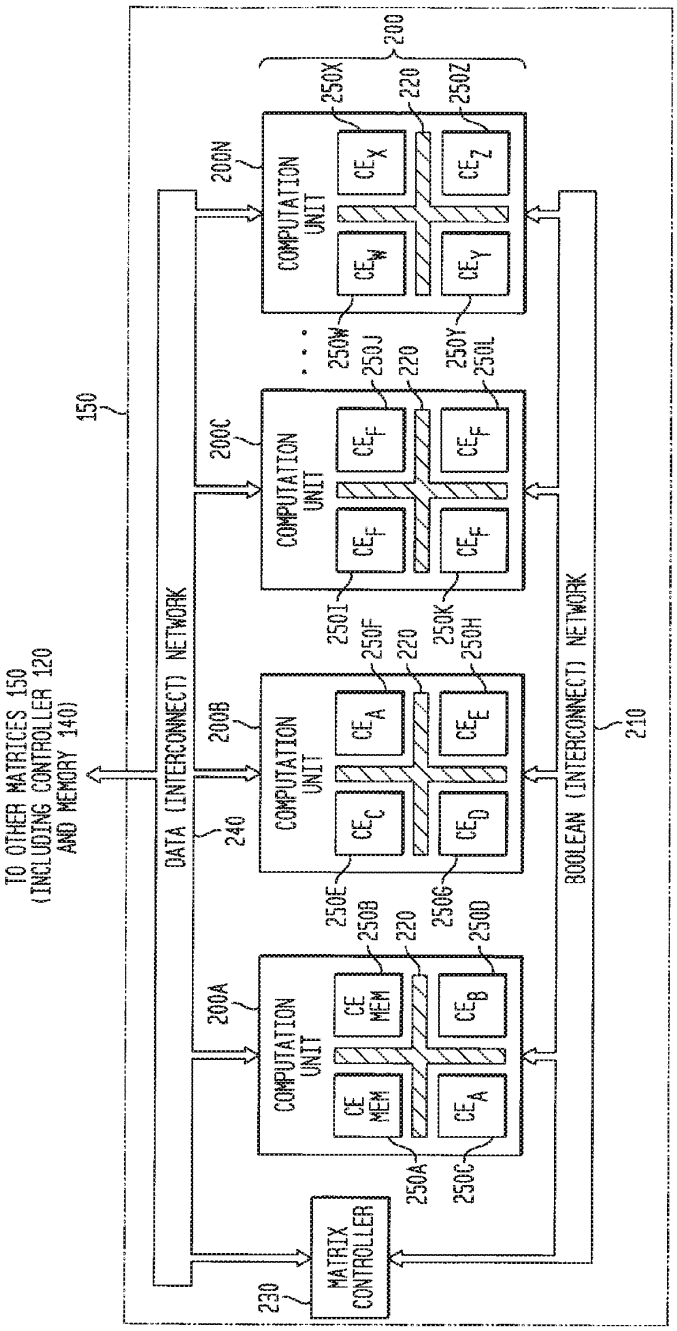

TO OTHER MATRICES 150
(INCLUDING CONTROLLER 120
AND MEMORY 140)
150
DATA (INTERCONNECT) NETWORK
BOOLEAN (INTERCONNECT) NETWORK
210
240
200
200A
200B
200C
200N
COMPUTATION UNIT
CE MEM
CE A
CE B
CE C
CE D
CE E
CE F
CE W
CE X
CE Y
CE Z
220
250A
250B
250C
250D
250E
250F
250H
250I
250J
250K
250L
250W
250X
250Y
250Z
MATRIX CONTROLLER
230

FIG. 4

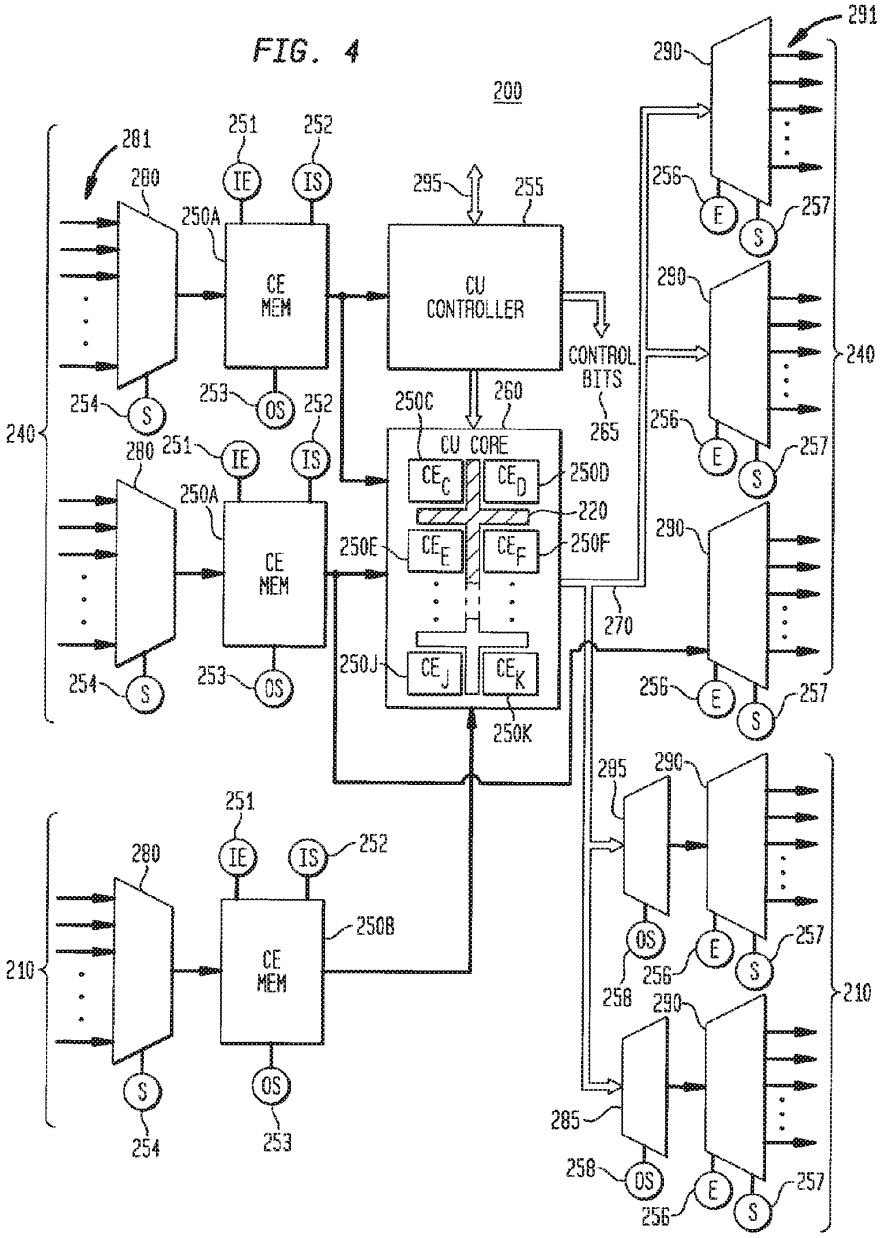

200
CU CONTROLLER
CU CORE
CE MEM
CONTROL BITS
IE
IS
OS
S
E
240
210

FIG. 5A

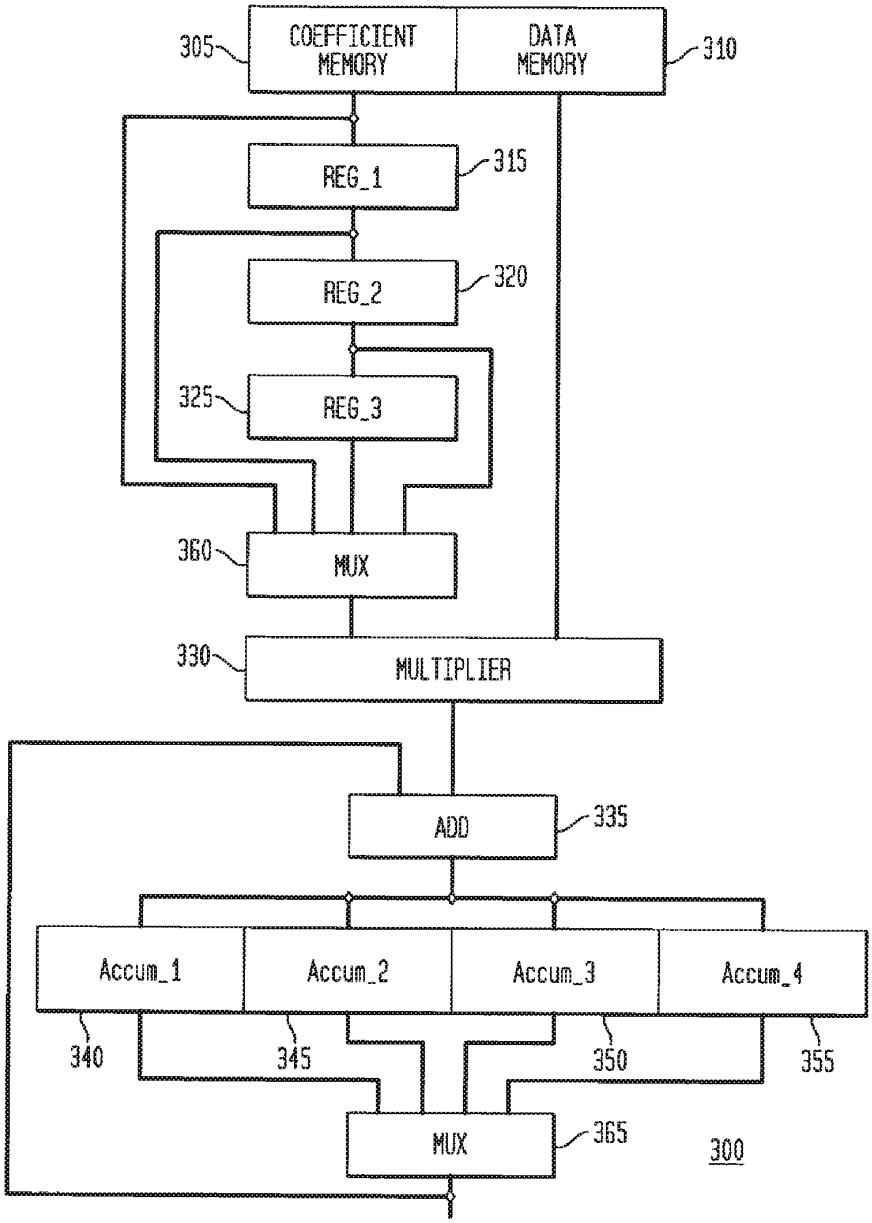

305
COEFFICIENT MEMORY
DATA MEMORY
310
REG_1
315
REG_2
320
325
REG_3
360
MUX
330
MULTIPLIER
ADD
335
Accum_1
Accum_2
Accum_3
Accum_4
340
345
350
355
MUX
365
300

FIG. 5B

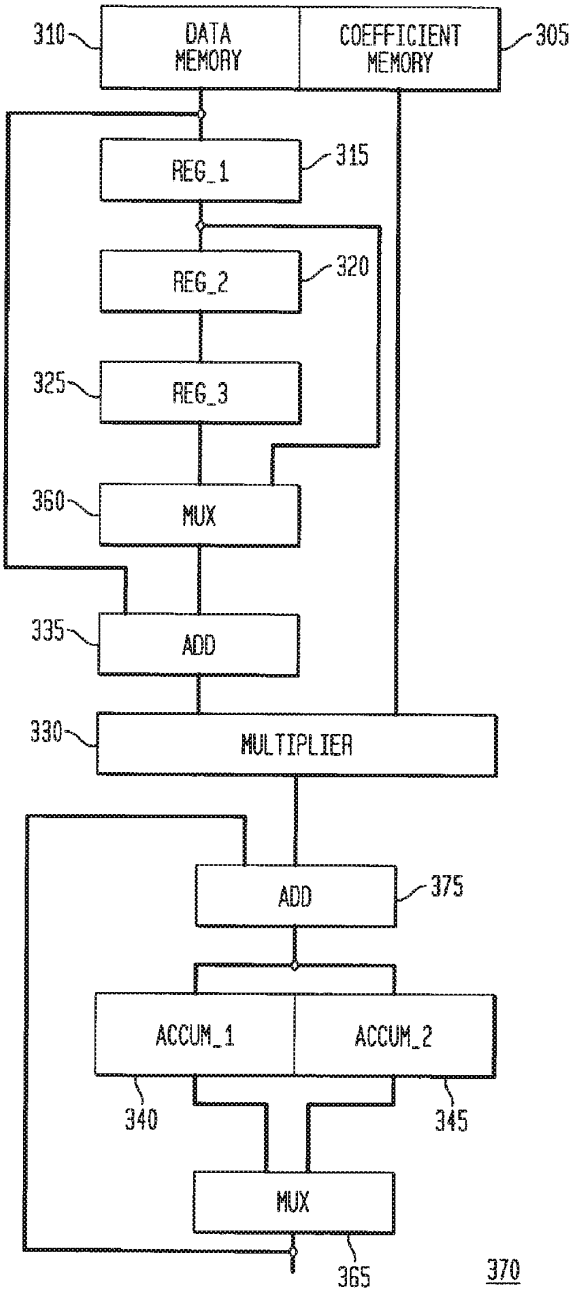

310
DATA MEMORY
COEFFICIENT MEMORY
305
REG_1
315
REG_2
320
325
REG_3
360
MUX
335
ADD
330
MULTIPLIER
ADD
375
ACCUM_1
ACCUM_2
340
345
MUX
365
370

FIG. 5C

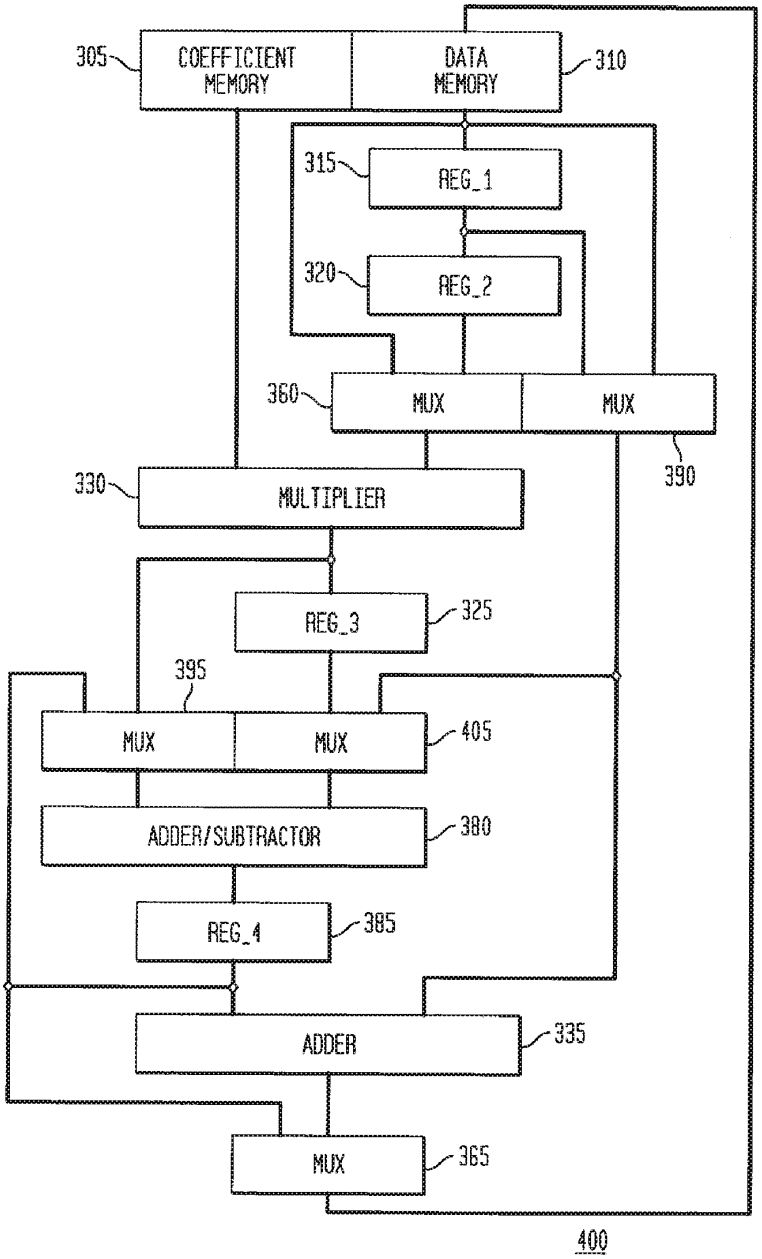

305
COEFFICIENT MEMORY
DATA MEMORY
310
315
REG_1
320
REG_2
360
MUX
MUX
390
330
MULTIPLIER
REG_3
325
395
MUX
MUX
405
ADDER/SUBTRACTOR
380
REG_4
385
ADDER
335
MUX
365
400

FIG. 5D

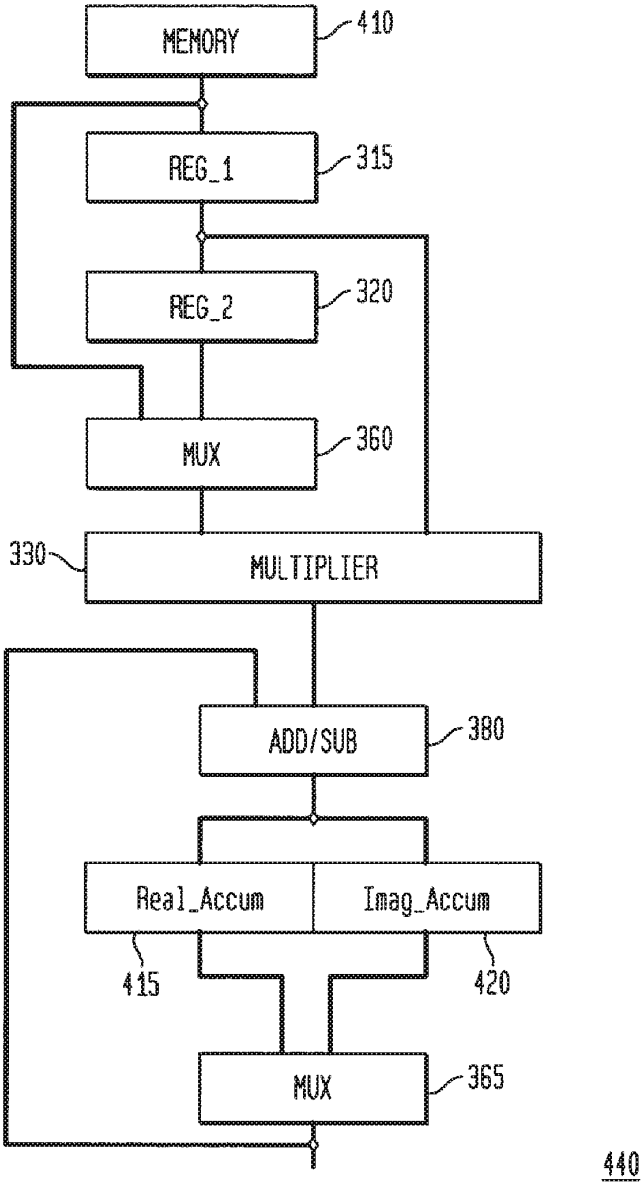

MEMORY
410
REG_1
315
REG_2
320
MUX
360
330
MULTIPLIER
ADD/SUB
380
Real_Accum
Imag_Accum
415
420
MUX
365
440

FIG. 5E

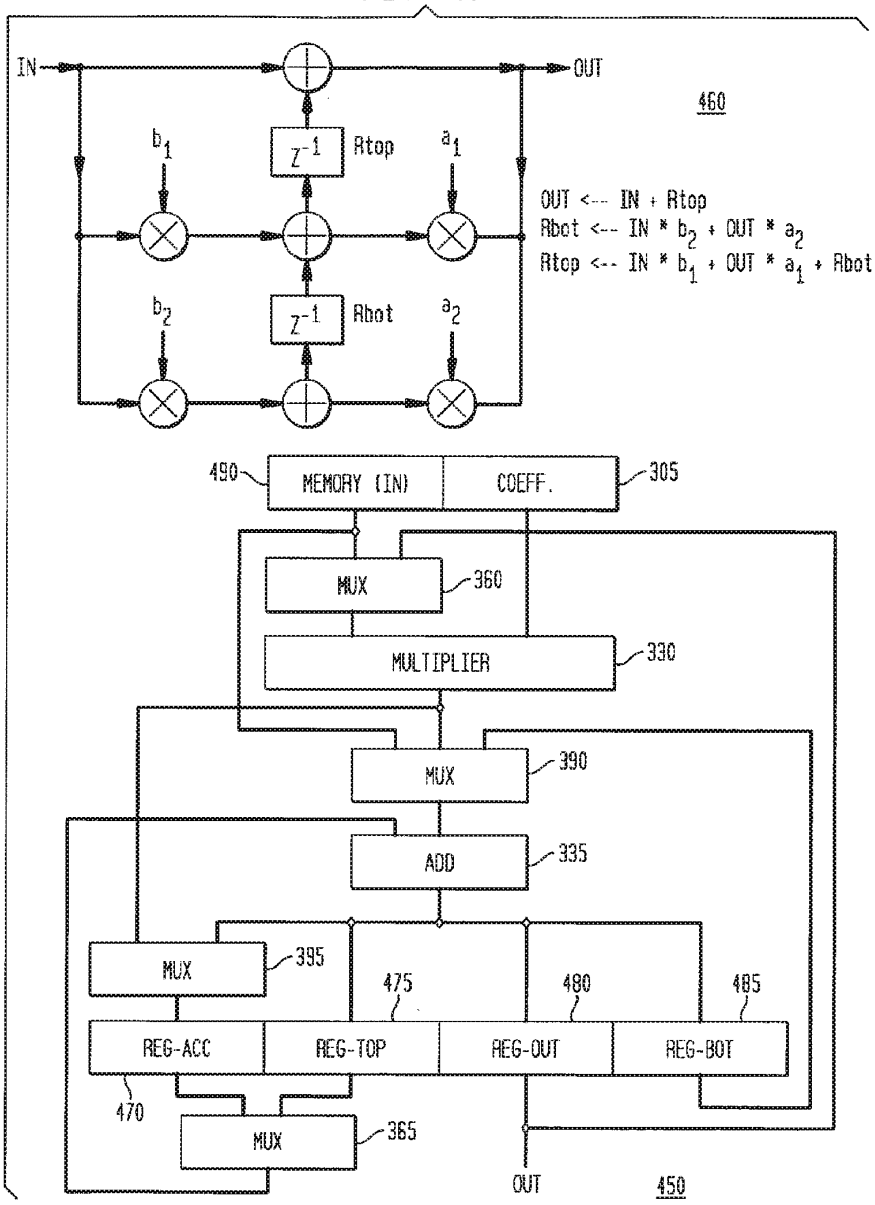

IN
OUT
460
b1
Z-1
Rtop
a1
OUT <-- IN + Rtop
Rbot <-- IN * b2 + OUT * a2
Rtop <-- IN * b1 + OUT * a1 + Rbot
b2
Z-1
Rbot
a2
490
MEMORY (IN)
COEFF.
305
MUX
360
MULTIPLIER
330
MUX
390
ADD
335
MUX
395
475
480
485
REG-ACC
REG-TOP
REG-OUT
REG-BOT
470
MUX
365
OUT
450

FIG. 6

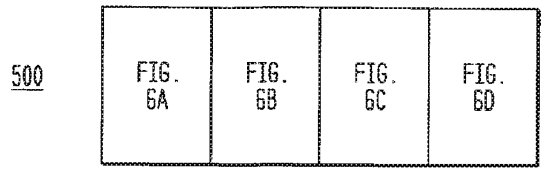
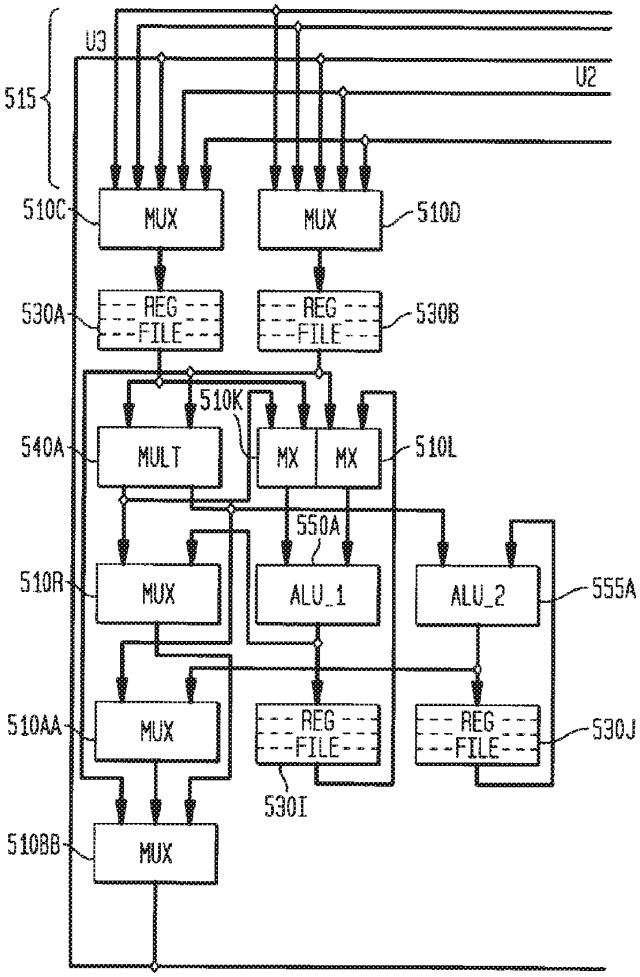

500
FIG. 6A
FIG. 6B
FIG. 6C
FIG. 6D

FIG. 6A


U3
U2
515
510C
MUX
MUX
510D
530A
REG FILE
REG FILE
530B
510K
540A
MULT
MX
MX
510L
550A
510R
MUX
ALU_1
ALU_2
555A
510AA
MUX
REG FILE
REG FILE
530J
530I
5108B
MUX

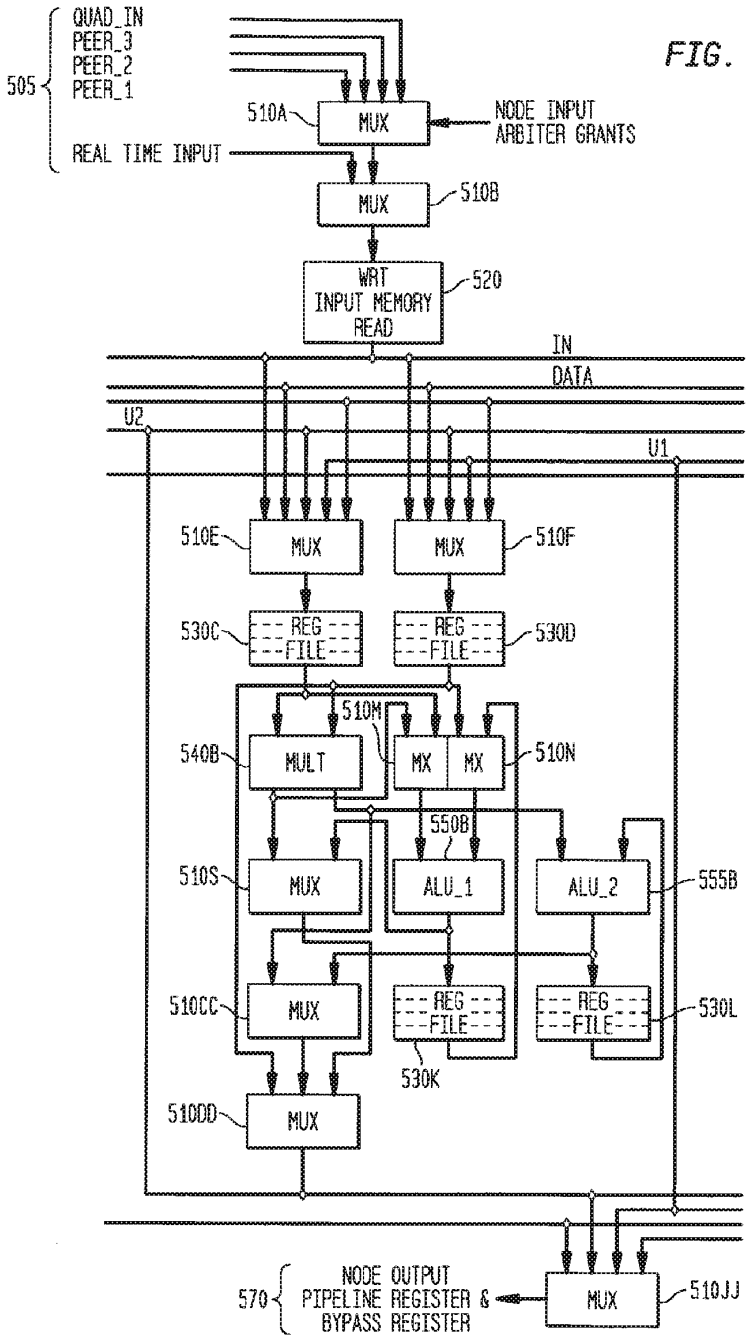

505
QUAD_IN
PEER_3
PEER_2
PEER_1
REAL TIME INPUT
510A
MUX
NODE INPUT
ARBITER GRANTS
MUX
510B
WRT
INPUT MEMORY
READ
520
IN
DATA
U2
U1
510E
MUX
MUX
510F
530C
REG
FILE
REG
FILE
530D
510M
540B
MULT
MX
MX
510N
550B
510S
MUX
ALU_1
ALU_2
555B
510CC
MUX
REG
FILE
REG
FILE
530L
530K
510DD
MUX
570
NODE OUTPUT
PIPELINE REGISTER &
BYPASS REGISTER
MUX
510JJ

FIG. 6B

FIG. 6C

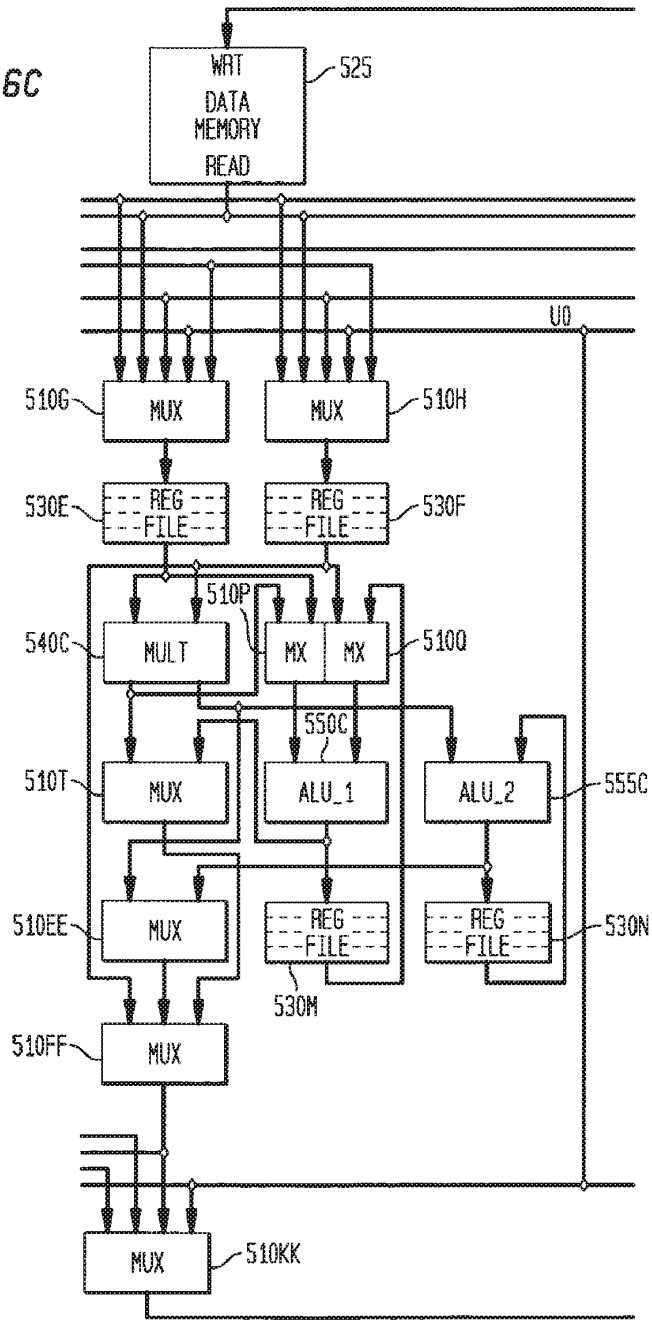

WRT
DATA
MEMORY
READ
525
UO
510G
MUX
MUX
510H
530E
REG
FILE
REG
FILE
530F
510P
540C
MULT
MX
MX
510Q
550C
510T
MUX
ALU_1
ALU_2
555C
510EE
MUX
REG
FILE
REG
FILE
530N
530M
510FF
MUX
MUX
510KK

FIG. 6D

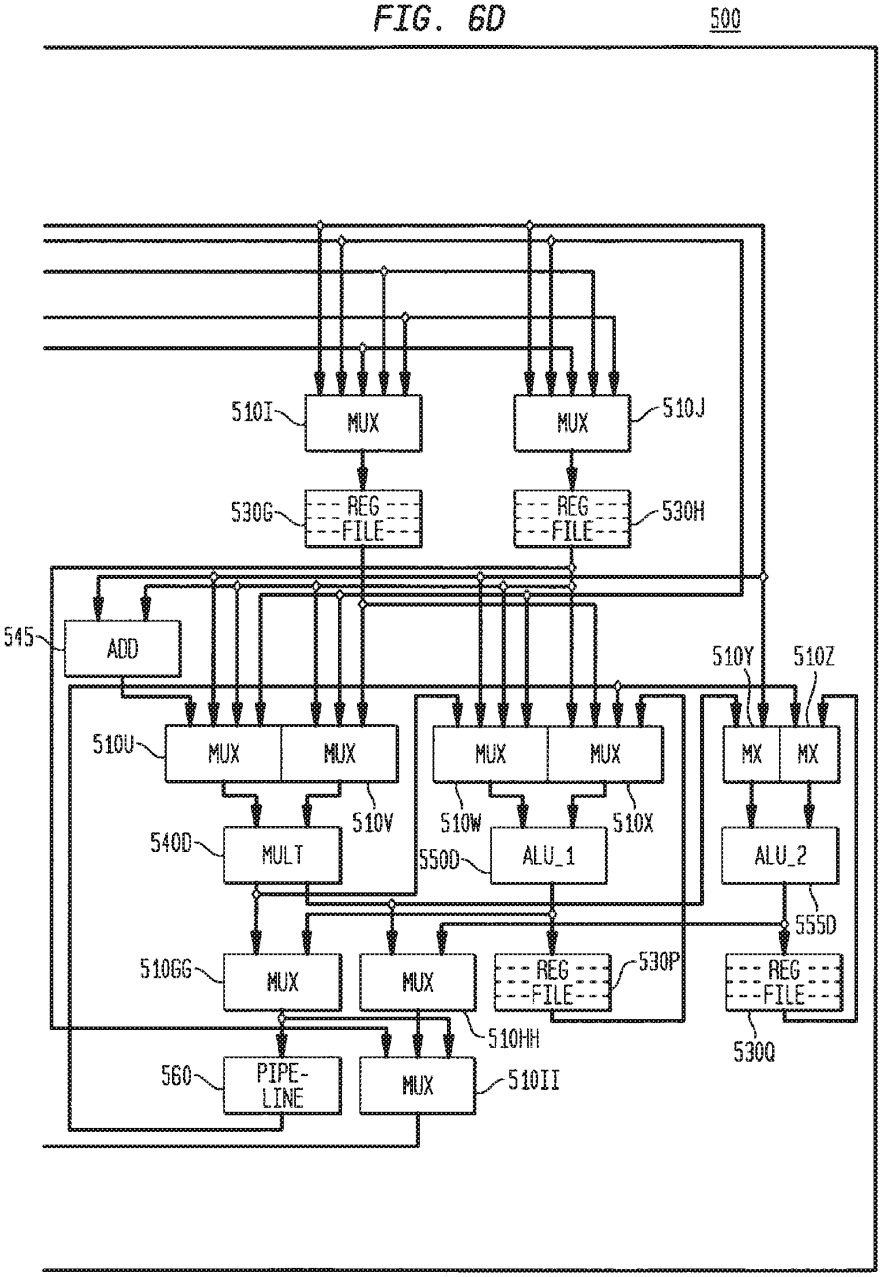
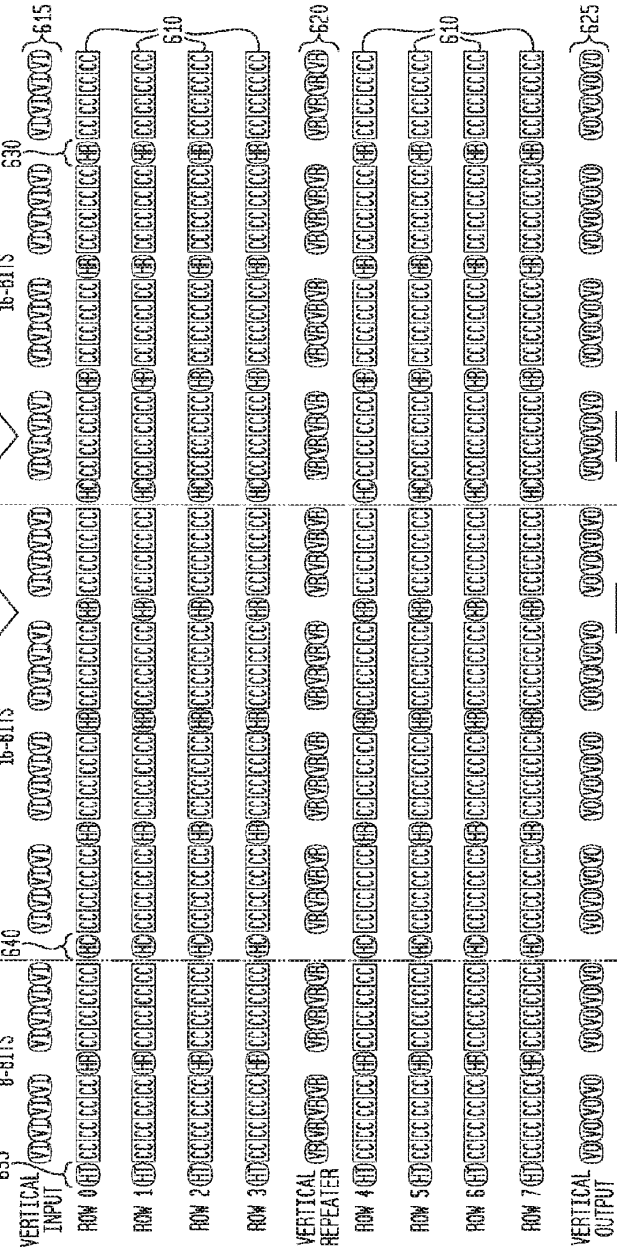

500
510I
MUX
MUX
510J
530G
REG FILE
REG FILE
530H
545
ADD
510Y
510Z
510U
MUX
MUX
MUX
MUX
MX
MX
510V
510W
510X
540D
MULT
550D
ALU_1
ALU_2
555D
510GG
MUX
MUX
REG FILE
530P
REG FILE
510HH
530Q
560
PIPE-LINE
MUX
510II

FIG. 7


Z PIPELINE 8-BITS
Y PIPELINE 16-BITS
X PIPELINE 16-BITS
Tin (INPUT)
Sin (INPUT)
Tout (OUTPUT)
Sout (OUTPUT)
VERTICAL INPUT
VERTICAL REPEATER
VERTICAL OUTPUT
ROW 0
ROW 1
ROW 2
ROW 3
ROW 4
ROW 5
ROW 6
ROW 7
635
640
630
615
610
620
625
KEY: 610 CORE CELL
615 VERTICAL INPUT
620 VERTICAL REPEATER
625 VERTICAL OUTPUT
630 HORIZONTAL REPEATER
635 HORIZONTAL TERMINATOR
640 HORIZONTAL CONTROLLER
600

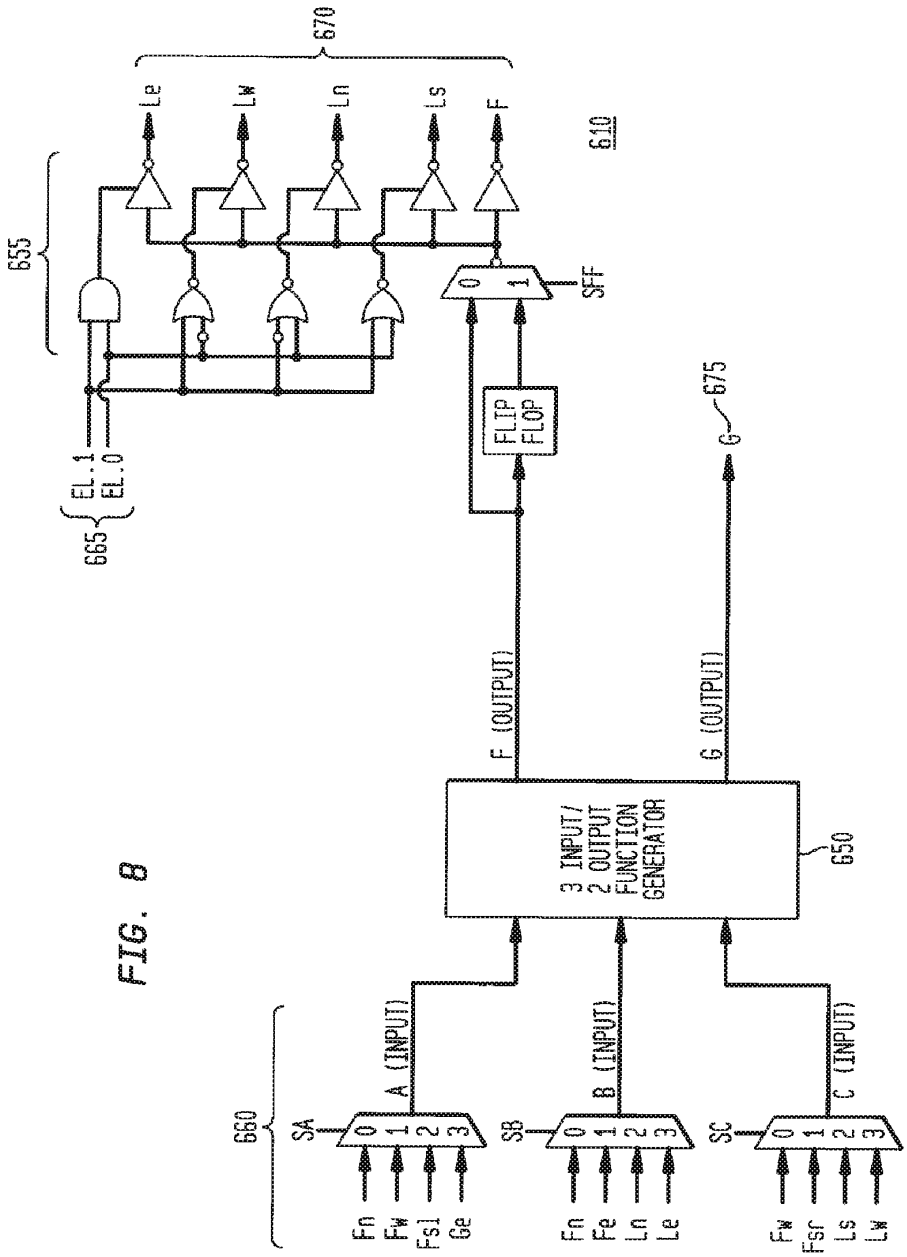

670
Le
Lw
Ln
Ls
F
610
655
SFF
FLIP FLOP
675
G
EL.1
EL.0
665
F (OUTPUT)
G (OUTPUT)
3 INPUT/ 2 OUTPUT FUNCTION GENERATOR
650
660
SA
SB
SC
A (INPUT)
B (INPUT)
C (INPUT)
Fn
Fw
Fsl
Ge
Fn
Fe
Ln
Le
Fw
Fsr
Ls
Lw

FIG. 8

FIG. 9

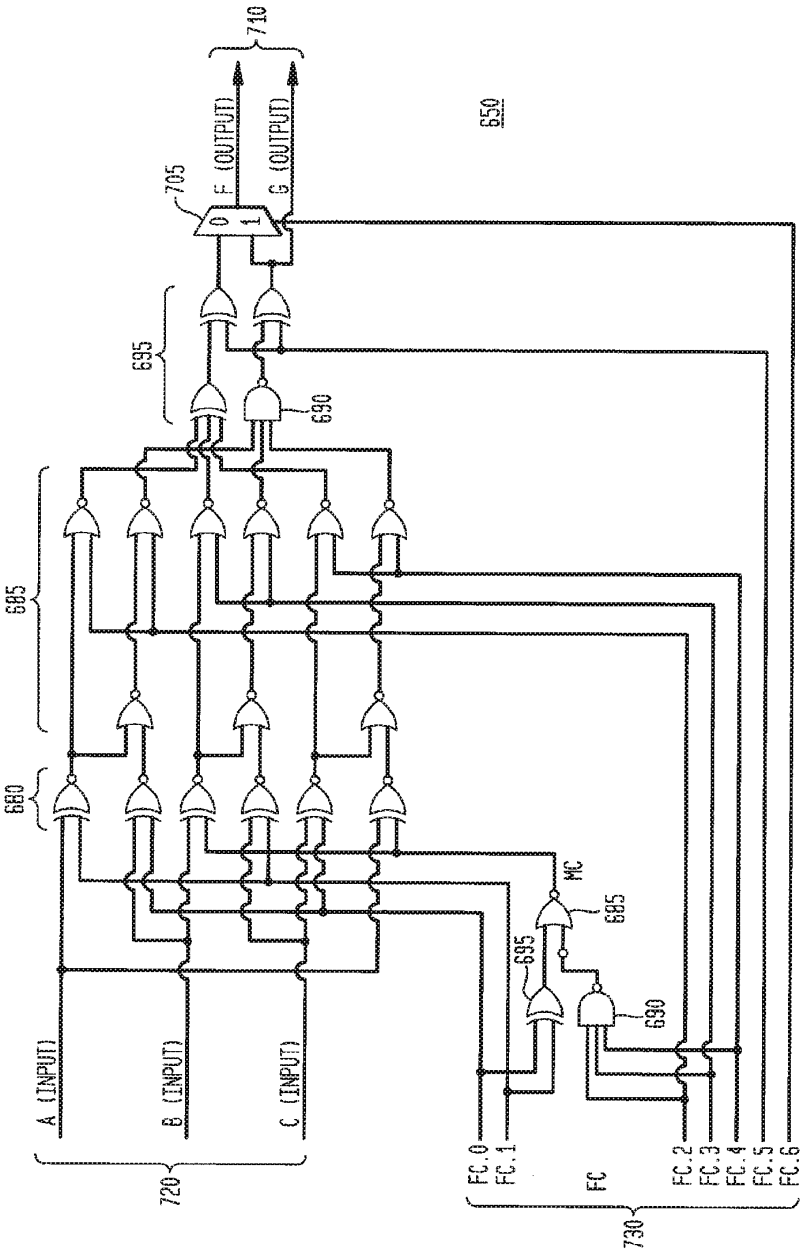

650
710
F (OUTPUT)
G (OUTPUT)
705
0
1
695
690
685
680
MC
A (INPUT)
B (INPUT)
C (INPUT)
720
FC.0
FC.1
FC
FC.2
FC.3
FC.4
FC.5
FC.6
730

FIG. 10

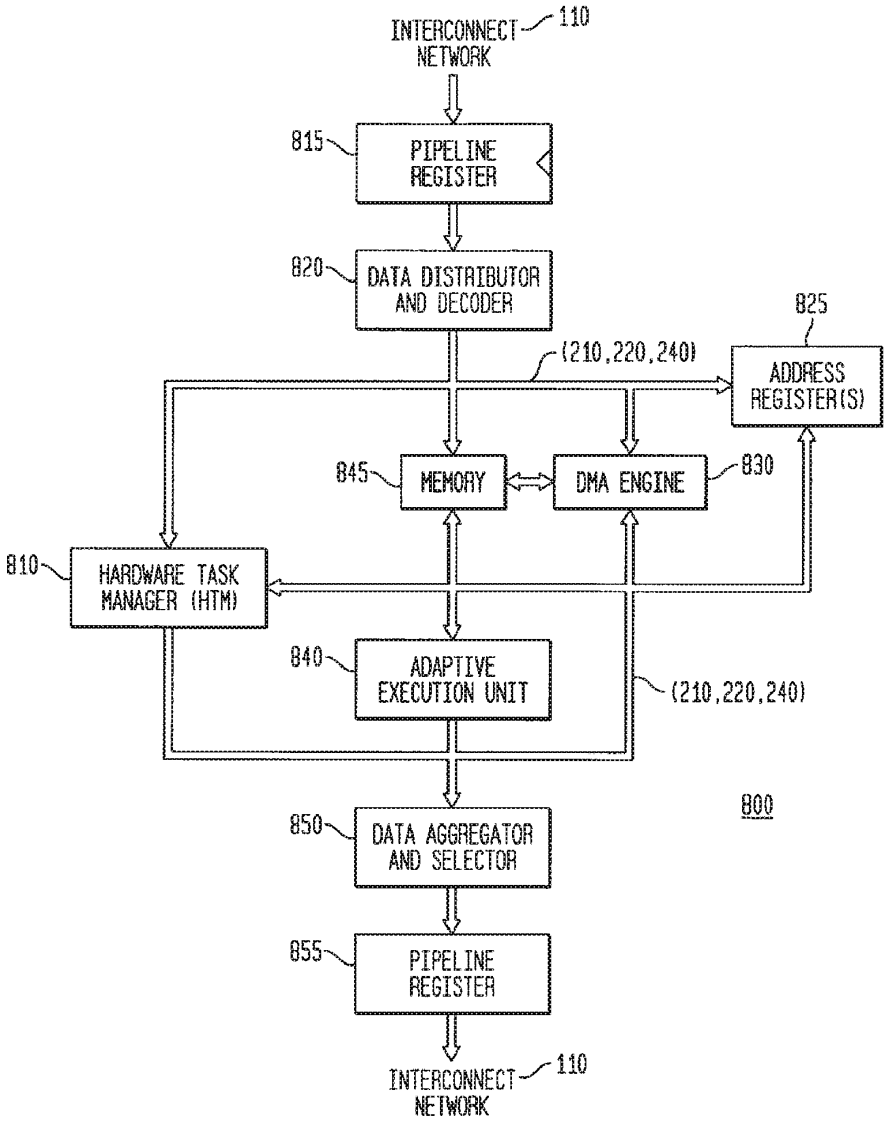

INTERCONNECT NETWORK
110
815
PIPELINE REGISTER
820
DATA DISTRIBUTOR AND DECODER
825
(210,220,240)
ADDRESS REGISTER(S)
845
MEMORY
DMA ENGINE
830
810
HARDWARE TASK MANAGER (HTM)
840
ADAPTIVE EXECUTION UNIT
(210,220,240)
800
850
DATA AGGREGATOR AND SELECTOR
855
PIPELINE REGISTER
INTERCONNECT NETWORK
110

FIG. 11

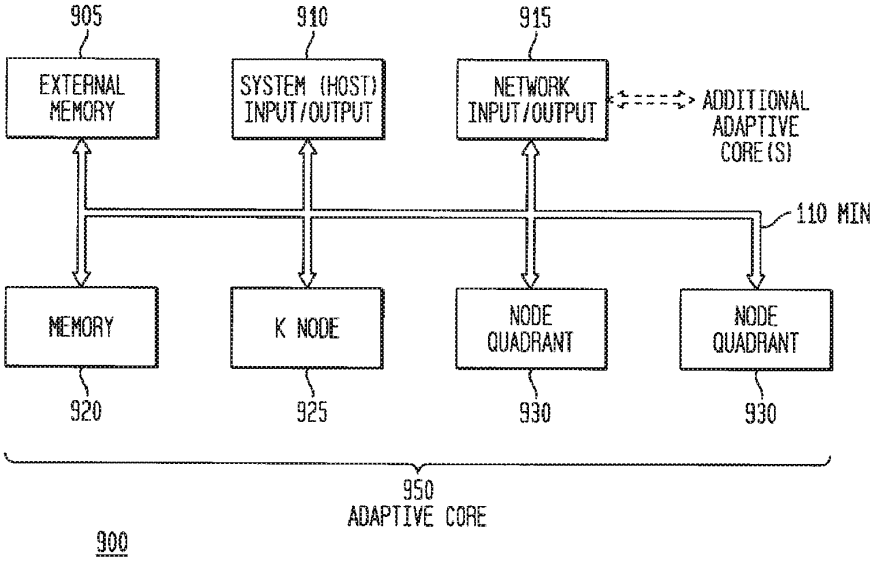

905
910
915
EXTERNAL MEMORY
SYSTEM (HOST) INPUT/OUTPUT
NETWORK INPUT/OUTPUT
ADDITIONAL ADAPTIVE CORE(S)
110 MIN
MEMORY
K NODE
NODE QUADRANT
NODE QUADRANT
920
925
930
930
950
ADAPTIVE CORE
900

FIG. 12

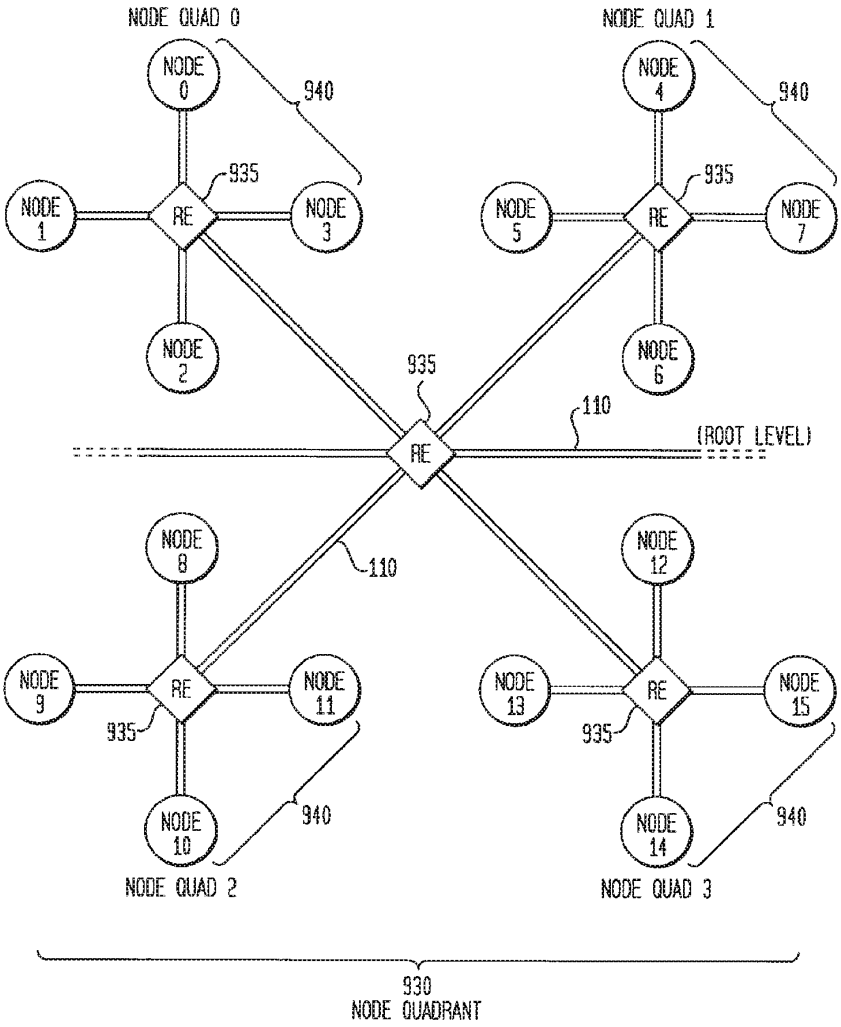

NODE QUAD 0
NODE QUAD 1
NODE 0
NODE 1
NODE 2
NODE 3
NODE 4
NODE 5
NODE 6
NODE 7
NODE 8
NODE 9
NODE 10
NODE 11
NODE 12
NODE 13
NODE 14
NODE 15
RE
940
935
110
(ROOT LEVEL)
NODE QUAD 2
NODE QUAD 3
930
NODE QUADRANT

FIG. 13

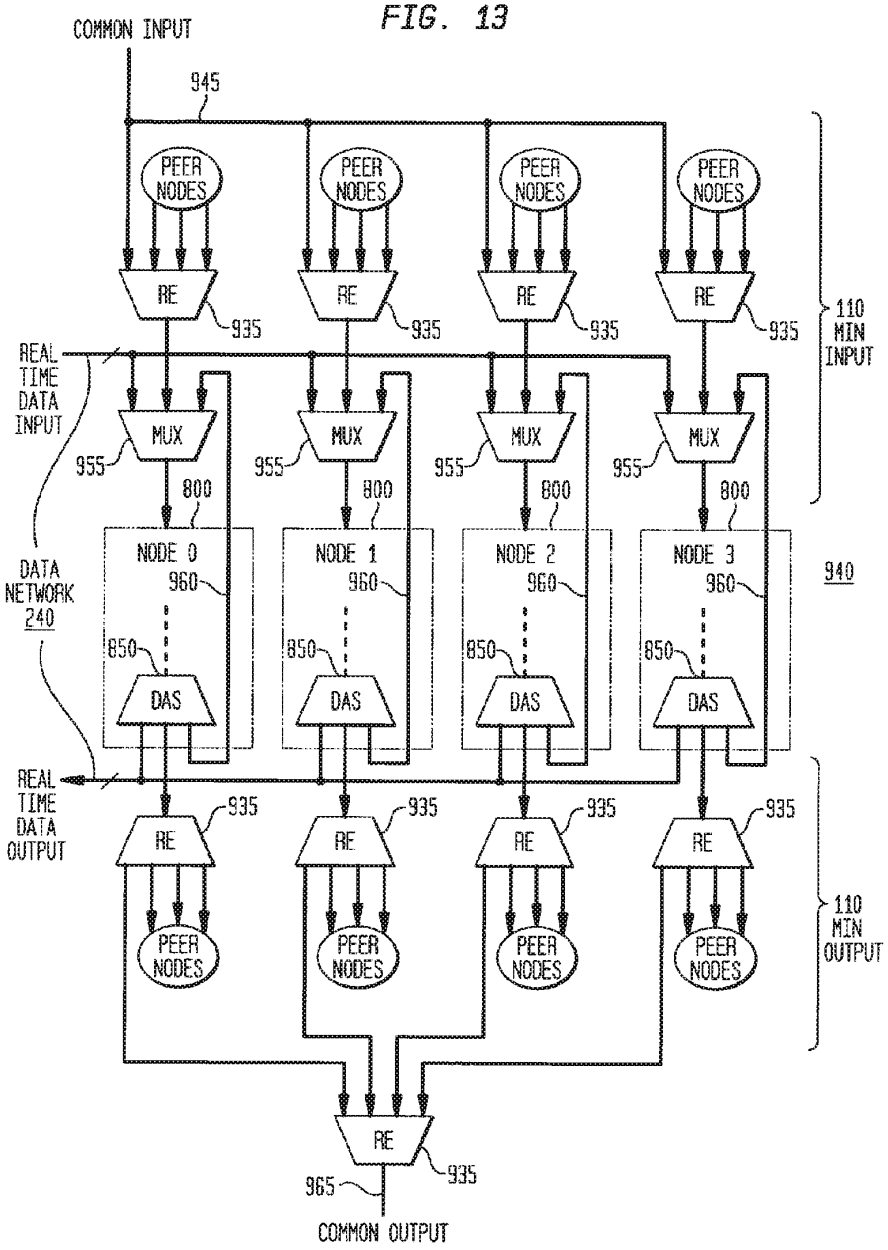

COMMON INPUT
945
PEER NODES
RE
935
110 MIN INPUT
REAL TIME DATA INPUT
MUX
955
800
NODE 0
NODE 1
NODE 2
NODE 3
960
850
DAS
940
DATA NETWORK 240
REAL TIME DATA OUTPUT
110 MIN OUTPUT
965
COMMON OUTPUT

FIG. 14

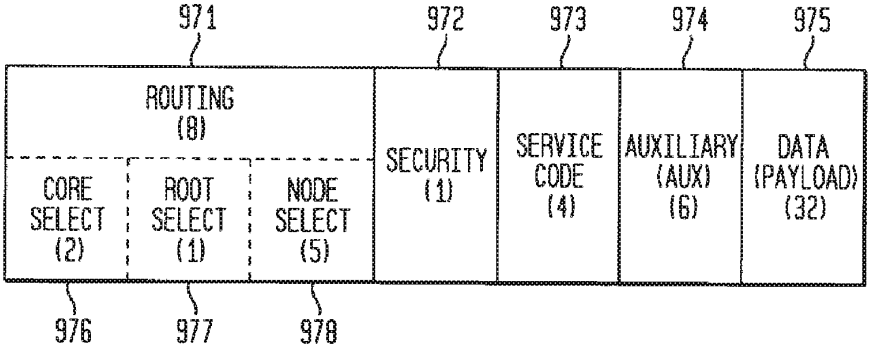

971
972
973
974
975
ROUTING
(8)
CORE
SELECT
(2)
ROOT
SELECT
(1)
NODE
SELECT
(5)
SECURITY
(1)
SERVICE
CODE
(4)
AUXILIARY
(AUX)
(6)
DATA
(PAYLOAD)
(32)
976
977
978
970

FIG. 15

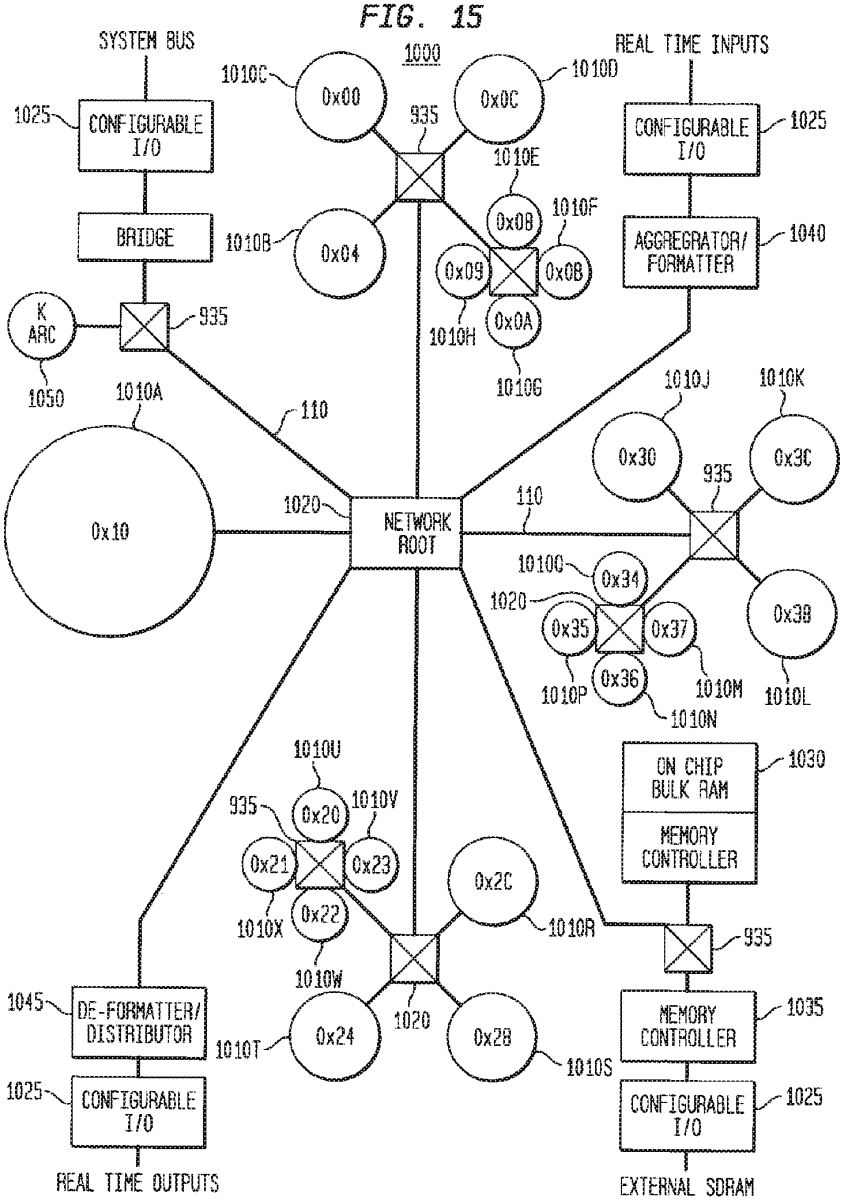

SYSTEM BUS
REAL TIME INPUTS
1000
1010C
0x00
0x0C
1010D
935
1025
CONFIGURABLE I/O
CONFIGURABLE I/O
1025
1010E
0x08
1010F
BRIDGE
1010B
0x04
AGGREGRATOR/ FORMATTER
1040
0x09
0x0B
K ARC
935
1010H
0x0A
1050
1010A
1010G
110
1010J
1010K
0x30
0x3C
935
0x10
1020
NETWORK ROOT
110
1010Q
0x34
1020
0x35
0x37
0x38
0x36
1010P
1010M
1010L
1010N
1010U
ON CHIP BULK RAM
1030
935
0x20
1010V
MEMORY CONTROLLER
0x21
0x23
0x2C
1010X
0x22
1010R
935
1010W
1045
DE-FORMATTER/ DISTRIBUTOR
1020
MEMORY CONTROLLER
1035
1010T
0x24
0x28
1010S
1025
CONFIGURABLE I/O
CONFIGURABLE I/O
1025
REAL TIME OUTPUTS
EXTERNAL SDRAM

FIG. 16A

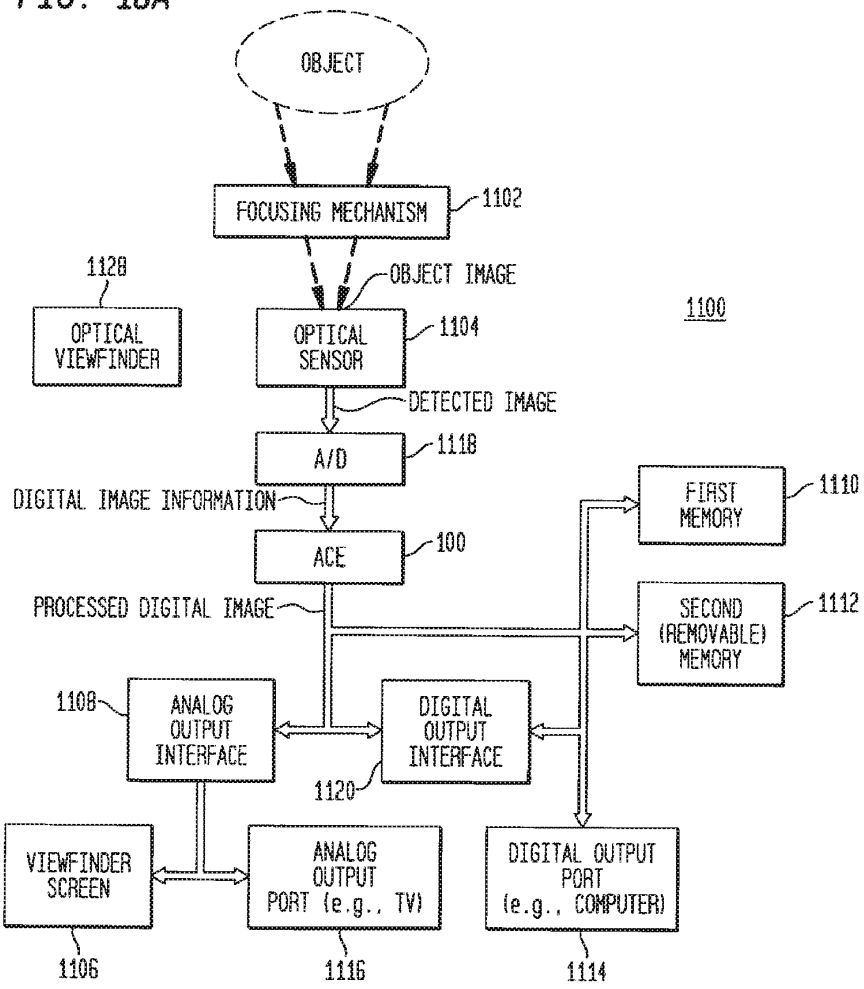

OBJECT
FOCUSING MECHANISM
1102
1128
OBJECT IMAGE
1100
OPTICAL VIEWFINDER
OPTICAL SENSOR
1104
DETECTED IMAGE
A/D
1118
DIGITAL IMAGE INFORMATION
FIRST MEMORY
1110
ACE
100
PROCESSED DIGITAL IMAGE
SECOND (REMOVABLE) MEMORY
1112
1108
ANALOG OUTPUT INTERFACE
DIGITAL OUTPUT INTERFACE
1120
VIEWFINDER SCREEN
ANALOG OUTPUT PORT (e.g., TV)
DIGITAL OUTPUT PORT (e.g., COMPUTER)
1106
1116
1114

FIG. 16B

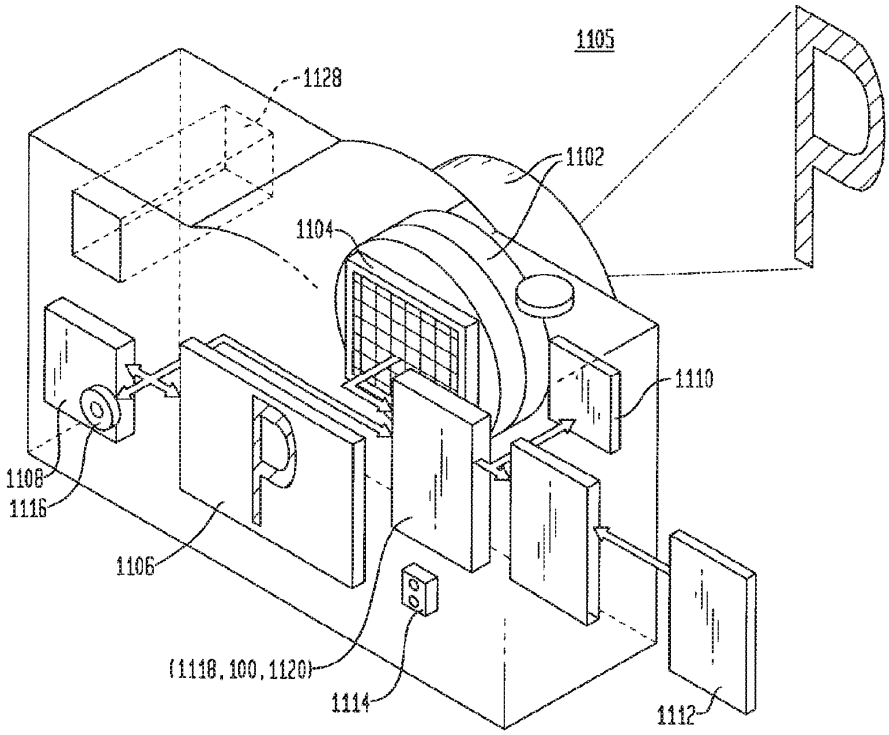
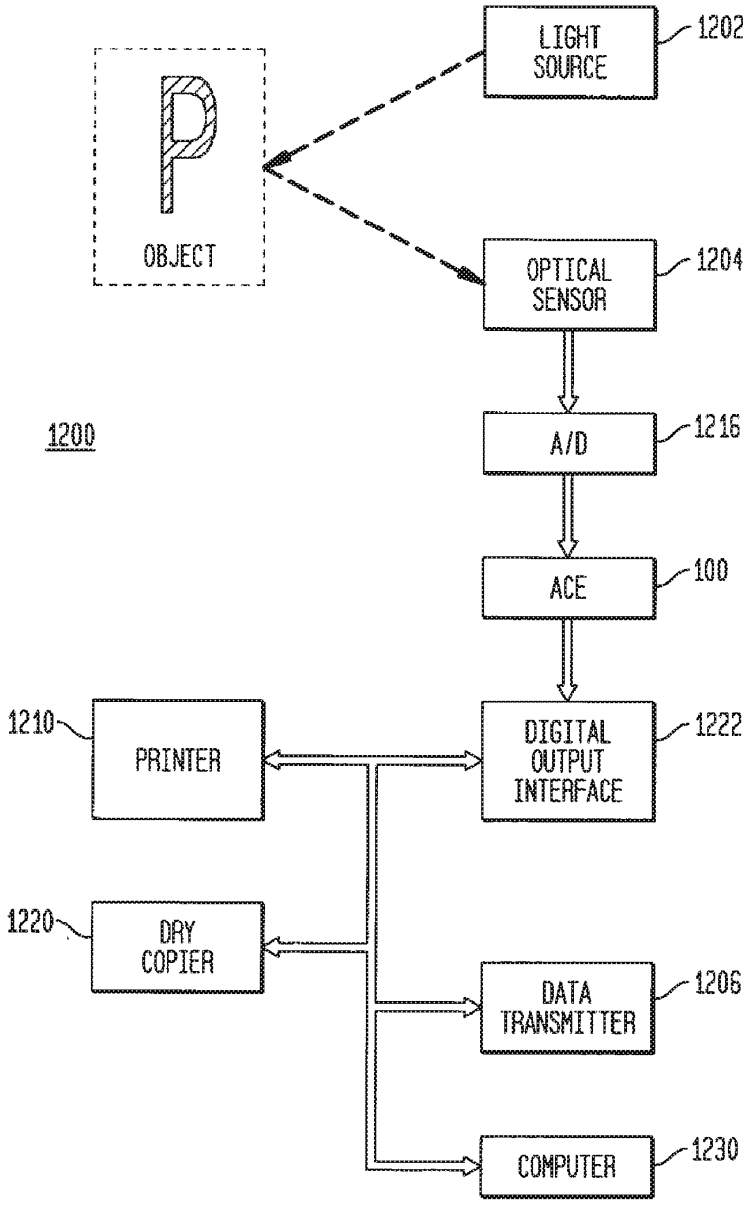

1105
1128
1102
1104
1110
1108
1116
1106
(1118, 100, 1120)
1114
1112

FIG. 17


LIGHT SOURCE
1202
OBJECT
OPTICAL SENSOR
1204
1200
A/D
1216
ACE
100
1210
PRINTER
DIGITAL OUTPUT INTERFACE
1222
1220
DRY COPIER
DATA TRANSMITTER
1206
COMPUTER
1230

CONFIGURABLE HARDWARE BASED DIGITAL IMAGING APPARATUS

CROSS-REFERENCE TO A RELATED APPLICATION

This application is related to a Paul L. Master et al., U.S. patent application Ser. No. 10/384,486, entitled "Adaptive Integrated Circuitry With Heterogeneous And Reconfigurable Matrices Of Diverse And Adaptive Computational Units Having Fixed, Application Specific Computational Elements", filed Mar. 7, 2003, commonly assigned to QuickSilver Technology, Inc., and incorporated by reference herein, which is a continuation-in-part of Paul L. Master et al., U.S. patent application Ser. No. 09/815,122, entitled "Adaptive Integrated Circuitry With Heterogeneous And Reconfigurable Matrices Of Diverse And Adaptive Computational Units Having Fixed, Application Specific Computational Elements", filed Mar. 22, 2001, now U.S. Pat. No. 6,836,839, commonly assigned to QuickSilver Technology, Inc.

FIELD OF THE INVENTION

The present invention relates, in general, to digital imaging and, more particularly, to digital imaging and other optical applications using adaptive integrated circuitry with heterogeneous and reconfigurable matrices of diverse and adaptive computational units having fixed, application specific computational elements.

BACKGROUND OF THE INVENTION

The related application discloses a new form or type of integrated circuit, referred to as an adaptive computing engine ("ACE"), which is readily reconfigurable, in real time, and is capable of having corresponding, multiple modes of operation.

The ACE architecture for adaptive or reconfigurable computing, includes a plurality of different or heterogeneous computational elements coupled to an interconnection network. The plurality of heterogeneous computational elements include corresponding computational elements having fixed and differing architectures, such as fixed architectures for different functions such as memory, addition, multiplication, complex multiplication, subtraction, configuration, reconfiguration, control, input, output, and field programmability. In response to configuration information, the interconnection network is operative in real time to adapt (configure and reconfigure) the plurality of heterogeneous computational elements for a plurality of different functional modes, including linear algorithmic operations, non-linear algorithmic operations, finite state machine operations, memory operations, and bit-level manipulations.

The ACE architecture provides a single IC, which may be adapted in real time, using these fixed and application specific computational elements, to perform a wide variety of tasks. For example, utilizing differing configurations over time of the same set of heterogeneous computational elements, the ACE architecture may implement functions such as finite impulse response filtering, fast Fourier transformation, discrete cosine transformation, and with other types of computational elements, may implement many other high level processing functions for advanced communications and computing.

Digital image processing is a comparatively recent field, and includes devices such as digital cameras, digital scanners, facsimile (fax) machines, and copying machines. Conventional digital image processing, however, utilizes conventional processing technology, such as digital signal processors ("DSPs"), microprocessors, or application-specific integrated circuits ("ASICs"). As a consequence, a need remains for digital image processing using an adaptive computing circuit architecture, such as using the ACE architecture of the related application.

SUMMARY OF THE INVENTION

The present invention provides a digital imaging apparatus which may be embodied, for example, as a digital camera, a scanner, a printer, a dry copier, or otherwise utilized in digital imaging applications. The digital imaging apparatus of the invention includes an optical sensor, an analog-to-digital converter, a plurality of computational elements, and an interconnection network. The optical sensor is capable of converting an object image into a detected image. The analog-to-digital converter is coupled to the optical sensor and is capable of converting the detected image to digital image information. The plurality of computational elements includes a first computational element having a first fixed architecture and a second computational element having a second fixed architecture, with the first fixed architecture being different than the second fixed architecture. The interconnection network is coupled to the plurality of computational elements and to the analog-to-digital converter, and is capable of providing a processed digital image from the digital image information by configuring the plurality of computational elements for performance of a first imaging function of a plurality of imaging functions in response to first configuration information, and by reconfiguring the plurality of computational elements for performance of a second imaging function of the plurality of imaging functions in response to second configuration information, with the first imaging function being different than the second imaging function.

The digital imaging apparatus may also include focusing means capable of providing the object image to the optical sensor, such as a focusing assembly having a lens, a shutter, an aperture, and a focusing motor. The optical sensor is at least one of a plurality of optical sensors, such as a charge coupled device (CCD), a charge injection device (CID), an optical complementary metal oxide silicon (CMOS) array, an optical bipolar junction transistor (BJT) array, a photogate array, or a photodiode array.

The digital imaging apparatus, in various embodiments, may also include an analog output interface coupled to the interconnection network, the analog output interface capable of converting the processed digital image to an analog form; a viewfinder screen coupled to the analog output interface, the viewfinder screen capable of visually displaying the analog form of the processed digital image, and an analog output port coupled to the analog output interface, the analog output port capable of outputting the analog form of the processed digital image, such as for connection to a television or other video display. The digital imaging apparatus may also include a digital output port coupled to the interconnection network, the digital output port capable of outputting the processed digital image, such as for connection to a computer or a data transmission device.

The processed digital image may also be provided as a plurality of processed digital image data packets. In this embodiment, the digital imaging apparatus may also include a digital output interface coupled to the interconnection network, with the digital output interface capable of selecting a plurality of processed digital image data words from the plurality of processed digital image data packets and assem-

bling the plurality of processed digital image data words to form the processed digital image.

The digital imaging apparatus also may be included within or coupled to, for example: a printer capable of printing the processed digital image on a tangible medium; a dry copier capable of transferring the processed digital image to a tangible medium; a data transmitter capable of transmitting the processed digital image to a remote location; a scanner capable of transferring the processed digital image to a storage medium, to a computer, and so on.

In the various embodiments, the plurality of imaging functions may include one or more of the following functions: linear filtering; nonlinear filtering; morphological filtering; median filtering; local weighted median filtering; center weighted median filtering; vector weighted median filtering; multichannel image recovery; multiframe image restoration; iterative image restoration; motion detection; motion estimation; low pass filtering; multirate filtering; wavelet-based multirate filtering; autofocusing; contrast enhancement; blur removal.

Also in the various embodiments, the first fixed architecture and the second fixed architecture of the a plurality of computational elements may be selected from a plurality of specific architectures, such as those architectures having the following corresponding functions: linear filtering, non-linear filtering, memory, addition, multiplication, complex multiplication, subtraction, synchronization, queuing, over sampling, under sampling, adaptation, configuration, reconfiguration, control, input, output, and field programmability.

Various types of memory may be included within the digital imaging apparatus. For example, a first memory may be couplable to the interconnection network and capable of storing the processed digital image, and this first memory may be a selectively removable flash memory. A second memory may also be included, coupled to the interconnection network, and be capable of storing the first configuration information and the second configuration information, such as synchronous dynamic random access memory (SDRAM).

In another embodiment, the digital imaging apparatus includes an optical sensor, an analog-to-digital converter, an input pipeline register, a first memory, a hardware task manager, a data distributor, an adaptive execution unit, a data selector, and an output pipeline register. The optical sensor is also capable of converting an object image into a detected image. The analog-to-digital converter is coupled to the optical sensor and is capable of converting the detected image to a plurality of digital image information data packets. The input pipeline register is coupled to the analog-to-digital converter and is capable of receiving the plurality of digital image information data packets, while the first memory is capable of storing the plurality of digital image information data packets. The hardware task manager is capable of processing a plurality of imaging tasks and determining that a first imaging task from the plurality of imaging tasks is capable of being performed and that a second imaging task from the plurality of imaging tasks is capable of being performed, with the first imaging task being different than the second imaging task. The data distributor is coupled to the input pipeline register, to the first memory, and to the hardware task manager, and is capable of distributing the plurality of digital image information data packets to the first memory. The adaptive execution unit is coupled to the hardware task manager and to the first memory, and is capable of configuring to perform the first imaging task and capable of performing the first imaging task using the plurality of digital image information data packets, the adaptive execution unit further capable of reconfiguring to perform the second imaging task and capable of performing the second imaging task, and the adaptive execution unit further capable of generating a corresponding plurality of processed digital image data packets from the performance of the first imaging task and the second imaging task. The data selector is coupled to the hardware task manager, to the adaptive execution unit and to the first memory, and is capable of determining routing for the corresponding plurality of processed digital image data packets. The output pipeline register is coupled to the data selector, and is capable of receiving the corresponding plurality of processed digital image data packets.

In this embodiment, the adaptive execution unit includes a plurality of computational elements and a plurality of switching elements coupled to the plurality of computational elements. In the plurality of computational elements, a first computational element has a first fixed architecture and a second computational element has a second fixed architecture, with the first fixed architecture being different from the second fixed architecture. The plurality of switching elements are capable of configuring the plurality of computational elements for performance of a first imaging function of a plurality of imaging functions in response to first configuration information, and are further capable of reconfiguring the plurality of computational elements for performance of a second imaging function of the plurality of imaging functions in response to second configuration information, with the first imaging function being different than the second imaging function.

Numerous other advantages and features of the present invention will become readily apparent from the following detailed description of the invention and the embodiments thereof, from the claims and from the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating an exemplary first apparatus embodiment in accordance with the present invention.

FIG. **2** is a schematic diagram illustrating an exemplary data flow graph.

FIG. **3** is a block diagram illustrating a reconfigurable matrix (or node), a plurality of computation units, and a plurality of computational elements.

FIG. **4** is a block diagram illustrating, in greater detail, a computational unit of a reconfigurable matrix.

FIGS. **5**A through **5**E are block diagrams illustrating, in detail, exemplary fixed and specific computational elements, forming computational units.

FIG. **6** is a block diagram illustrating, in detail, an exemplary multi-function adaptive computational unit having a plurality of different, fixed computational elements.

FIG. **7** is a block diagram illustrating, in detail, an adaptive logic processor computational unit having a plurality of fixed computational elements.

FIG. **8** is a block diagram illustrating, in greater detail, an exemplary core cell of an adaptive logic processor computational unit with a fixed computational element.

FIG. **9** is a block diagram illustrating, in greater detail, an exemplary fixed computational element of a core cell of an adaptive logic processor computational unit.

FIG. **10** is a block diagram illustrating a second exemplary apparatus embodiment in accordance with the present invention.

FIG. **11** is a block diagram illustrating an exemplary first system embodiment in accordance with the present invention.

FIG. **12** is a block diagram illustrating an exemplary node quadrant with routing elements in accordance with the present invention.

FIG. **13** is a block diagram illustrating exemplary network interconnections in accordance with the present invention.

FIG. **14** is a block diagram illustrating an exemplary data structure embodiment in accordance with the present invention.

FIG. **15** is a block diagram illustrating an exemplary second system embodiment in accordance with the present invention.

FIG. **16**A is a block diagram of an exemplary digital camera in accordance with the present invention.

FIG. **16**B is a perspective view of the exemplary digital camera in accordance with the present invention.

FIG. **17** is a block diagram of an exemplary facsimile, scanner, or photocopier machine in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

While the present invention is susceptible of embodiment in many different forms, there are shown in the drawings and will be described herein in detail specific embodiments thereof, with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the specific embodiments illustrated.

The present invention provides digital image processing using an adaptive computing architecture such as the ACE architecture. The adaptive computing architecture of the invention uses a plurality of computational elements, which themselves have fixed architectures, in conjunction with an interconnection network, to configure and reconfigure the same computational elements to perform a wide variety of functions and operations which, in this case, pertain to digital image processing. The ACE architecture, for example, may be configured and reconfigured to process an optically detected image to provide a processed digital image, such as for use in a digital camera, a video camera, video telephony applications, digital TV, digital cinema, a fax machine, a photocopier, or any number of other devices that create or reproduce an image from visible spectrum (light) signals.

FIG. **1** is a block diagram illustrating a first apparatus **100** embodiment in accordance with the present invention. The apparatus **100**, referred to herein as an adaptive computing engine ("ACE") **100**, is preferably embodied as an integrated circuit, or as a portion of an integrated circuit having other, additional components. In the first apparatus embodiment, and as discussed in greater detail below, the ACE **100** includes one or more reconfigurable matrices (or nodes) **150**, such as matrices **150**A through **150**N as illustrated, and a matrix interconnection network **110**. Also in the first apparatus embodiment, and as discussed in detail below, one or more of the matrices (nodes) **150**, such as matrices **150**A and **150**B, are configured for functionality as a controller **120**, while other matrices, such as matrices **150**C and **150**D, are configured for functionality as a memory **140**. The various matrices **150** and matrix interconnection network **110** may also be implemented together as fractal subunits, which may be scaled from a few nodes to thousands of nodes.

A significant departure from the prior art, the ACE **100** does not utilize traditional (and typically separate) data, direct memory access (DMA), random access, configuration and instruction busses for signaling and other transmission between and among the reconfigurable matrices **150**, the controller **120**, and the memory **140**, or for other input/output ("I/O") functionality. Rather, data, control and configuration information are transmitted between and among these matrix **150** elements, utilizing the matrix interconnection network **110**, which may be configured and reconfigured, in real time, to provide any given connection between and among the reconfigurable matrices **150**, including those matrices **150** configured as the controller **120** and the memory **140**, as discussed in greater detail below.

The matrices **150** configured to function as memory **140** may be implemented in any desired or preferred way, utilizing computational elements (discussed below) of fixed memory elements, and may be included within the ACE **100** or incorporated within another IC or portion of an IC. In the first apparatus embodiment, the memory **140** is included within the ACE **100**, and preferably is comprised of computational elements which are low power consumption random access memory (RAM), but also may be comprised of computational elements of any other form of memory, such as flash, DRAM, SRAM, SDRAM, FeRAM, MRAM, ROM, EPROM or E^2PROM. In the first apparatus embodiment, the memory **140** preferably includes DMA engines, not separately illustrated.

The controller **120** is preferably implemented, using matrices **150**A and **150**B configured as adaptive finite state machines, as a reduced instruction set ("RISC") processor, controller or other device or IC capable of performing the two types of functionality discussed below. (Alternatively, these functions may be implemented utilizing a conventional RISC or other processor.) The first control functionality, referred to as "kernel" control, is illustrated as kernel controller ("KARC") of matrix **150**A, and the second control functionality, referred to as "matrix" control, is illustrated as matrix controller ("MARC") of matrix **150**B. The kernel and matrix control functions of the controller **120** are explained in greater detail below, with reference to the configurability and reconfigurability of the various matrices **150**, and with reference to the exemplary form of combined data, configuration and control information referred to herein as a "silverware" module. The kernel controller is also referred to as a "K-node", discussed in greater detail below with reference to FIGS. **10** and **11**.

The matrix interconnection network ("MIN") **110** of FIG. **1**, and its subset interconnection networks separately illustrated in FIGS. **3** and **4** (Boolean interconnection network **210**, data interconnection network **240**, and interconnect **220**), collectively and generally referred to herein as "interconnect", "interconnection(s)" or "interconnection network(s)", may be implemented generally as known in the art, such as utilizing FPGA interconnection networks or switching fabrics, albeit in a considerably more varied fashion. In the first apparatus embodiment, the various interconnection networks are implemented as described, for example, in U.S. Pat. No. 5,218,240, U.S. Pat. No. 5,336,950, U.S. Pat. No. 5,245,227, and U.S. Pat. No. 5,144,166, and also as discussed below and as illustrated with reference to FIGS. **7**, **8** and **9**. These various interconnection networks provide selectable (or switchable) connections between and among the controller **120**, the memory **140**, the various matrices **150**, and the computational units **200** and computational elements **250** discussed below, providing the physical basis for the configuration and reconfiguration referred to herein, in response to and under the control of configuration signaling generally referred to herein as "configuration information". In addition, the various interconnection networks (**110**, **210**, **240** and **220**) provide selectable or switchable data, input, output, control and configuration paths, between and among the controller **120**, the memory **140**, the various matrices **150**, and the computational units **200** and computational elements **250**, in

lieu of any form of traditional or separate input/output busses, data busses, DMA, RAM, configuration and instruction busses. In the second apparatus embodiment, the various interconnection networks are implemented as described below with reference to FIGS. **12** and **13**, using various combinations of routing elements, such as token rings or arbiters, and multiplexers, at varying levels within the system and apparatus embodiments.

It should be pointed out, however, that while any given level of switching or selecting operation of or within the various interconnection networks (**110**, **210**, **240** and **220**) may be implemented as known in the art, the combinations of routing elements and multiplexing elements, the use of different routing elements and multiplexing elements at differing levels within the system, and the design and layout of the various interconnection networks (**110**, **210**, **240** and **220**) are new and novel, as discussed in greater detail below. For example, varying levels of interconnection are provided to correspond to the varying levels of the matrices **150**, the computational units **200**, and the computational elements **250**, discussed below. At the matrix **150** level, in comparison with the prior art FPGA interconnect, the matrix interconnection network **110** is considerably more limited and less "rich", with lesser connection capability in a given area, to reduce capacitance and increase speed of operation. Within a particular matrix **150** or computational unit **200**, however, the interconnection network (**210**, **220** and **240**) may be considerably more dense and rich, to provide greater adaptation and reconfiguration capability within a narrow or close locality of reference.

The various matrices or nodes **150** are reconfigurable and heterogeneous, namely, in general, and depending upon the desired configuration: reconfigurable matrix **150**A is generally different from reconfigurable matrices **150**B through **150**N; reconfigurable matrix **150**B is generally different from reconfigurable matrices **150**A and **150**C through **150**N; reconfigurable matrix **150**C is generally different from reconfigurable matrices **150**A, **150**B and **150**D through **150**N, and so on. The various reconfigurable matrices **150** each generally contain a different or varied mix of adaptive and reconfigurable computational (or computation) units (**200**); the computational units **200**, in turn, generally contain a different or varied mix of fixed, application specific computational elements (**250**), discussed in greater detail below with reference to FIGS. **3** and **4**, which may be adaptively connected, configured and reconfigured in various ways to perform varied functions, through the various interconnection networks. In addition to varied internal configurations and reconfigurations, the various matrices **150** may be connected, configured and reconfigured at a higher level, with respect to each of the other matrices **150**, through the matrix interconnection network **110**, also as discussed in greater detail below.

Several different, insightful and novel concepts are incorporated within the ACE **100** architecture and provide a useful explanatory basis for the real time operation of the ACE **100** and its inherent advantages.

The first novel concepts concern the adaptive and reconfigurable use of application specific, dedicated or fixed hardware units (computational elements **250**), and the selection of particular functions for acceleration, to be included within these application specific, dedicated or fixed hardware units (computational elements **250**) within the computational units **200** (FIG. **3**) of the matrices **150**, such as pluralities of multipliers, complex multipliers, and adders, each of which are designed for optimal execution of corresponding multiplication, complex multiplication, and addition functions. Given that the ACE **100** is to be optimized, in the first apparatus embodiment, for low power consumption, the functions for acceleration are selected based upon power consumption. For example, for a given application such as mobile communication, corresponding C (C# or C++) or other code may be analyzed for power consumption. Such empirical analysis may reveal, for example, that a small portion of such code, such as 10%, actually consumes 90% of the operating power when executed. On the basis of such power utilization, this small portion of code is selected for acceleration within certain types of the reconfigurable matrices **150**, with the remaining code, for example, adapted to run within matrices **150** configured as controller **120**. Additional code may also be selected for acceleration, resulting in an optimization of power consumption by the ACE **100**, up to any potential trade-off resulting from design or operational complexity. In addition, as discussed with respect to FIG. **3**, other functionality, such as control code, may be accelerated within matrices **150** when configured as finite state machines.

Next, algorithms or other functions selected for acceleration are converted into a form referred to as a "data flow graph" ("DFG"). A schematic diagram of an exemplary data flow graph, in accordance with the present invention, is illustrated in FIG. **2**. As illustrated in FIG. **2**, an algorithm or function useful for CDMA voice coding (QCELP (Qualcomm code excited linear prediction) is implemented utilizing four multipliers **190** followed by four adders **195**. Through the varying levels of interconnect, the algorithms of this data flow graph are then implemented, at any given time, through the configuration and reconfiguration of fixed computational elements (**250**), namely, implemented within hardware which has been optimized and configured for efficiency, i.e., a "machine" is configured in real time which is optimized to perform the particular algorithm. Continuing with the exemplary DFG of FIG. **2**, four fixed or dedicated multipliers, as computational elements **250**, and four fixed or dedicated adders, also as different computational elements **250**, are configured in real time through the interconnect to perform the functions or algorithms of the particular DFG. Using this data flow model, data which is produced, such as by the multipliers **190**, is immediately consumed, such as by adders **195**.

The third and perhaps most significant concept, and a marked departure from the concepts and precepts of the prior art, is the concept of reconfigurable "heterogeneity" utilized to implement the various selected algorithms mentioned above. As indicated above, prior art reconfigurability has relied exclusively on homogeneous FPGAs, in which identical blocks of logic gates are repeated as an array within a rich, programmable interconnect, with the interconnect subsequently configured to provide connections between and among the identical gates to implement a particular function, albeit inefficiently and often with routing and combinatorial problems. In stark contrast, within computation units **200**, different computational elements (**250**) are implemented directly as correspondingly different fixed (or dedicated) application specific hardware, such as dedicated multipliers, complex multipliers, accumulators, arithmetic logic units (ALUs), registers, and adders. Utilizing interconnect (**210** and **220**), these differing, heterogeneous computational elements (**250**) may then be adaptively configured, in real time, to perform the selected algorithm, such as the performance of discrete cosine transformations often utilized in mobile communications. For the data flow graph example of FIG. **2**, four multipliers and four adders will be configured, i.e., connected in real time, to perform the particular algorithm. As a consequence, different ("heterogeneous") computational elements (**250**) are configured and reconfigured, at any given time, to

optimally perform a given algorithm or other function. In addition, for repetitive functions, a given instantiation or configuration of computational elements may also remain in place over time, i.e., unchanged, throughout the course of such repetitive calculations.

The temporal nature of the ACE **100** architecture should also be noted. At any given instant of time, utilizing different levels of interconnect (**110**, **210**, **240** and **220**), a particular configuration may exist within the ACE **100** which has been optimized to perform a given function or implement a particular algorithm. At another instant in time, the configuration may be changed, to interconnect other computational elements (**250**) or connect the same computational elements **250** differently, for the performance of another function or algorithm. Two important features arise from this temporal reconfigurability. First, as algorithms may change over time to, for example, implement a new technology standard, the ACE **100** may co-evolve and be reconfigured to implement the new algorithm. For a simplified example, a fifth multiplier and a fifth adder may be incorporated into the DFG of FIG. **2** to execute a correspondingly new algorithm, with additional interconnect also potentially utilized to implement any additional bussing functionality. Second, because computational elements are interconnected at one instant in time, as an instantiation of a given algorithm, and then reconfigured at another instant in time for performance of another, different algorithm, gate (or transistor) utilization is maximized, providing significantly better performance than the most efficient ASICs relative to their activity factors.

This temporal reconfigurability of computational elements **250**, for the performance of various different algorithms, also illustrates a conceptual distinction utilized herein between adaptation (configuration and reconfiguration), on the one hand, and programming or reprogrammability, on the other hand. Typical programmability utilizes a pre-existing group or set of functions, which may be called in various orders, over time, to implement a particular algorithm. In contrast, configurability and reconfigurability (or adaptation), as used herein, includes the additional capability of adding or creating new functions which were previously unavailable or nonexistent.

Next, the ACE **100** also utilizes a tight coupling (or interdigitation) of data and configuration (or other control) information, within one, effectively continuous stream of information. This coupling or commingling of data and configuration information, referred to as a "silverware" module, is the subject of a separate, related patent application. For purposes of the present invention, however, it is sufficient to note that this coupling of data and configuration information into one information (or bit) stream helps to enable real time reconfigurability of the ACE **100**, without a need for the (often unused) multiple, overlaying networks of hardware interconnections of the prior art. For example, as an analogy, a particular, first configuration of computational elements at a particular, first period of time, as the hardware to execute a corresponding algorithm during or after that first period of time, may be viewed or conceptualized as a hardware analog of "calling" a subroutine in software which may perform the same algorithm. As a consequence, once the configuration of the computational elements **250** has occurred (i.e., is in place), as directed by the configuration information, the data for use in the algorithm is immediately available as part of the silverware module. The same computational elements may then be reconfigured for a second period of time, as directed by second configuration information, for execution of a second, different algorithm, also utilizing immediately available data. The immediacy of the data, for use in the configured computational elements **250**, provides a one or two clock cycle hardware analog to the multiple and separate software steps of determining a memory address and fetching stored data from the addressed registers. This has the further result of additional efficiency, as the configured computational elements may execute, in comparatively few clock cycles, an algorithm which may require orders of magnitude more clock cycles for execution if called as a subroutine in a conventional microprocessor or DSP.

This use of silverware modules, as a commingling of data and configuration information, in conjunction with the real time reconfigurability of a plurality of heterogeneous and fixed computational elements **250** to form adaptive, different and heterogeneous computation units **200** and matrices **150**, enables the ACE **100** architecture to have multiple and different modes of operation. For example, when included within a hand-held device, given a corresponding silverware module, the ACE **100** may have various and different operating modes as a cellular or other mobile telephone, a music player, a pager, a personal digital assistant, and other new or existing functionalities. In addition, these operating modes may change based upon the physical location of the device; for example, when configured as a CDMA mobile telephone for use in the United States, the ACE **100** may be reconfigured as a GSM mobile telephone for use in Europe.

Referring again to FIG. **1**, the functions of the controller **120** (preferably matrix (KARC) **150**A and matrix (MARC) **150**B, configured as finite state machines) may be explained: (1) with reference to a silverware module, namely, the tight coupling of data and configuration information within a single stream of information; (2) with reference to multiple potential modes of operation; (3) with reference to the reconfigurable matrices **150**; and (4) with reference to the reconfigurable computation units **200** and the computational elements **150** illustrated in FIG. **3**. As indicated above, through a silverware module, the ACE **100** may be configured or reconfigured to perform a new or additional function, such as an upgrade to a new technology standard or the addition of an entirely new function, such as the addition of a music function to a mobile communication device. Such a silverware module may be stored in the matrices **150** of memory **140**, or may be input from an external (wired or wireless) source through, for example, matrix interconnection network **110**. In the first apparatus embodiment, one of the plurality of matrices **150** is configured to decrypt such a module and verify its validity, for security purposes. Next, prior to any configuration or reconfiguration of existing ACE **100** resources, the controller **120**, through the matrix (KARC) **150**A, checks and verifies that the configuration or reconfiguration may occur without adversely affecting any pre-existing functionality, such as whether the addition of music functionality would adversely affect pre-existing mobile communications functionality. In the first apparatus embodiment, the system requirements for such configuration or reconfiguration are included within the silverware module, for use by the matrix (KARC) **150**A in performing this evaluative function. If the configuration or reconfiguration may occur without such adverse affects, the silverware module is allowed to load into the matrices **150** of memory **140**, with the matrix (KARC) **150**A setting up the DMA engines within the matrices **150**C and **150**D of the memory **140** (or other stand-alone DMA engines of a conventional memory). If the configuration or reconfiguration would or may have such adverse affects, the matrix (KARC) **150**A does not allow the new module to be incorporated within the ACE **100**. Additional functions of the kernel controller, as a K-node, are discussed in greater detail below.

Continuing to refer to FIG. **1**, the matrix (MARC) **150**B manages the scheduling of matrix **150** resources and the timing of any corresponding data, to synchronize any configuration or reconfiguration of the various computational elements **250** and computation units **200** with any corresponding input data and output data. In the first apparatus embodiment, timing information is also included within a silverware module, to allow the matrix (MARC) **150**B through the various interconnection networks to direct a reconfiguration of the various matrices **150** in time, and preferably just in time, for the reconfiguration to occur before corresponding data has appeared at any inputs of the various reconfigured computation units **200**. In addition, the matrix (MARC) **150**B may also perform any residual processing which has not been accelerated within any of the various matrices **150**. As a consequence, the matrix (MARC) **150**B may be viewed as a control unit which "calls" the configurations and reconfigurations of the matrices **150**, computation units **200** and computational elements **250**, in real time, in synchronization with any corresponding data to be utilized by these various reconfigurable hardware units, and which performs any residual or other control processing. Other matrices **150** may also include this control functionality, with any given matrix **150** capable of calling and controlling a configuration and reconfiguration of other matrices **150**. This matrix control functionality may also be combined with kernel control, such as in the K-node, discussed below.

FIG. **3** is a block diagram illustrating, in greater detail, a reconfigurable matrix (or node) **150** with a plurality of computation units **200** (illustrated as computation units **200**A through **200**N), and a plurality of computational elements **250** (illustrated as computational elements **250**A through **250**Z), and provides additional illustration of the exemplary types of computational elements **250** and a useful summary. As illustrated in FIG. **3**, any matrix **150** generally includes a matrix controller **230**, a plurality of computation (or computational) units **200**, and as logical or conceptual subsets or portions of the matrix interconnect network **110**, a data interconnect network **240** and a Boolean interconnect network **210**. The matrix controller **230** may also be implemented as a hardware task manager, discussed below with reference to FIG. **10**. As mentioned above, in the first apparatus embodiment, at increasing "depths" within the ACE **100** architecture, the interconnect networks become increasingly rich, for greater levels of adaptability and reconfiguration. The Boolean interconnect network **210**, also as mentioned above, provides the reconfiguration and data interconnection capability between and among the various computation units **200**, and is preferably small (i.e., only a few bits wide), while the data interconnect network **240** provides the reconfiguration and data interconnection capability for data input and output between and among the various computation units **200**, and is preferably comparatively large (i.e., many bits wide). It should be noted, however, that while conceptually divided into reconfiguration and data capabilities, any given physical portion of the matrix interconnection network **110**, at any given time, may be operating as either the Boolean interconnect network **210**, the data interconnect network **240**, the lowest level interconnect **220** (between and among the various computational elements **250**), or other input, output, or connection functionality. It should also be noted that other, exemplary forms of interconnect are discussed in greater detail below with reference to FIGS. **11**-**13**.

Continuing to refer to FIG. **3**, included within a computation unit **200** are a plurality of computational elements **250**, illustrated as computational elements **250**A through **250**Z (individually and collectively referred to as computational elements **250**), and additional interconnect **220**. The interconnect **220** provides the reconfigurable interconnection capability and input/output paths between and among the various computational elements **250**. As indicated above, each of the various computational elements **250** consist of dedicated, application specific hardware designed to perform a given task or range of tasks, resulting in a plurality of different, fixed computational elements **250**. Utilizing the interconnect **220**, the fixed computational elements **250** may be reconfigurably connected together into adaptive and varied computational units **200**, which also may be further reconfigured and interconnected, to execute an algorithm or other function, at any given time, such as the quadruple multiplications and additions of the DFG of FIG. **2**, utilizing the interconnect **220**, the Boolean network **210**, and the matrix interconnection network **110**. For example, using the multiplexing or routing capabilities discussed below, the inputs/outputs of a computational element **250** may be coupled to outputs/inputs of a first set of (other) computational elements **250**, for performance of a first function or algorithm, and subsequently adapted or reconfigured, such that these inputs/outputs are coupled to outputs/inputs of a second set of (other) computational elements **250**, for performance of a second function or algorithm.

In the first apparatus embodiment, the various computational elements **250** are designed and grouped together, into the various adaptive and reconfigurable computation units **200** (as illustrated, for example, in FIGS. **5**A through **9**). In addition to computational elements **250** which are designed to execute a particular algorithm or function, such as multiplication or addition, other types of computational elements **250** are also utilized in the first apparatus embodiment. As illustrated in FIG. **3**, computational elements **250**A and **250**B implement memory, to provide local memory elements for any given calculation or processing function (compared to the more "remote" memory **140**). In addition, computational elements **250**I, **250**J, **250**K and **250**L are configured to implement finite state machines (using, for example, the computational elements illustrated in FIGS. **7**, **8** and **9**), to provide local processing capability (compared to the more "remote" matrix (MARC) **150**B), especially suitable for complicated control processing, and which may be utilized within the hardware task manager, discussed below.

With the various types of different computational elements **250** which may be available, depending upon the desired functionality of the ACE **100**, the computation units **200** may be loosely categorized. A first category of computation units **200** includes computational elements **250** performing linear operations, such as multiplication, addition, finite impulse response filtering, and so on (as illustrated below, for example, with reference to FIGS. **5**A through **5**E and FIG. **6**). A second category of computation units **200** includes computational elements **250** performing non-linear operations, such as discrete cosine transformation, trigonometric calculations, and complex multiplications. A third type of computation unit **200** implements a finite state machine, such as computation unit **200**C as illustrated in FIG. **3** and as illustrated in greater detail below with respect to FIGS. **7** through **9**), particularly useful for complicated control sequences, dynamic scheduling, and input/output management, while a fourth type may implement memory and memory management, such as computation unit **200**A as illustrated in FIG. **3**. Lastly, a fifth type of computation unit **200** may be included to perform bit-level manipulation, such as for encryption, decryption, channel coding, Viterbi decoding, and packet and protocol processing (such as Internet Protocol processing).

In the first apparatus embodiment, in addition to control from other matrices or nodes **150**, a matrix controller **230** may also be included within any given matrix **150**, also to provide greater locality of reference and control of any reconfiguration processes and any corresponding data manipulations. For example, once a reconfiguration of computational elements **250** has occurred within any given computation unit **200**, the matrix controller **230** may direct that that particular instantiation (or configuration) remain intact for a certain period of time to, for example, continue repetitive data processing for a given application.

As indicated above, the plurality of heterogeneous computational elements **250** may be configured and reconfigured, through the levels of the interconnect network (**110**, **210**, **220**, **240**), for performance of a plurality of functional or operational modes, such as linear operations, non-linear operations, finite state machine operations, memory and memory management, and bit-level manipulation. This configuration and reconfiguration of the plurality of heterogeneous computational elements **250** through the levels of the interconnect network (**110**, **210**, **220**, **240**), however, may be conceptualized on another, higher or more abstract level, namely, configuration and reconfiguration for the performance of a plurality of algorithmic elements.

At this more abstract level of the algorithmic element, the performance of any one of the algorithmic elements may be considered to require a simultaneous performance of a plurality of the lower-level functions or operations, such as move, input, output, add, subtract, multiply, complex multiply, divide, shift, multiply and accumulate, and so on, using a configuration (and reconfiguration) of computational elements having a plurality of fixed architectures such as memory, addition, multiplication, complex multiplication, subtraction, synchronization, queuing, over sampling, under sampling, adaptation, configuration, reconfiguration, control, input, output, and field programmability.

When such a plurality of fixed architectures are configured and reconfigured for performance of an entire algorithmic element, this performance may occur using comparatively few clock cycles, compared to the orders of magnitude more clock cycles typically required. The algorithmic elements may be selected from a plurality of algorithmic elements comprising, for example: a radix-2 Fast Fourier Transformation (FFT), a radix-4 Fast Fourier Transformation (FFT), a radix-2 inverse Fast Fourier Transformation (IFFT), a radix-4 IFFT, a one-dimensional Discrete Cosine Transformation (DCT), a multi-dimensional Discrete Cosine Transformation (DCT), finite impulse response (FIR) filtering, convolutional encoding, scrambling, puncturing, interleaving, modulation mapping, Golay correlation, OVSF code generation, Haddamard Transformation, Turbo Decoding, bit correlation, Griffiths LMS algorithm, variable length encoding, uplink scrambling code generation, downlink scrambling code generation, downlink despreading, uplink spreading, uplink concatenation, Viterbi encoding, Viterbi decoding, cyclic redundancy coding (CRC), complex multiplication, data compression, motion compensation, channel searching, channel acquisition, and multipath correlation. Numerous other algorithmic element examples are discussed in greater detail below with reference to FIG. **10**.

In another embodiment of the ACE **100**, one or more of the matrices (or nodes) **150** may be designed to be application specific, having a fixed architecture with a corresponding fixed function (or predetermined application), rather than being comprised of a plurality of heterogeneous computational elements which may be configured and reconfigured for performance of a plurality of operations, functions, or algorithmic elements. For example, an analog-to-digital (A/D) or digital-to-analog (D/A) converter may be implemented without adaptive capability. As discussed in greater detail below, common node (matrix) functions also may be implemented without adaptive capability, such as the node wrapper functions discussed below. Under various circumstances, however, the fixed function node may be capable of parameter adjustment for performance of the predetermined application. For example, the parameter adjustment may comprise changing one or more of the following parameters: a number of filter coefficients, a number of parallel input bits, a number of parallel output bits, a number of selected points for Fast Fourier Transformation, a number of bits of precision, a code rate, a number of bits of interpolation of a trigonometric function, and real or complex number valuation. This fixed function node (or matrix) **150**, which may be parametizable, will typically be utilized in circumstances where an algorithmic element is used on a virtually continuous basis, such as in certain types of communications or computing applications.

For example, the fixed function node **150** may be a microprocessor (such as a RISC processor), a digital signal processor (DSP), or a co-processor, and may or may not have an embedded operating system. Such a controller or processor fixed function node **150** may be utilized for the various KARC **150**A or MARC **150**B applications mentioned above, such as providing configuration information to the interconnection network, directing and scheduling the configuration of the plurality of heterogeneous computational elements **250** of the other nodes **150** for performance of the various functional modes or algorithmic elements, or timing and scheduling the configuration and reconfiguration of the plurality of heterogeneous computational elements with corresponding data. In other applications, also for example, the fixed function node may be a cascaded integrated comb (CIC) filter or a parameterized, cascaded integrated comb (CIC) filter; a finite impulse response (FIR) filter or a finite impulse response (FIR) filter parameterized for variable filter length; or an A/D or D/A converter.

FIG. **4** is a block diagram illustrating, in greater detail, an exemplary or representative computation unit **200** of a reconfigurable matrix **150**. As illustrated in FIG. **4**, a computation unit **200** typically includes a plurality of diverse, heterogeneous and fixed computational elements **250**, such as a plurality of memory computational elements **250**A and **250**B, and forming a computational unit ("CU") core **260**, a plurality of algorithmic or finite state machine computational elements **250**C through **250**K. As discussed above, each computational element **250**, of the plurality of diverse computational elements **250**, is a fixed or dedicated, application specific circuit, designed and having a corresponding logic gate layout to perform a specific function or algorithm, such as addition or multiplication. In addition, the various memory computational elements **250**A and **250**B may be implemented with various bit depths, such as RAM (having significant depth), or as a register, having a depth of 1 or 2 bits.

Forming the conceptual data and Boolean interconnect networks **240** and **210**, respectively, the exemplary computation unit **200** also includes a plurality of input multiplexers **280**, a plurality of input lines (or wires) **281**, and for the output of the CU core **260** (illustrated as line or wire **270**), a plurality of output demultiplexers **285** and **290**, and a plurality of output lines (or wires) **291**. Through the input multiplexers **280**, an appropriate input line **281** may be selected for input use in data transformation and in the configuration and interconnection processes, and through the output demultiplexers **285** and **290**, an output or multiple outputs may be placed on

a selected output line **291**, also for use in additional data transformation and in the configuration and interconnection processes.

In the first apparatus embodiment, the selection of various input and output lines **281** and **291**, and the creation of various connections through the interconnect (**210**, **220** and **240**), is under control of control bits **265** from a computational unit controller **255**, as discussed below. Based upon these control bits **265**, any of the various input enables **251**, input selects **252**, output selects **253**, MUX selects **254**, DEMUX enables **256**, DEMUX selects **257**, and DEMUX output selects **258**, may be activated or deactivated.

The exemplary computation unit **200** includes the computation unit controller **255** which provides control, through control bits **265**, over what each computational element **250**, interconnect (**210**, **220** and **240**), and other elements (above) does with every clock cycle. Not separately illustrated, through the interconnect (**210**, **220** and **240**), the various control bits **265** are distributed, as may be needed, to the various portions of the computation unit **200**, such as the various input enables **251**, input selects **252**, output selects **253**, MUX selects **254**, DEMUX enables **256**, DEMUX selects **257**, and DEMUX output selects **258**. The CU controller **255** also includes one or more lines **295** for reception of control (or configuration) information and transmission of status information.

As mentioned above, the interconnect may include a conceptual division into a data interconnect network **240** and a Boolean interconnect network **210**, of varying bit widths, as mentioned above. In general, the (wider) data interconnection network **240** is utilized for creating configurable and reconfigurable connections, for corresponding routing of data and configuration information. The (narrower) Boolean interconnect network **210**, while also utilized for creating configurable and reconfigurable connections, is utilized for control of logic (or Boolean) decisions of the various data flow graphs, generating decision nodes in such DFGs, and may also be used for data routing within such DFGs.

FIGS. **5**A through **5**E are block diagrams illustrating, in detail, exemplary fixed and specific computational elements, forming computational units. As will be apparent from review of these Figures, many of the same fixed computational elements are utilized, with varying configurations, for the performance of different algorithms.

FIG. **5**A is a block diagram illustrating a four-point asymmetric finite impulse response (FIR) filter computational unit **300**. As illustrated, this exemplary computational unit **300** includes a particular, first configuration of a plurality of fixed computational elements, including coefficient memory **305**, data memory **310**, registers **315**, **320** and **325**, multiplier **330**, adder **335**, and accumulator registers **340**, **345**, **350** and **355**, with multiplexers (MUXes) **360** and **365** forming a portion of the interconnection network (**210**, **220** and **240**).

FIG. **5**B is a block diagram illustrating a two-point symmetric finite impulse response (FIR) filter computational unit **370**. As illustrated, this exemplary computational unit **370** includes a second configuration of a plurality of fixed computational elements, including coefficient memory **305**, data memory **310**, registers **315**, **320** and **325**, multiplier **330**, adder **335**, second adder **375**, and accumulator registers **340** and **345**, also with multiplexers (MUXes) **360** and **365** forming a portion of the interconnection network (**210**, **220** and **240**).

FIG. **5**C is a block diagram illustrating a subunit for a fast Fourier transform (FFT) computational unit **400**. As illustrated, this exemplary computational unit **400** includes a third configuration of a plurality of fixed computational elements, including coefficient memory **305**, data memory **310**, registers **315**, **320**, **325** and **385**, multiplier **330**, adder **335**, and adder/subtracter **380**, with multiplexers (MUXes) **360**, **365**, **390**, **395** and **405** forming a portion of the interconnection network (**210**, **220** and **240**).

FIG. **5**D is a block diagram illustrating a complex finite impulse response (FIR) filter computational unit **440**. As illustrated, this exemplary computational unit **440** includes a fourth configuration of a plurality of fixed computational elements, including memory **410**, registers **315** and **320**, multiplier **330**, adder/subtracter **380**, and real and imaginary accumulator registers **415** and **420**, also with multiplexers (MUXes) **360** and **365** forming a portion of the interconnection network (**210**, **220** and **240**).

FIG. **5**E is a block diagram illustrating a biquad infinite impulse response (IIR) filter computational unit **450**, with a corresponding data flow graph **460**. As illustrated, this exemplary computational unit **450** includes a fifth configuration of a plurality of fixed computational elements, including coefficient memory **305**, input memory **490**, registers **470**, **475**, **480** and **485**, multiplier **330**, and adder **335**, with multiplexers (MUXes) **360**, **365**, **390** and **395** forming a portion of the interconnection network (**210**, **220** and **240**).

FIG. **6** is a block diagram illustrating, in detail, an exemplary multi-function adaptive computational unit **500** having a plurality of different, fixed computational elements. When configured accordingly, the adaptive computation unit **500** performs each of the various functions previously illustrated with reference to FIGS. **5**A though **5**E, plus other functions such as discrete cosine transformation. As illustrated, this multi-function adaptive computational unit **500** includes capability for a plurality of configurations of a plurality of fixed computational elements, including input memory **520**, data memory **525**, registers **530** (illustrated as registers **530**A through **530**Q), multipliers **540** (illustrated as multipliers **540**A through **540**D), adder **545**, first arithmetic logic unit (ALU) **550** (illustrated as ALU_1s **550**A through **550**D), second arithmetic logic unit (ALU) **555** (illustrated as ALU_2s **555**A through **555**D), and pipeline (length 1) register **560**, with inputs **505**, lines **515**, outputs **570**, and multiplexers (MUXes or MXes) **510** (illustrates as MUXes and MXes **510**A through **510**KK) forming an interconnection network (**210**, **220** and **240**). The two different ALUs **550** and **555** are preferably utilized, for example, for parallel addition and subtraction operations, particularly useful for radix 2 operations in discrete cosine transformation.

FIG. **7** is a block diagram illustrating, in detail, an exemplary adaptive logic processor (ALP) computational unit **600** having a plurality of fixed computational elements. The ALP **600** is highly adaptable, and is preferably utilized for input/output configuration, finite state machine implementation, general field programmability, and bit manipulation. The fixed computational element of ALP **600** is a portion (**650**) of each of the plurality of adaptive core cells (CCs) **610** (FIG. **8**), as separately illustrated in FIG. **9**. An interconnection network (**210**, **220** and **240**) is formed from various combinations and permutations of the pluralities of vertical inputs (VIs) **615**, vertical repeaters (VRs) **620**, vertical outputs (VOs) **625**, horizontal repeaters (HRs) **630**, horizontal terminators (HTs) **635**, and horizontal controllers (HCs) **640**.

FIG. **8** is a block diagram illustrating, in greater detail, an exemplary core cell **610** of an adaptive logic processor computational unit **600** with a fixed computational element **650**. The fixed computational element is a 3 input-2 output function generator **550**, separately illustrated in FIG. **9**. The preferred core cell **610** also includes control logic **655**, control inputs **665**, control outputs **670** (providing output intercon-

nect), output **675**, and inputs (with interconnect muxes) **660** (providing input interconnect).

FIG. **9** is a block diagram illustrating, in greater detail, an exemplary fixed computational element **650** of a core cell **610** of an adaptive logic processor computational unit **600**. The fixed computational element **650** is comprised of a fixed layout of pluralities of exclusive NOR (XNOR) gates **680**, NOR gates **685**, NAND gates **690**, and exclusive OR (XOR) gates **695**, with three inputs **720** and two outputs **710**. Configuration and interconnection is provided through MUX **705** and interconnect inputs **730**.

FIG. **10** is a block diagram illustrating a prototypical node or matrix **800** comprising the second apparatus embodiment. The node **800** is connected to other nodes **150** within the ACE **100** through the matrix interconnection network **110**. The prototypical node **800** includes a fixed (and non-reconfigurable) "node wrapper", an adaptive (reconfigurable) execution unit **840**, and a memory **845** (which also may be variable). This fixed and non-reconfigurable "node wrapper" includes an input pipeline register **815**, a data decoder and distributor **820**, a hardware task manager **810**, an address register **825** (optional), a DMA engine **830** (optional), a data aggregator and selector **850**, and an output pipeline register **855**. These components comprising the node wrapper are generally common to all nodes of the ACE **100**, and are comprised of fixed architectures (i.e., application-specific or non-reconfigurable architectures). As a consequence, the node or matrix **800** is a unique blend of fixed, non-reconfigurable node wrapper components, memory, and the reconfigurable components of an adaptive execution unit **840** (which, in turn, are comprised of fixed computational elements and an interconnection network).

Various nodes **800**, in general, will have a distinctive and variably-sized adaptive execution unit **840**, tailored for one or more particular applications or algorithms, and a memory **845**, also implemented in various sizes depending upon the requirements of the adaptive execution unit **840**. An adaptive execution unit **840** for a given node **800** will generally be different than the adaptive execution units **840** of the other nodes **800**. Each adaptive execution unit **840** is reconfigurable in response to configuration information, and is comprised of a plurality of computation units **200**, which are in turn further comprised of a plurality of computational elements **250**, and corresponding interconnect networks **210**, **220** and **240**. Particular adaptive execution units **840** utilized in exemplary embodiments, and the operation of the node **800** and node wrapper, are discussed in greater detail below.

FIG. **11** is a block diagram illustrating a first system embodiment **900**. This first system **900** may be included as part of a larger system or host environment, such as within a computer or communications device, for example. FIG. **11** illustrates a "root" level of such a system **100**, where global resources have connectivity (or otherwise may be found). At this root level, the first system **900** includes one or more adaptive cores **950**, external (off-IC or off-chip) memory **905** (such as SDRAM), host (system) input and output connections, and network (MIN **110**) input and output connections (for additional adaptive cores **950**). Each adaptive core **950** includes (on-IC or on-chip) memory **920**, a "K-node" **925**, and one or more sets of nodes (**150**, **800**) referred to as a node quadrant **930**. The K-node **925** (like the kernel controller **150**A) provides an operating system for the adaptive core **950**. Generally, each node quadrant **930** consists of 16 nodes in a scalable by-four (×4) fractal arrangement. At this root level, each of these (seven) illustrated elements has total connectivity with all other (six) elements. As a consequence, the output of a root-level element is provided to (and may drive) all other root-level inputs, and the input of each root-level input is provided with the outputs of all other root-level elements. Not separately illustrated, at this root-level of the first system **900**, the MIN **110** includes a network with routing (or switching) elements (**935**), such as round-robin, token ring, cross point switches, or other arbiter elements, and a network (or path) for real time data transfer (or transmission) (such as a data network **240**).

FIG. **12** is a block diagram illustrating an exemplary node quadrant **930** with routing elements **935**. From the root-level, the node quadrant **930** has a tree topology and consists of 16 nodes (**150** or **800**), with every four nodes connected as a node "quad" **940** having a routing (or switching) element **935**. The routing elements may be implemented variously, such as through round-robin, token ring, cross point switches, (four-way) switching, (¼, ⅓ or ½) arbitration or other arbiter or arbitration elements, or depending upon the degree of control overhead which may be tolerable, through other routing or switching elements such as multiplexers and demultiplexers. This by-four fractal architecture provides for routing capability, scalability, and expansion, without logical limitation. The node quadrant **930** is coupled within the first system **900** at the root-level, as illustrated. This by-four fractal architecture also provides for significant and complete connectivity, with the worst-case distance between any node being $\log_4$ of "k" hops (or number of nodes) (rather than a linear distance), and provides for avoiding the overhead and capacitance of, for example, a full crossbar switch or busses.

The node quadrant **930** and node quad **940** structures exhibit a fractal self-similarity with regard to scalability, repeating structures, and expansion. The node quadrant **930** and node quad **940** structures also exhibit a fractal self-similarity with regard to a heterogeneity of the plurality of heterogeneous and reconfigurable nodes **800**, heterogeneity of the plurality of heterogeneous computation units **200**, and heterogeneity of the plurality of heterogeneous computational elements **250**. With regard to the increasing heterogeneity, the adaptive computing integrated circuit **900** exhibits increasing heterogeneity from a first level of the plurality of heterogeneous and reconfigurable matrices, to a second level of the plurality of heterogeneous computation units, and further to a third level of the plurality of heterogeneous computational elements. The plurality of interconnection levels also exhibit a fractal self-similarity with regard to each interconnection level of the plurality of interconnection levels. At increasing depths within the ACE **100**, from the matrix **150** level to the computation unit **200** level and further to the computational element **250** level, the interconnection network is increasingly rich, providing an increasing amount of bandwidth and an increasing number of connections or connectability for a correspondingly increased level of reconfigurability. As a consequence, the matrix-level interconnection network, the computation unit-level interconnection network, and the computational element-level interconnection network also constitute a fractal arrangement.

Referring to FIGS. **11** and **12**, and as explained in greater detail below, the system embodiment **900** utilizes point-to-point service for streaming data and configuration information transfer, using a data packet (or data structure) discussed below. A packet-switched protocol is utilized for this communication, and in an exemplary embodiment the packet length is limited to a single word (of length 51 bits) to obviate any need for data buffering. The routing information within the data packet provides for selecting the particular adaptive core **950**, followed by selecting root-level (or not) of the selected adaptive core **950**, followed by selecting a particular node (**110** or **800**) of the selected adaptive core **950**. This

selection path may be visualized by following the illustrated connections of FIGS. **11** and **12**. Routing of data packets out of a particular node may be performed similarly, or may be provided more directly, such as by switching or arbitrating within a node **800** or quad **940**, as discussed below.

FIG. **13** is a block diagram illustrating exemplary network interconnections into and out of nodes **800** and node quads **940**. Referring to FIG. **13**, MIN **100** connections into a node, via a routing element **935**, include a common input **945** (provided to all four nodes **800** within a quad **940**), and inputs from the other (three) "peer" nodes within the particular quad **940**. For example, outputs from peer nodes **1**, **2** and **3** are utilized for input into node **0**, and so on. At this level, the routing element **935** may be implemented, for example, as a round-robin, token ring, arbiter, cross point switch, or other four-way switching element. The output from the routing element **935** is provided to a multiplexer **955** (or other switching element) for the corresponding node **800**, along with a feedback input **960** from the corresponding node **800**, and an input for real time data (from data network **240**) (to provide a fast track for input of real time data into nodes **800**). The multiplexer **955** (or other switching element) provides selection (switching or arbitration) of one of 3 inputs, namely, selection of input from the selected peer or common **945**, selection of input from the same node as feedback, or selection of input of real time data, with the output of the multiplexer **955** provided as the network (MIN **110**) input into the corresponding node **800** (via the node's pipeline register **815**).

The node **800** output is provided to the data aggregator and selector ("DAS") **850** within the node **800**, which determines the routing of output information to the node itself (same node feedback), to the network (MIN **110**) (for routing to another node or other system element), or to the data network **240** (for real time data output). When the output information is selected for routing to the MIN **110**, the output from the DAS **850** is provided to the corresponding output routing element **935**, which routes the output information to peer nodes within the quad **940** or to another, subsequent routing element **935** for routing out of the particular quad **940** through a common output **965** (such for routing to another node quad **940**, node quadrant **930**, or adaptive core **950**).

FIG. **14** is a block diagram illustrating an exemplary data structure embodiment. The system embodiment **900** utilizes point-to-point data and configuration information transfer, using a data packet (as an exemplary data structure) **970**, and may be considered as an exemplary form of "silverware", as previously described herein. The exemplary data packet **970** provides for 51 bits per packet, with 8 bits provided for a routing field (**971**), 1 bit for a security field (**972**), 4 bits for a service code field (**973**), 6 bits for an auxiliary field (**974**), and 32 bits (one word length) for data (as a data payload or data field) (**975**). As indicated above, the routing field **971** may be further divided into fields for adaptive core selection (**976**), root selection (**977**), and node selection (**978**). In this selected 51-bit embodiment, up to four adaptive cores may be selected, and up to 32 nodes per adaptive core. As the packet is being routed, the routing bits may be stripped from the packet as they are being used in the routing process. The service code field **973** provides for designations such as point-to-point inter-process communication, acknowledgements for data flow control, "peeks" and "pokes" (as coined terminology referring to reads and writes by the K-node into memory **845**), DMA operations (for memory moves), and random addressing for reads and writes to memory **845**. The auxiliary (AUX) field **974** supports up to 32 streams for any of up to 32 tasks for execution on the adaptive execution unit **840**, as discussed below, and may be considered to be a configuration information payload. The one word length (32-bit) data payload is then provided in the data field **975**. The exemplary data structure **970** (as a data packet) illustrates the interdigitation of data and configuration/control information, as discussed above.

Referring to FIG. **10**, in light of the first system **900** structure and data structure discussed above, the node **800** architecture of the second apparatus embodiment may be described in more detail. The input pipeline register **815** is utilized to receive data and configuration information from the network interconnect **110**. Preferably, the input pipeline register **815** does not permit any data stalls. More particularly, in accordance with the data flow modeling of the present invention, the input pipeline register **815** should accept new data from the interconnection network **110** every clock period; consequently, the data should also be consumed as it is produced. This imposes the requirement that any contention issues among the input pipeline register **815** and other resources within the node **800** be resolved in favor of the input pipeline register **815**, i.e., input data in the input pipeline register has priority in the selection process implemented in various routing (or switching) elements **935**, multiplexers **955**, or other switching or arbitration elements which may be utilized.

The data decoder and distributor **820** interfaces the input pipeline register **815** to the various memories (e.g., **845**) and registers (e.g., **825**) within the node **800**, the hardware task manager **810**, and the DMA engine **830**, based upon the values in the service and auxiliary fields of the 51-bit data structure. The data decoder **820** also decodes security, service, and auxiliary fields of the 51-bit network data structure (of the configuration information or of operand data) to direct the received word to its intended destination within the node **800**.

Conversely, data from the node **800** to the network (MIN **110** or to other nodes) is transferred via the output pipeline register **855**, which holds data from one of the various memories (**845**) or registers (e.g., **825** or registers within the adaptive execution unit **840**) of the node **800**, the adaptive execution unit **840**, the DMA engine **830**, and/or the hardware task manager **810**. Permission to load data into the output pipeline register **855** is granted by the data aggregator and selector (DAS) **850**, which arbitrates or selects between and among any competing demands of the various (four) components of the node **800** (namely, requests from the hardware task manager **810**, the adaptive execution unit **840**, the memory **845**, and the DMA engine **830**). The data aggregator and selector **850** will issue one and only one grant whenever there is one or more requests and the output pipeline register **855** is available. In the selected embodiment, the priority for issuance of such a grant is, first, for K-node peek (read) data; second, for the adaptive execution unit **840** output data; third, for source DMA data; and fourth, for hardware task manager **810** message data. The output pipeline register **855** is available when it is empty or when its contents will be transferred to another register at the end of the current clock cycle.

The DMA engine **830** of the node **800** is an optional component. In general, the DMA engine **830** will follow a five register model, providing a starting address register, an address stride register, a transfer count register, a duty cycle register, and a control register. The control register within the DMA engine **830** utilizes a GO bit, a target node number and/or port number, and a DONE protocol. The K-node **925** writes the registers, sets the GO bit, and receives a DONE message when the data transfer is complete. The DMA engine **830** facilitates block moves from any of the memories of the

node **800** to another memory, such as an on-chip bulk memory, external SDRAM memory, another node's memory, or a K-node memory for diagnostics and/or operational purposes. The DMA engine **830**, in general, is controlled by the K-node **925**.

The hardware task manager **810** is configured and controlled by the K-node **925** and interfaces to all node components except the DMA engine **830**. The hardware task manager **810** executes on each node **800**, processing a task list and producing a task ready-to-run queue implemented as a first in-first out (FIFO) memory. The hardware task manager **810** has a top level finite state machine that interfaces with a number of subordinate finite state machines that control the individual hardware task manager components. The hardware task manager **810** controls the configuration and reconfiguration of the computational elements **250** within the adaptive execution unit **840** for the execution of any given task by the adaptive execution unit **840**.

The K-node **925** initializes the hardware task manager **810** and provides it with set up information for the tasks needed for a given operating mode, such as operating as a communication processor or an MP3 player. The K-node **925** provides configuration information as a stored (task) program within memory **845** and within local memory within the adaptive execution unit **840**. The K-node **925** initializes the hardware task manager **810** (as a parameter table) with designations of input ports, output ports, routing information, the type of operations (tasks) to be executed (e.g., FFT, DCT), and memory pointers. The K-node **925** also initializes the DMA engine **830**.

The hardware task manager **810** maintains a port translation table and generates addresses for point-to-point data delivery, mapping input port numbers to a current address of where incoming data should be stored in memory **845**. The hardware task manager **810** provides data flow control services, tracking both production and consumption of data, using corresponding production and consumption counters, and thereby determines whether a data buffer is available for a given task. The hardware task manager **810** maintains a state table for tasks and, in the selected embodiment, for up to 32 tasks. The state table includes a GO bit (which is enabled or not enabled (suspended) by the K-node **925**), a state bit for the task (idle, ready-to-run, run (running)), an input port count, and an output port count (for tracking input data and output data). In the selected embodiment, up to 32 tasks may be enabled at a given time. For a given enabled task, if its state is idle, and if sufficient input data (at the input ports) are available and sufficient output ports are available for output data, its state is changed to ready-to-run and queued for running (transferred into a ready-to-run FIFO or queue). Typically, the adaptive execution unit **840** is provided with configuration information (or code) and two data operands (x and y).

From the ready-to-run queue, the task is transferred to an active task queue, the adaptive execution unit **840** is configured for the task (set up), the task is executed by the adaptive execution unit **840**, and output data is provided to the data aggregator and selector **850**. Following this execution, the adaptive execution unit **840** provides an acknowledgement message to the hardware task manager **810**, requesting the next item. The hardware task manager **810** may then direct the adaptive execution unit **840** to continue to process data with the same configuration in place, or to tear down the current configuration, acknowledge completion of the tear down and request the next task from the ready-to-run queue. Once configured for execution of a selected algorithm, new configuration information is not needed from the hardware task manager **810**, and the adaptive execution unit **840** functions effectively like an ASIC, with the limited additional overhead of acknowledgement messaging to the hardware task manager **810**. These operations are described in additional detail below.

A module is a self-contained block of code (for execution by a processor) or a hardware-implemented function (embodied as configured computational elements **250**), which is processed or performed by an execution unit **840**. A task is an instance of a module, and has four states: suspend, idle, ready or run. A task is created by associating the task to a specific module (computational elements **250**) on a specific node **800**; by associating physical memories and logical input buffers, logical output buffers, logical input ports and logical output ports of the module; and by initializing configuration parameters for the task. A task is formed by the K-node writing the control registers in the node **800** where the task is being created (i.e., enabling the configuration of computational elements **250** to perform the task), and by the K-node writing to the control registers in other nodes, if any, that will be producing data for the task and/or consuming data from the task. These registers are memory mapped into the K-node's address space, and "peek and poke" network services are used to read and write these values. A newly created task starts in the "suspend" state.

Once a task is configured, the K-node can issue a "go" command, setting a bit in a control register in the hardware task manager **810**. The action of this command is to move the task from the "suspend" state to the "idle" state. When the task is "idle" and all its input buffers and output buffers are available, the task is added to the "ready-to-run" queue which is implemented as a FIFO; and the task state is changed to "ready/run". Buffers are available to the task when subsequent task execution will not consume more data than is present in its input buffers or will not produce more data than there is capacity in its output buffers.

When the adaptive execution unit **840** is not busy and the FIFO is not empty, the task number for the next task that is ready to execute is removed from the FIFO, and the state of this task is "run". In the "run" state, the task (executed by the configured adaptive execution unit **840**) consumes data from its input buffers and produces data for its output buffers.

The adaptive execution units **840** will vary depending upon the type of node **800** implemented. Various adaptive execution units **840** may be specifically designed and implemented for use in heterogeneous nodes **800**, for example, for a programmable RISC processing node; for a programmable DSP node; for an adaptive or reconfigurable node for a particular domain, such as an arithmetic node; and for an adaptive bit-manipulation unit (RBU). Various adaptive execution units **840** are discussed in greater detail below.

For example, a node **800**, through its execution unit **840**, will perform an entire algorithmic element in a comparatively few clock cycles, such as one or two clock cycles, compared to performing a long sequence of separate operations, loads/stores, memory fetches, and so on, over many hundreds or thousands of clock cycles, to eventually achieve the same end result. Through its computational elements **250**, the execution unit **840** may then be reconfigured to perform another, different algorithmic element. These algorithmic elements are selected from a plurality of algorithmic elements comprising, for example: a radix-2 Fast Fourier Transformation (FFT), a radix-4 Fast Fourier Transformation (FFT), a radix-2 Inverse Fast Fourier Transformation (IFFT), a radix-4 Inverse Fast Fourier Transformation (IFFT), a one-dimensional Discrete Cosine Transformation (DCT), a multi-dimensional Discrete Cosine Transformation (DCT), finite impulse response (FIR) filtering, convolutional encoding, scrambling, puncturing,

interleaving, modulation mapping, Golay correlation, OVSF code generation, Haddamard Transformation, Turbo Decoding, bit correlation, Griffiths LMS algorithm, variable length encoding, uplink scrambling code generation, downlink scrambling code generation, downlink despreading, uplink spreading, uplink concatenation, Viterbi encoding, Viterbi decoding, cyclic redundancy coding (CRC), complex multiplication, data compression, motion compensation, channel searching, channel acquisition, and multipath correlation.

In an exemplary embodiment, a plurality of different nodes **800** are created, by varying the type and amount of computational elements **250** (forming computational units **200**), and varying the type, amount and location of interconnect (with switching or routing elements) which form the execution unit **840** of each such node **800**. In the exemplary embodiment, two different nodes **800** perform, generally, arithmetic or mathematical algorithms, and are referred to as adaptive (or reconfigurable) arithmetic nodes (AN), as AN1 and AN2. For example, the AN1 node, as a first node **800** of the plurality of heterogeneous and reconfigurable nodes, comprises a first selection of computational elements **250** from the plurality of heterogeneous computational elements to form a first reconfigurable arithmetic node for performance of Fast Fourier Transformation (FFT) and Discrete Cosine Transformation (DCT). Continuing with the example, the AN2 node, as a second node **800** of the plurality of heterogeneous and reconfigurable nodes, comprises a second selection of computational elements **250** from the plurality of heterogeneous computational elements to form a second reconfigurable arithmetic node, the second selection different than the first selection, for performance of at least two of the following algorithmic elements: multi-dimensional Discrete Cosine Transformation (DCT), finite impulse response (FIR) filtering, OVSF code generation, Haddamard Transformation, bit-wise WCDMA Turbo interleaving, WCDMA uplink concatenation, WCDMA uplink repeating, and WCDMA uplink real spreading and gain scaling.

Also in the exemplary embodiment, a plurality of other types of nodes **800** are defined, such as, for example:

A bit manipulation node, as a third node of the plurality of heterogeneous and reconfigurable nodes, comprising a third selection of computational elements **250** from the plurality of heterogeneous computational elements, the third selection different than the first selection, for performance of at least two of the following algorithmic elements: variable and multiple rate convolutional encoding, scrambling code generation, puncturing, interleaving, modulation mapping, complex multiplication, Viterbi algorithm, Turbo encoding, Turbo decoding, correlation, linear feedback shifting, downlink despreading, uplink spreading, CRC encoding, de-puncturing, and de-repeating.

A reconfigurable filter node, as a fourth node of the plurality of heterogeneous and reconfigurable nodes, comprising a fourth selection of computational elements **250** from the plurality of heterogeneous computational elements, the fourth selection different than the first selection, for performance of at least two of the following algorithmic elements: adaptive finite impulse response (FIR) filtering, Griffith's LMS algorithm, and RRC filtering.

A reconfigurable finite state machine node, as a fifth node of the plurality of heterogeneous and reconfigurable nodes, comprising a fifth selection of computational elements **250** from the plurality of heterogeneous computational elements, the fifth selection different than the first selection, for performance of at least two of the following processes: control processing; routing data and control information between and among the plurality of heterogeneous computational elements **250**; directing and scheduling the configuration of the plurality of heterogeneous computational elements for performance of a first algorithmic element and the reconfiguration of the plurality of heterogeneous computational elements for performance of a second algorithmic element; timing and scheduling the configuration and reconfiguration of the plurality of heterogeneous computational elements with corresponding data; controlling power distribution to the plurality of heterogeneous computational elements and the interconnection network; and selecting the first configuration information and the second configuration information from a singular bit stream comprising data commingled with a plurality of configuration information.

A reconfigurable multimedia node, as a sixth node of the plurality of heterogeneous and reconfigurable nodes, comprising a sixth selection of computational elements **250** from the plurality of heterogeneous computational elements, the sixth selection different than the first selection, for performance of at least two of the following algorithmic elements: radix-4 Fast Fourier Transformation (FFT), multi-dimensional radix-2 Discrete Cosine Transformation (DCT); Golay correlation; adaptive finite impulse response (FIR) filtering; Griffith's LMS algorithm; and RRC filtering.

A reconfigurable hybrid node, as a seventh node of the plurality of heterogeneous and reconfigurable nodes, comprising a seventh selection of computational elements **250** from the plurality of heterogeneous computational elements, the seventh selection different than the first selection, for performance of arithmetic functions and bit manipulation functions.

A reconfigurable input and output (I/O) node, as an eighth node of the plurality of heterogeneous and reconfigurable nodes, comprising an eighth selection of computational elements **250** from the plurality of heterogeneous computational elements, the eighth selection different than the first selection, for adaptation of input and output functionality for a plurality of types of I/O standards, the plurality of types of I/O standards comprising standards for at least two of the following: PCI busses, Universal Serial Bus types one and two (USB1 and USB2), and small computer systems interface (SCSI).

A reconfigurable operating system node, as a ninth node of the plurality of heterogeneous and reconfigurable nodes, comprising a ninth selection of computational elements **250** from the plurality of heterogeneous computational elements, the ninth selection different than the first selection, for storing and executing a selected operating system of a plurality of operating systems.

FIG. **15** is a block diagram illustrating a second system embodiment **1000** in accordance with the present invention. The second system embodiment **1000** is comprised of a plurality of variably-sized nodes (or matrices) **1010** (illustrated as nodes **1010**A through **1010**X), with the illustrated size of a given node **1010** also indicative of an amount of computational elements **250** within the node **1010** and an amount of memory included within the node **1010** itself. The nodes **1010** are coupled to an interconnect network **10**, for configuration, reconfiguration, routing, and so on, as discussed above. The second system embodiment **1000** illustrates node **800** and system configurations which are different and more varied than the quadrant **930** and quad **940** configurations discussed above.

As illustrated, the second system embodiment **1000** is designed for use with other circuits within a larger system and, as a consequence, includes configurable input/output (I/O) circuits **1025**, comprised of a plurality of heterogeneous computational elements configurable (through correspond-

ing interconnect, not separately illustrated) for I/O) functionality. The configurable input/output (I/O) circuits **1025** provide connectivity to and communication with a system bus (external), external SDRAM, and provide for real time inputs and outputs. A K-node (KARC) **1050** provides the K-node (KARC) functionality discussed above. The second system embodiment **1000** further includes memory **1030** (as on-chip RAM, with a memory controller), and a memory controller **1035** (for use with the external memory (SDRAM)). Also included in the apparatus **1000** are an aggregator/formatter **1040** and a de-formatter/distributor **1045**, providing functions corresponding to the functions of the data aggregator and selector **850** and data distributor and decoder **820**, respectively, but for the larger system **1000** (rather than within a node **800**).

Referring again to FIG. **10**, as previously mentioned, the node **800** can be tailored, via varying the configuration of the adaptive execution unit **840** and the size of the memory **845**, to perform one or more particular applications or algorithms. By varying the type and amount of computational elements **250** and by varying the type, amount and location of interconnect (**110**, **210**, **220**, **240**), any number of different types of nodes **800** may be created. For example, it may be desirable to configure the adaptive execution unit **840** and the memory **845** in one or more nodes **800** of an ACE **100** to perform optical data processing to produce a processed digital image, such as for use in a digital camera, a video camera, video telephony applications, digital TV, digital cinema, a fax machine, a photocopier, or any number of other devices that create or reproduce an image from visible spectrum (light) signals.

Typical conventional cameras, including both single lens reflex (SLR) and compact camera types, are DSP or microprocessor-based devices. In general, one or more optical sensors, such as a charge-coupled device ("CCD"), detect the amount of light entering the camera. That amount of light varies depending on the object image captured by the lens system of the camera. The resulting data produced by the camera's optical sensor, herein referred to as a detected image of the object, is processed by the microprocessor or DSP and used to adjust camera settings, such as for proper exposure and focus (e.g., lens aperture size, shutter speed, flash charge, autofocus, etc.). In the case of a conventional digital camera, the resulting (analog) data from the CCD is converted to digital data and is processed by the microprocessor or DSP to produce a digital form of the original, detected image, referred to herein as a processed digital image. As previously mentioned, however, microprocessors are comparatively inefficient in the performance of actual algorithmic operations—in this case, algorithms used to adjust camera settings and algorithms to produce a digitized image—and consequently consume significantly more IC area and significantly more power compared to other types of ICs such as the ACE **100**.

FIG. **16**A is a block diagram of an exemplary digital camera **1100** in accordance with the present invention. FIG. **16**B is a perspective view of the exemplary digital camera **1100** in accordance with the present invention. The exemplary digital camera **1100** utilizes the adaptive computing engine (ACE) **100** to process and provide a processed digital image to a variety of outputs, and to adjust any applicable camera settings. The digital camera **1100** includes a focusing means **1102** (e.g., a lens, shutter, aperture, filters, motor, and so on); an optical sensor **1104** of which a CCD is a type; an analog-to-digital ("A/D") converter **1118** (which also may be included within the ACE **100**); the ACE **100** (e.g., one or more nodes **800**); one or more memories such as a memory IC **1110** and a removable memory or storage medium **1112** (e.g., flash, DRAM, SRAM, SDRAM, FeRAM, MRAM, ROM, EPROM and/or E^2PROM); an analog output interface **1108** to interface the digital output of the ACE **100** (a processed digital image or a plurality of processed digital image data packets) with one or more analog output ports, such as a television output port **1116** and a view (viewfinder) screen **1106**; a digital output interface **1120**, in some embodiments, to interface the digital output of the ACE **100** (as a plurality of processed digital image data packets) with one or more digital output ports, such as a computer output port **1114** (or, not separately illustrated, a printer port, a data transmission port, etc.); and an optional optical viewfinder **1118**. The viewfinder screen **1106** of the exemplary digital camera **1110** is preferably a color liquid crystal display (LCD) screen, although other types of suitable screens may be used. In addition, although flash memory is typically used as the removable memory **1112** for storing processed digital images created by the exemplary digital camera **1110**, processed digital images may also be stored on any other form of memory such as other memory ICs, diskettes, CDs, PC or PCMCIA cards (or any other suitable storage medium having physical size, weight, aspect, and other properties suitable for the design of the particular imaging device, such as suitable for the portability of a hand-held camera, and so on).

Instead of capturing images on film, which undergoes a chemical change when exposed to light, the digital camera **1100** uses an optical sensor **1104** having a light sensitive array (organized or typically referred to as pixels) which creates an electrical signal of some kind for each pixel or element, that is subsequently converted to digital form. Light transmitted or reflected from an object is projected or focused (by focusing means **1102**), as an object image, onto the optical sensor (**1104**, **1204**). Optical sensing in the digital camera **1100** typically maybe performed by a charge-coupled device (CCD), from the object image projected onto the optical sensor **1104**, to produce a detected image. For example, when embodied as a CCD, the optical sensor **1104** is a semiconductor material in which charge is transferred through storage areas. The charge (i.e., electrical signals) output from the optical sensor **1104** is then provided to the A/D converter **1108**. The A/D converter **1118** samples and converts the electric signals into a digital form (i.e., provides a digital value corresponding to the level of charge on each optical sensor element), providing digital image information representing the detected image (which was detected from the object image projected onto the optical sensor **1104** by the focusing means **1102**). Depending upon the selected embodiment, this digital image information from A/D converter **1118** may also be provided (to a node **800**) as a plurality of digital image information data packets, such as digital image information data packets having a data structure illustrated in FIG. **14**.

The digital image information (or plurality of digital image information data packets) is provided to the ACE **100** where it is processed to produce a processed digital image (or, equivalently, a plurality of processed digital image data packets). From the ACE **100**, the processed digital image (or the plurality of processed digital image data packets) is provided to the various outputs, for example: to the memory **1110**; to the removable (or replaceable) memory **1112** (possibly via the a digital output interface **1120**) for long term storage or for use to print a digital photograph from the processed digital image; to the digital output interface **1120** (optionally); to various digital ports (such as computer port **1114** or a printer port, not separately illustrated); and to the analog output interface **1108**, for conversion to an analog form suitable for

display on the either the view (viewfinder) screen **1106** or a television screen (via an analog output port such as the television output port **1116**).

As indicated above, data is generally transferred on the MIN **110** in the form of data packets, such as data packets having the structure illustrated in FIG. **14**. As a consequence, depending upon the selected embodiment, the digital image information from the A/D converter **1118** may have the form of a plurality of digital image information data packets, which are provided to the input pipeline register **815** of a node **800**.

Also depending on the selected embodiment, such as when a plurality of nodes **800** are utilized to form the ACE **100**, the various nodes **800** provide output data packets via output pipeline register **855**. For digital imaging, these output data packets have a data payload of a plurality of data words comprising the processed digital image, i.e., the output data packets are a plurality of processed digital image data packets. A digital output interface (**1120** or **1222** in FIG. **17**) may then assemble the data words of the plurality of processed digital image data packets to form the overall or entire processed digital image (which then may be printed, copied, stored, converted to an analog form, and so on). In other embodiments, the various digital imaging applications may be able to directly utilize the plurality of processed digital image data packets and, if so, use of such a digital output interface to assemble a processed digital image from the plurality of processed digital image data packets is not required in the apparatus **1100**. Similarly, for an analog output, an analog output interface **1108** that converts the processed digital image to an analog form (such as digital-to-analog ("D/A") conversion) may similarly provide such assembly of a processed digital image from the data word payloads of the plurality of processed digital image data packets (then followed by conversion to an analog form).

Designs of an optical sensor **1104** (such as a CCD) used in the exemplary digital camera **1100** (or the optical sensor **1204**, discussed below) may vary from application to application; for purposes of the present invention, the optical sensor need only convert light signals projected or reflected from an object (generally through focusing means **1102**) to an electrical form (such as a stored charge or voltage) which may be processed, and all such optical sensors are within the scope of the present invention. Optical sensors **1104**, **1204** will typically be solid state IC devices, such as a CCD, a charge injection device ("CID"), optical CMOS (passive or active pixel sensors), optical bipolar junction transistors ("BJTs"), photogate or photodiode arrays, any of which may be linear or full frame arrays, have any type of charge or other information readout capability, and may include dark pixels and anti-bloom drains, microlenses, color filter arrays, and so on. In addition, other types of optical sensors utilizing different detector arrays are used in a variety of optical sensor applications. For example, an optical sensor configured to convert brightness variations, captured from a page of text or graphics, into electrical signals may be utilized to perform xerography (i.e., dry copying) commonly associated with photocopiers, scanners and fax machines, discussed in greater detail below. Use of optical sensors in this context enables photoconductivity (i.e., certain substances that are resistant to the passage of electric current become more conductive when exposed to light) to be applied to textual and graphic material to generate the multiple copies of textual and graphic material.

FIG. **17** is a block diagram of an exemplary facsimile, scanner, or photocopier machine **1200** in accordance with the present invention. The exemplary facsimile/scanner/photocopier machine **1200** utilizes the adaptive computing engine (ACE) **100** (e.g., one or more nodes **800**) to process digital image information to produce a processed digital image. Various embodiments also convert the processed digital image for display on a tangible medium, such as by printing or dry copying onto paper. The exemplary facsimile/scanner/photocopier machine **1200** generally includes a light source **1202**; an optical sensor **1204**; an A/D converter **1216** (which also may be included within the ACE **100**); an ACE **100** (e.g., one or more nodes **800**); a digital output interface (or port) **1222** (depending upon the selected embodiment); a printer (or printing means) **1210** such as a laser, inkjet or other printer (including a laser, inkjet or other print head, and depending upon the selected embodiment, other printing mechanisms such as a drum-charging electrode, a revolving drum, and so on); a dry copier **1220** (such as xerography or other dry copying mechanisms or means); and a data transmitter **1206** such as an analog, digital, DSL, or cable modem (which also may include an ACE **100**) (for faxing or other data transmission). In selected embodiments, the apparatus **1200** may also include focusing mechanisms, as described above.

The various printing mechanisms **1210** or dry copier (xerography) mechanisms **1220** may be implemented as known or as becomes known in the art, and generally include components for storing and feeding paper or other media, collating, user interfacing, and physical image production (e.g., a print head (laser, inkjet), toner cartridges, drum, charging electrode, and so on). The data transmission mechanism **1206** may also include a wireless link (such as a radio frequency (RF) link), a wireline or other bus link, an Ethernet link, or a public network link such as the Internet. The exemplary facsimile/scanner/photocopier machine **1200** may also be coupled to a computer **1230**, such as for scanning. It should be noted that there are a wide variety of possible implementations of the exemplary facsimile/scanner/photocopier machine **1200** which are within the scope of the present invention. For these various embodiments, the present invention requires an optical sensor (**1104** or **1204**) and an ACE **100** (e.g., one or more nodes **800**); these components may then be included within one or more printers **1210**, dry copiers (or, equivalently, xerography means) **1220**, or data transmitters **1206**, to form the selected embodiment.

The exemplary facsimile/scanner/photocopier machine **1200** operates to capture an image (and transmit or generate one or more copies of textual or graphic material): the optical sensor **1204** receives (as an object image) light reflected from an object (shown here as a large "P"), using the light source **1202**, and registers light and dark areas of the object image as varying voltages (or charges) (to form a detected image). Much like the exemplary digital camera **1100** described in FIG. **16**, the voltage (or charge) variations correlate to the light and dark areas captured by an array of light sensitive pixels of the optical sensor **1204**, as the detected image. The optical sensor **1204** may be any type of optical sensor as previously discussed with reference to optical sensor **1104**. An analog electrical signal output from the optical sensor **1204** is composed of a series of electrical voltages (or charges) representing the brightness variations of the detected image (and corresponding to the brightness variations of the object image). The analog electrical signal is converted to a stream of digital bits by an A/D converter **1216**, or a plurality of digital image information data packets, as previously discussed. The stream of digital bits, also referred to herein as the digital image information (or, equivalently, the plurality of digital image information data packets) is then received and processed by the ACE **100** to produce a processed digital image or a plurality of processed digital image data packets (corresponding to the object image projected or reflected onto

the optical sensor **1204**) suitable for use in faxing, display as a scanned image, for printing or dry copying as a photocopy. As will be appreciated by those of ordinary skill in the art, any of the optical sensor **1204**, the ACE **100** or the A/D converter **1216** may be co-located or integrated on the same semiconductor (IC) as a system on a chip ("SOC") embodiment or on several ICs coupled on a circuit board (e.g., a printed circuit board).

Upon completion of processing by the ACE **100**, the processed digital image (from either apparatus **1100** or **1200**) may be physically embodied on a tangible medium or otherwise displayed through a wide variety of mechanisms, including printed via printer **1210** and dry copied via dry (xerography) copier **1220**, or transmitted via the data transmission mechanism **1206** to any number of locations for use in any number of applications. For example, the processed digital image may be transmitted to a receiving end of a remote facsimile machine, to a printer, to a wireless cell phone, to a computer for display on a computer screen, or to a network (such as the Internet). Also for example, the data transmission mechanism **1206** may include one or more modems **1304**, a radio frequency (RF) link **1306**, a wired bus link **1308**, an Ethernet link **1310**, or a public network link **1312** such as the Internet. A receiving device may include one or more computers **1314** that may be a laptop, a desktop, or a handheld computer, a wireless cell phone **1316**, a printer **1318**, or a receiving facsimile machine **1320**, or any other device that displays or prints the final copy (from the processed digital image) corresponding to the object image (and, presumably, the object).

For example, referring again to FIG. **17**, if the receiving device is the receiving facsimile machine, a laser beam turns on and off in response to the incoming stream of digital bits (representing the processed digital image), discharging areas of a revolving drum, previously charged by the drum-charging electrode, that correspond to light areas of the image. A pixilated final copy of the original object image is reproduce on a medium, for example, paper, output at the receiving end. It will be apparent to those of skill in the art that any suitable type of printing or xerography (dry copying) means may be utilized, and all are within the scope of the present invention.

In general, in accordance with the present invention, an optical sensor for detecting an object image, such as capturing an object image of a scene or textual or graphic material, may be used in conjunction with an ACE **100** for generating a processed digital image in any digital imaging application, including still and moving image photography, printing, scanning, copying, television, video, video telephony, digital TV, digital cinema, and so on. As indicated above, although the analog-to-digital converters **1118** and **1216** are illustrated separately, it is contemplated that the conversion of the optical sensor output (the detected image) to digital image information may be performed by an A/D converter co-located or integrated with the ACE **100** on the same IC or SOC. In addition, depending upon the type of optical sensor utilized, the optical sensor may also be co-located or integrated on the same IC with the ACE **100** and/or A/D converter. For example, the various nodes **800** comprising an ACE **100** may be co-located or integrated with an optical sensor and A/D converter at the root level (illustrated in FIG. **11**), with the digital image information (output from the A/D converter) embodied in the form of data packets transmitted on the MIN **110**. In other embodiments, the optical sensor (potentially with the A/D converter) may be or considered to be one or more fixed function nodes **800** (e.g., comprised of a plurality of optical sensing and A/D converting computational elements **250**) which are used in conjunction with one or more reconfigurable nodes **800** that perform digital image processing. (As a fixed function optical node, however, the optical sensor may not require many of the components of the node wrapper discussed above.) It is also contemplated that optical sensors may be developed which directly provide a quantized, digital readout, which are also within the scope of the present invention.

In these various integrated (SOC) or non-integrated embodiments, it is implicit herein that the optical sensor may produce either an analog output (when embodied solely as a CCD or optical CMOS, for example) or a digital output (when embodied in combination as a CCD or optical CMOS integrated with A/D conversion functionality). As a consequence, as used herein, the optical sensor may be considered more generally to convert an object image (such as from the focusing means or reflected from an object) to "image information" suitable for further processing by a configured and reconfigured plurality of computational elements; in the event the image information is analog, then intervening A/D conversion is implicit (transforming an analog detected image into digital image information). In addition, to provide the processed digital image suitable for one or more imaging applications, such as digital photography, copying or printing, using the image information (or digital image information), the plurality of computational elements are configured for a first imaging function or algorithm, and reconfigured for performance of a second imaging function or algorithm, with the first imaging function or algorithm being different than the second imaging function or algorithm.

Image sensing, or photo-detection, performed by the optical sensor **1104**, **1204** is generally accomplished by an array of millions of light-sensitive cells commonly referred to as pixels or picture elements ("pels") that convert light into varying analog electrical signals represented as a series of electrical charges (or voltages). Each light-sensitive cell of the array of millions detects an amount of light from (or corresponding to) an object image. In color applications, the light-sensitive cell will detect an amount of light corresponding to a particular color (or frequency band) as well. As a result, the analog electrical signals produced by the optical sensor **1104**, **1204** correspond to the varying amount of light that strikes the array of light-sensitive cells. After detecting the light, the optical sensor **1104**, **1204** transfers the electrical charges in a sequential fashion to an output amplifier of the optical sensor (discussed below), which is subsequently converted to a digital image information stream (or a plurality of digital image information data packets) and ultimately processed by the ACE **100**.

The central building block of the optical sensor **1104**, **1204** is generally a metal insulator semiconductor material. In one embodiment, the optical sensor **1104**, **1204** utilizes a complementary metal-oxide semiconductor (CMOS) IC that may be configured to include, for example, either an array of photodiodes or an array of photogates. When light falls on the light sensitive pixels of the optical sensor **1104**, **1204**, energy (in the form of photons) is absorbed which then releases or provides excited electrons in the semiconductive silicon layer. The more intense the light on a pixel, the more electrons are released and the bigger the resulting charge for that pixel.

The charges (or voltages) from each pixel are then read out (or moved) from the array into corresponding registers, depending upon the type of array (such as linear or full frame), such as reading out columns, transferring charge from one gate to the next per clock cycle, and into a horizontal serial readout row register, for example. This is accomplished by manipulating gate voltages of the array (columns and rows of CMOS gates) in a systematic manner, causing the electrons

to be transferred from one gate to the next, in a sequential fashion. At the end of each column of CMOS gates, the horizontal rows of pixels are collected one row at a time by the serial readout row register and then transported to an output amplifier (to provide an amplified output) for subsequent conversion to digital information (e.g., by an A/D converter **1118**, **1216**). This process creates a serial data stream, digital image information, that represents a two dimensional image associated with the image being photographed, copied or transmitted. In the various embodiments, this digital image information also may be provided in data packets, as a plurality of digital image information data packets, for transmission on the MIN **110** to various nodes **800**, such as in the data payload portion of the exemplary data structure illustrated in FIG. **14**.

For example, for a CCD having a 3×3 array of image pixels with three MOS gates per image pixel, an electronic image is created on the nine pixels when the CCD is illuminated. Next, each of the columns of the 3×3 array are shifted down in parallel, one gate at a time, one clock pulse at a time. After reaching the serial readout row register, the pixels are shifted out to the output amplifier, one row at a time. The entire serial row is clocked out before the next row of pixel contents (i.e., charges) is transferred into the serial readout row register. This process continues until charge transfer of all of the image pixels to the output amplifier is complete.

Although the optical sensor described above is a simple pixel array of columns and rows, the optical sensor **1104**, **1204** may also be configured as a linear one-line array, a full frame transfer array, a frame transfer array (i.e., two identical arrays; one for image pixels, one for storage), or a interline transfer array (i.e., photodiodes separated by vertical transfer registers). Further, optical sensors **1104**, **1204** can be fabricated using any suitable technology with any suitable transistor structure such as, for example, a neuron-bipolar junction transistor (vBJT) structure or a silicon on sapphire CMOS structure.

For ease of discussion, the exemplary digital camera **1100** of FIGS. **16**A and **16**B will be used to illustrate a number of ACE **100** configurations that can be used in conjunction with optical sensors to produce a processed digital image, with corresponding operation occurring in the exemplary facsimile, scanner, or photocopier machine **1200**. As will be appreciated by those of ordinary skill in the art, however, other devices that utilize optical sensors in their operation may be similarly configured with an ACE **100**, such as a facsimile device, copier, scanner, projector, video camera, etc.

Referring again to operation of the exemplary digital camera **1100** of FIGS. **16**A and **16**B, upon completion of analog processing (the charge read-out and amplification discussed above), the detected image (as the optical sensor **1104** output) is converted into digital image information by the analog-to-digital converter **1118**. The analog-to-digital converter **1118** samples and quantizes the optical sensor output to convert the analog electrical signal into digital image information (i.e., a series of high and low voltages, or logic 1's and 0's, which may be a serial bit stream or one or more digital image information data packets). The digital image information is then processed by the ACE **100** (discussed below) to produce a processed digital image (or, equivalently, a plurality of processed digital image data packets) suitable for use in any number of applications, for example, in a digital camera application, a copying application, a printing application, a faxing or other data transmission application, and so on, where it may be displayed or stored on a tangible medium, such as displayed on a computer screen, displayed on a television screen, saved to the memory **1112**, stored on a CD or disk, viewed on the viewfinder screen **1106**, printed as a photograph by a laser or inkjet printer, dry copied onto paper, or transmitted over a wireline or wireless link, and so on. As mentioned above, when the processed digital image is provided as a plurality of processed digital image data packets, the packets may be assembled to form the processed digital image for use in any of these applications, such as through a digital output interface, or directly by the application.

The processed digital image may also be used in multi-frame applications (e.g., moving image photography, a video cassette recorder (VCR)), multichannel applications (e.g., positron emission tomography (PET) scans), or it may be transmitted to a remote receiver for remote display via a facsimile machine, a computer, etc.

Referring again to FIGS. **16**A and **16**B, if provided in the exemplary digital camera **1100**, an autofocus system also utilizes the optical sensor **1104** and the ACE **100** to cause a small motor (not separately illustrated) to adjust or move the focusing means **1102** to automatically provide a focused object image as input to the optical sensor **1104**. Utilizing digital image information provided by the A/D converter **1118** (and the optical sensor **1104**), the ACE **100** first detects "edge points" (i.e., areas with a large change in contrast, such as where a white shirt meets a black background). At the edge points, one pixel will have one value (e.g., representing black) while an adjacent pixel will have a very different value (e.g., representing white). Based on the values associated with the detected edge points, the ACE **100** causes the motor to adjust the focusing means **1104** so that the difference between the values at the edges is maximized. In other words, an incorrect adjustment to the focusing means **1104** (e.g., adjusting in from the image rather than out towards the image) by the ACE **100**, would yield a smaller difference between the values of the adjacent pixels.

In addition, if provided in the exemplary digital camera **1100** of FIGS. **16**A and **16**B (or any other apparatus having an optical sensor and an ACE **100**), an optical image stabilizer system utilizes the ACE **100** coupled to a motion sensor (not separately illustrated) to cause a lens actuator (not separately illustrated) to move the lens **1104** up or down, or from side-to-side, to compensate for camera movements.

In general, because of imperfections in the image capturing or detection process, without additional processing, the recorded image usually represents a distorted or degraded version of the original image or object. As a consequence, image enhancement is generally needed in the imaging process as an image is converted from one form to another, from acquisition of the object image to generation of the processed digital image, as many types of distortions, artifacts, noise or noise-like degradations can be introduced into the image (e.g., as the image is acquired, copied, scanned, digitized, transmitted, displayed, printed, or compressed). For instance, various distortions are introduced in image detection, and when the detected image (as an analog signal) is converted by the A/D converter **1118**, the resulting digital signal generally contains quantization distortion or noise. Similarly, when an image is transmitted through a communication channel, the received image contains channel noise, and so on. Thus, as used herein, the term "image enhancement" refers to one or more processes, functions or algorithms applied to the recorded image (such as to the detected image or the digital image information) which enhances or highlights some aspect of the information contained in the image, or which minimizes irregularities (e.g., blurring), distortions or noise due to errors in signal acquisition that may have corrupted the image.

Because the various nodes **800** can be tailored to perform one or more selected algorithms, the ACE **100** may be configured to perform many of the image detection, restoration and enhancement functions or operations useful in digital imaging applications such as in cameras, facsimile machines, copier machines, etc. The ACE **100** may be configured to perform a number of image restoration algorithms (e.g., deblurring, debugging) including, for example: (1) linear filtering utilizing low pass filters to suppress high frequency noise; (2) non-linear filtering utilizing morphologic and median filters to reduce distortion in (de-noise) the image; and (3) wavelet-based distortion reduction utilizing multirate filter banks. In wavelet-based distortion reduction, a discrete wavelet transform ("DWT") compacts image energy into a small number of DWT coefficients having large amplitudes, spreads the energy of the noise over a large number of DWT coefficients having small amplitudes, and removes the noise and other distortions via an adjustable threshold filter.

For instance, underexposure and low-light conditions in photography lead to images with "grain noise", which, together with the image signal itself, are captured during the digitization process. The grain noise is generally present because of some physical randomness of image acquisition systems using optical sensors **1104**. Linear filtering image enhancement may be used to remove such distortions and other noise, as discrete-space image signals can be expressed as a sum of weighted, shifted impulses with each weighted impulse comprising one of the pixels of the image. The nodes **800** of the ACE **100** can be configured to filter out the noise from the impulses to yield a less distorted image.

Also for example, one or more of the nodes **800** can be configured to perform low pass filtering to reject the high frequency content of white noise or broadband noise responsible for image corruption. The nodes **800** may also be configured to provide ideal low-pass filtering or Gaussian filtering for the digitized image. Further, due to temporal nature of the ACE **100**, the filtering capability of the ACE **100** can be virtually "real-time" optimized, depending on the image conditions, to perform filtering and minimize image content degradation.

In another example, one or more of the nodes **800** may be configured to provide weighted median ("WM") filters for non-linear filtering, or smoothing, of the digitized image to improve the appearance of the image. In general, rather than using linear combinations of pixel values within a local window, WM filters use the local weighted median. By selecting an appropriate configuration for the computational elements **250** and configuring the computational units **200** and interconnect to achieve a median filter configuration, the ACE **100** can provide impulse noise removal (e.g., by a center WM filter where not all samples are equally weighted), image enlargement and zooming with little edge degradation, and image analysis including execution of edge-detection algorithms. Further, center weighted median smoothing may be provided by the ACE **100** (configured with weighted median filters) which allows for emphasizing and deemphasizing specific input samples. The center sample of a window is emphasized by tuning the center weight, while keeping the weighted values of all other samples at unity. This concept can be extended to include color images via the inclusion of vector weighted median filters in the ACE **100**.

In yet another example, one or more of the nodes **800** may be configured to provide morphological filters for image detection and enhancement, otherwise known as morphological image processing. Morphological image detection and enhancement refers to a broad collection of nonlinear filters (e.g., morphological filters), design methodologies, and algorithms to enhance the visibility and perceptibility of the various regions into which an image can be partitioned. Essentially, the mathematical morphology for image analysis aims to quantitatively describe the geometrical structure of image objects. For example, morphological filters (i.e., morphological signal transformation) which are more suitable than linear filter for shape analysis, play a major role for geometry-based enhancement and detection. Morphological filters are also well suited for non-Gaussian noise suppression.

In some cases, the images acquired by the optical sensor **1104** are used in multichannel or multiframe applications where, after digital processing, the multiple frames or channels are assembled, or recovered, to form a restored image. Accordingly, the nodes **800** of the ACE **100** may be configured to perform multichannel image recovery algorithms for multichannel image applications (i.e., applications where a there is a collection of images that are not identical but exhibit strong between-channel correlations). Such image recovery algorithms compute an image from observed data that alone does not uniquely define the desired image. Multichannel image recovery algorithms may include algorithms for image distortion reduction (de-noising), image deblurring, decoding of compressed images, and medical image reconstruction. For example, implicit multichannel recovery can be performed by the ACE **100** to provide multichannel reconstruction of medical image sequences obtained using positron emission tomography (PET).

Similarly, the nodes **800** of the ACE **100** may be configured to perform multiframe image restoration algorithms to improve imagery acquired in the presence of varying degradations due to, for example, undersampling image data acquired by the optical sensor **1104**. Undersampling may result from a tradeoff between the field of view and the pixel size, as the pixel size for the CCD **1104** becomes larger as the field of view increases. A microscanning algorithm, where a sequence of undersampled image frames is processed to restore image resolution, is one type of multiframe image restoration algorithm that may be performed by the ACE **100** to overcome possible undersampling problems.

Other algorithms that may be provided or performed by the ACE **100** include, without limitation, iterative image restoration algorithms, motion detection and estimation algorithms for recorded images sequences (e.g., video, moving images captured with a still digital camera), video enhancement and restoration algorithms, 3D reconstruction, and image sequence stabilization algorithms. As will be appreciated by those of ordinary skill in the art, the type or kind of image processing for which the ACE **100** may be configured is virtually limitless, and all such image processing algorithms for performance by one or more nodes **800** of the ACE **100** are within the scope of the present invention.

In summary, the present invention provides a digital imaging apparatus which may be embodied, for example, as a digital camera, a scanner, a printer, a dry copier, or otherwise utilized in digital imaging applications. The digital imaging apparatus of the invention includes an optical sensor, an analog-to-digital converter, a plurality of computational elements, and an interconnection network. The optical sensor is capable of converting an object image into a detected image. The analog-to-digital converter is coupled to the optical sensor and is capable of converting the detected image to digital image information. The plurality of computational elements includes a first computational element having a first fixed architecture and a second computational element having a second fixed architecture, with the first fixed architecture being different than the second fixed architecture. The interconnection network is coupled to the plurality of computa-

tional elements and to the analog-to-digital converter, and is capable of providing a processed digital image from the digital image information by configuring the plurality of computational elements for performance of a first imaging function of a plurality of imaging functions in response to first configuration information, and by reconfiguring the plurality of computational elements for performance of a second imaging function of the plurality of imaging functions in response to second configuration information, with the first imaging function being different than the second imaging function.

The digital imaging apparatus may also include focusing means capable of providing the object image to the optical sensor, such as a focusing assembly having a lens, a shutter, an aperture, and a focusing motor. The optical sensor is at least one of a plurality of optical sensors, such as a charge coupled device (CCD), a charge injection device (CID), an optical complementary metal oxide silicon (CMOS) array, an optical bipolar junction transistor (BJT) array, a photogate array, or a photodiode array.

The digital imaging apparatus, in various embodiments, may also include an analog output interface coupled to the interconnection network, the analog output interface capable of converting the processed digital image to an analog form; a viewfinder screen coupled to the analog output interface, the viewfinder screen capable of visually displaying the analog form of the processed digital image; and an analog output port coupled to the analog output interface, the analog output port capable of outputting the analog form of the processed digital image, such as for connection to a television or other video display. The digital imaging apparatus may also include a digital output port coupled to the interconnection network, the digital output port capable of outputting the processed digital image, such as for connection to a computer or a data transmission device.

The processed digital image may also be provided as a plurality of processed digital image data packets. In this embodiment, the digital imaging apparatus may also include a digital output interface coupled to the interconnection network, with the digital output interface capable of selecting a plurality of processed digital image data words from the plurality of processed digital image data packets and assembling the plurality of processed digital image data words to form the processed digital image.

The digital imaging apparatus also may be included within or coupled to, for example: a printer capable of printing the processed digital image on a tangible medium; a dry copier capable of transferring the processed digital image to a tangible medium; a data transmitter capable of transmitting the processed digital image to a remote location; a scanner capable of transferring the processed digital image to a storage medium, to a computer, and so on.

In the various embodiments, the plurality of imaging functions may include one or more of the following functions: linear filtering; nonlinear filtering; morphological filtering; median filtering; local weighted median filtering; center weighted median filtering; vector weighted median filtering; multichannel image recovery; multiframe image restoration; iterative image restoration; motion detection; motion estimation; low pass filtering; multirate filtering; wavelet-based multirate filtering; autofocusing; contrast enhancement; blur removal.

Also in the various embodiments, the first fixed architecture and the second fixed architecture of the a plurality of computational elements may be selected from a plurality of specific architectures, such as those architectures having the following corresponding functions: linear filtering, non-linear filtering, memory, addition, multiplication, complex multiplication, subtraction, synchronization, queuing, over sampling, under sampling, adaptation, configuration, reconfiguration, control, input, output, and field programmability.

Various types of memory may be included within the digital imaging apparatus. For example, a first memory may be couplable to the interconnection network and capable of storing the processed digital image, and this first memory may be a selectively removable flash memory. A second memory may also be included, coupled to the interconnection network, and be capable of storing the first configuration information and the second configuration information, such as synchronous dynamic random access memory (SDRAM).

Also in summary, in another embodiment, the digital imaging apparatus includes an optical sensor, an analog-to-digital converter, an input pipeline register, a first memory, a hardware task manager, a data distributor, an adaptive execution unit, a data selector, and an output pipeline register. The optical sensor is also capable of converting an object image into a detected image. The analog-to-digital converter is coupled to the optical sensor and is capable of converting the detected image to a plurality of digital image information data packets. The input pipeline register is coupled to the analog-to-digital converter and is capable of receiving the plurality of digital image information data packets, while the first memory is capable of storing the plurality of digital image information data packets. The hardware task manager is capable of processing a plurality of imaging tasks and determining that a first imaging task from the plurality of imaging tasks is capable of being performed and that a second imaging task from the plurality of imaging tasks is capable of being performed, with the first imaging task being different than the second imaging task. The data distributor is coupled to the input pipeline register, to the first memory, and to the hardware task manager, and is capable of distributing the plurality of digital image information data packets to the first memory. The adaptive execution unit is coupled to the hardware task manager and to the first memory, and is capable of configuring to perform the first imaging task and capable of performing the first imaging task using the plurality of digital image information data packets, the adaptive execution unit further capable of reconfiguring to perform the second imaging task and capable of performing the second imaging task, and the adaptive execution unit further capable of generating a corresponding plurality of processed digital image data packets from the performance of the first imaging task and the second imaging task. The data selector is coupled to the hardware task manager, to the adaptive execution unit and to the first memory, and is capable of determining routing for the corresponding plurality of processed digital image data packets. The output pipeline register is coupled to the data selector, and is capable of receiving the corresponding plurality of processed digital image data packets.

In this embodiment, the adaptive execution unit includes a plurality of computational elements and a plurality of switching elements coupled to the plurality of computational elements. In the plurality of computational elements, a first computational element has a first fixed architecture and a second computational element has a second fixed architecture, with the first fixed architecture being different from the second fixed architecture. The plurality of switching elements are capable of configuring the plurality of computational elements for performance of a first imaging function of a plurality of imaging functions in response to first configuration information, and are further capable of reconfiguring the plurality of computational elements for performance of a second imaging function of the plurality of imaging functions

in response to second configuration information, with the first imaging function being different than the second imaging function.

Numerous advantages of the present invention may be readily apparent to those of skill in the art. First, the reconfigurability of the computational elements to perform a plurality of different imaging or optical functions and algorithms readily allows for ready implementation of any new or changed algorithms. Second, once a particular configuration is in place for the performance of an imaging optical algorithm, the various nodes have a very high efficiency and corresponding low latency, comparable to that of an ASIC, while maintaining flexibility of implementation. In addition, the present invention is also capable of implementations which provide considerable savings of IC area and power consumption.

From the foregoing, it will be observed that numerous variations and modifications may be effected without departing from the spirit and scope of the novel concept of the invention. It is to be understood that no limitation with respect to the specific methods and apparatus illustrated herein is intended or should be inferred. It is, of course, intended to cover by the appended claims all such modifications as fall within the scope of the claims.

It is claimed:

1. A digital imaging apparatus, comprising:

an optical sensor converting an object image into a detected image;

an analog-to-digital converter coupled to the optical sensor, the analog-to-digital converter converting the detected image to digital image information;

a plurality of heterogeneous computational units processing the digital image information to produce a processed digital image, the plurality of heterogeneous computational units including a first computational unit having a first architecture of a first plurality of computational elements each including algorithmic logic for simple computations, a data input and a data output, and a second computational unit having a second digital signal processing architecture of a second plurality of computational elements each including algorithmic logic for digital signal processing, a data input and a data output; and

an interconnection network coupled to the plurality of heterogeneous computational units and to the analog-to-digital converter, the interconnection network providing the digital image information to the plurality of heterogeneous computational units, configuring the plurality of heterogeneous computational units for performance of a first imaging function on the digital imaging information in response to configuration information that configures interconnections between at least the first plurality of computational elements and simultaneously in response to different configuration information to configure interconnections between the second plurality of computational elements, and reconfiguring the plurality of heterogeneous computational units for performance of a second imaging function on the digital image information in response to configuration information that reconfigures the interconnections between at least the first plurality of computational elements, the first imaging function being different than the second imaging function.

2. The digital imaging apparatus of claim **1**, further comprising: focusing means providing the object image to the optical sensor.

3. The digital imaging apparatus of claim **2**, wherein the focusing means comprises a focusing assembly, the focusing assembly further comprising: a lens; a shutter; an aperture; and a focusing motor.

4. The digital imaging apparatus of claim **1**, wherein the optical sensor is at least one of a charge coupled device (CCD), a charge injection device (CID), an optical complementary metal oxide silicon (CMOS) array, an optical bipolar junction transistor (BJT) array, a photogate array, or a photodiode array.

5. The digital imaging apparatus of claim **1**, further comprising:

an analog output interface coupled to the interconnection network, the analog output interface converting the processed digital image to an analog form; and

a viewfinder screen coupled to the analog output interface, the viewfinder screen visually displaying the analog form of the processed digital image.

6. The digital imaging apparatus of claim **1**, further comprising:

an analog output interface coupled to the interconnection network, the analog output interface converting the processed digital image to an analog form; and

an analog output port coupled to the analog output interface, the analog output port outputting the analog form of the processed digital image.

7. The digital imaging apparatus of claim **1**, further comprising: a first memory couplable to the interconnection network, the first memory storing the processed digital image.

8. The digital imaging apparatus of claim **7**, wherein the first memory is selectively removable flash memory.

9. The digital imaging apparatus of claim **7**, further comprising: a second memory coupled to the interconnection network, the second memory storing the first configuration information and the second configuration information.

10. The digital imaging apparatus of claim **9**, wherein the second memory is synchronous dynamic random access memory (SDRAM).

11. The digital imaging apparatus of claim **9**, wherein the first memory and the second memory are at least one of flash memory, DRAM, SRAM, SDRAM, FeRAM, MRAM, ROM, EPROM and E^2PROM.

12. The digital imaging apparatus of claim **1**, further comprising: a digital output port coupled to the interconnection network, the digital output port outputting the processed digital image.

13. The digital imaging apparatus of claim **1**, wherein the processed digital image is provided as a plurality of processed digital image data packets.

14. The digital imaging apparatus of claim **13**, further comprising:

a digital output interface coupled to the interconnection network, the digital output interface selecting a plurality of processed digital image data words from the plurality of processed digital image data packets and assembling the plurality of processed digital image data words to form the processed digital image.

15. The digital imaging apparatus of claim **1**, wherein the digital image information is provided as a plurality of digital image information data packets.

16. The digital imaging apparatus of claim **1**, further comprising: a light source providing light for reflection from an object to form the object image.

17. The digital imaging apparatus of claim **1**, further comprising: a printer coupled to the interconnection network, the printer printing the processed digital image on a tangible medium.

18. The digital imaging apparatus of claim 1, further comprising: a dry copier coupled to the interconnection network, the dry copier transferring the processed digital image to a tangible medium.

19. The digital imaging apparatus of claim 1, further comprising: a data transmitter coupled to the interconnection network, the data transmitter transmitting the processed digital image to a remote location.

20. The digital imaging apparatus of claim 19, wherein the data transmitter is at least one of an analog (voice band) modem; a digital modem; a digital subscriber line modem; and a cable modem.

21. The digital imaging apparatus of claim 1, wherein the plurality of imaging functions comprises at least two of linear filtering; nonlinear filtering; morphological filtering; median filtering; local weighted median filtering; center weighted median filtering; vector weighted median filtering; multichannel image recovery; multiframe image restoration; iterative image restoration; motion detection; motion estimation; low pass filtering; multirate filtering, wavelet-based multirate filtering; autofocusing; contrast enhancement; and blur removal.

22. The digital imaging apparatus of claim 1, wherein the algorithmic logic of the first and second plurality of computational elements each perform different functions including at least two of linear filtering, non-linear filtering, memory, addition, multiplication, complex multiplication, subtraction, synchronization, queuing, over sampling, under sampling, adaptation, configuration, reconfiguration, control, input, output, and field programmability.

23. The digital imaging apparatus of claim 1, wherein the detected image comprises an electrical signal corresponding to brightness and color variations of the object image.

24. The digital imaging apparatus of claim 1, wherein the digital imaging apparatus is embodied as at least one integrated circuit.

25. The digital imaging apparatus of claim 1, wherein the digital imaging apparatus is embodied as a digital camera.

26. The digital imaging apparatus of claim 1, wherein the digital imaging apparatus is embodied as one or more of a scanner, a printer, or a dry copier.

27. A digital imaging apparatus, comprising:

an optical sensor converting an object image into a detected image;

an analog-to-digital converter coupled to the optical sensor, the analog-to-digital converter convening the detected image to a plurality of digital image information data packets;

a plurality of heterogeneous computational units including a first computational unit having a first architecture of a first plurality of computational elements each including algorithmic logic for simple computations, a data input and a data output, and a second computational unit having a second digital signal processing architecture of a second plurality of computational elements each including algorithmic logic for digital signal processing, a data input and a data output;

an interconnection network coupled to the plurality of heterogeneous computational units and to the analog-to-digital converter, the interconnection network providing the plurality of digital image information data packets, configuring the plurality of heterogeneous computational units for performance of a first imaging function in response to configuration information that configures the interconnections between at least the first plurality of computational elements and simultaneously in response to different configuration information to configure interconnections between the second plurality of computational elements, and by reconfiguring the plurality of heterogeneous computational units for performance of a second imaging function in response to configuration information that reconfigures interconnections between at least the first plurality of computational elements, the first imaging function being different than the second imaging function thereby providing a plurality of processed digital image data packets based on at least the first or second imaging function; and

a digital output interface coupled to the interconnection network, the digital output interface selecting a plurality of processed digital image data words from the plurality of processed digital image data packets and assembling the plurality of processed digital image data words to form a processed digital image.

28. The digital imaging apparatus of claim 27, wherein the optical sensor is at least one of a charge coupled device (CCD), a charge injection device (CID), an optical complementary metal oxide silicon (CMOS) array, an optical bipolar junction transistor (BJT) array, a photogate array, or a photodiode array.

29. The digital imaging apparatus of claim 27, further comprising:

an analog output interface coupled to the interconnection network, the analog output interface convening the processed digital image to an analog form;

a viewfinder screen coupled to the analog output interface, the viewfinder screen visually displaying the analog form of the processed digital image;

an analog output port coupled to the analog output interface, the analog output port outputting the analog form of the processed digital image; and

a digital output port coupled to the interconnection network, the digital output port outputting the processed digital image.

30. The digital imaging apparatus of claim 27, wherein the plurality of imaging functions comprises linear filtering; nonlinear filtering; morphological filtering; median filtering; local weighted median filtering; center weighted median filtering; vector weighted median filtering; multichannel image recovery; multiframe image restoration; iterative image restoration; motion detection; motion estimation; low pass filtering; multirate filtering; wavelet-based multirate filtering; autofocusing; contrast enhancement; and blur removal.

31. The digital imaging apparatus of claim 27, wherein the algorithmic logic of the first and second plurality of computational elements each perform different functions including at least two of: linear filtering, non-linear filtering, memory, addition, multiplication, complex multiplication, subtraction, synchronization, queuing, over sampling, under sampling, adaptation, configuration, reconfiguration, control, input, output, and field programmability.

32. The digital imaging apparatus of claim 27, wherein the digital imaging apparatus is embodied as a digital camera.

33. A method of processing a digital image comprising:

convening an object image into a detected image via an analog-to-digital converter;

convening the detected image to digital image information;

providing a plurality of heterogeneous computational units including a first simple computational unit having a first architecture of a first plurality of computational elements each including algorithmic logic for simple computations, a data input and a data output, and a second digital signal processing computational unit having a second architecture of a second plurality of computa-

tional elements each including algorithmic logic for digital signal processing, a data input and a data output;

providing an interconnection network coupled to each of the plurality of computational elements and to the analog-to-digital converter;

configuring the plurality of computational units via the interconnections between at least the first plurality of computational elements and simultaneously in response to different configuration information to configure interconnections between the second plurality of computational elements for performance of a first imaging function; and

reconfiguring the plurality of computational units for performance of a second imaging function in response to second configuration information by changing the interconnections between at least the first plurality of computational elements, the first imaging function being different than the second imaging function.

34. A digital imaging apparatus, comprising:

a digital image information input;

a plurality of heterogeneous computational units to process digital image information to produce a processed digital image, the plurality of heterogeneous computational units including a first simple computational unit having a first architecture of a first plurality of computational elements each including algorithmic logic for simple computations, a data input and a data output, and a second computational unit having a second digital signal processing architecture of a second plurality of computational elements each including algorithmic logic for digital signal processing, a data input and a data output; and

an interconnection network coupled to the plurality of heterogeneous computational units, the interconnection network providing the digital image information to the plurality of heterogeneous computational elements and configuring the plurality of heterogeneous computational units to perform a first imaging function by simultaneous providing different configuration information to interconnections between the first plurality of computational elements and the interconnections between the second plurality of computational elements, and reconfiguring the plurality of heterogeneous computational units for performance of a second imaging function in response to providing configuration information that reconfigures the interconnections between at least some of the first plurality of heterogeneous computational elements.

35. The image apparatus of claim **34**, further comprising:

an optical sensor converting an object image into a detected image; and

an analog-to-digital converter coupled to the optical sensor, the analog-to-digital converter converting the detected image to the digital image information, the converter coupled to the digital image input.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,609,297 B2
APPLICATION NO. : 10/606031
DATED : October 27, 2009
INVENTOR(S) : Master et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page:

The first or sole Notice should read --

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1332 days.

Signed and Sealed this

Twelfth Day of October, 2010

David J. Kappos

David J. Kappos
Director of the United States Patent and Trademark Office

US007936392B2

(12) **United States Patent**
Ng et al.

(10) **Patent No.: US 7,936,392 B2**
(45) **Date of Patent: May 3, 2011**

(54) **IMAGING ARRANGEMENTS AND METHODS THEREFOR**

(75) Inventors: **Yi-Ren Ng**, Mountain View, CA (US); **Patrick M. Hanrahan**, Portola Valley, CA (US); **Marc S. Levoy**, Stanford, CA (US); **Mark A. Horowitz**, Menlo Park, CA (US)

(73) Assignee: **The Board of Trustees of the Leland Stanford Junior University**, Palo Alto, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 670 days.

(21) Appl. No.: **11/576,438**

(22) PCT Filed: **Sep. 30, 2005**

(86) PCT No.: **PCT/US2005/035189**

§ 371 (c)(1),
(2), (4) Date: **Jun. 6, 2007**

(87) PCT Pub. No.: **WO2006/039486**

PCT Pub. Date: **Apr. 13, 2006**

(65) **Prior Publication Data**

US 2007/0252074 A1 Nov. 1, 2007

Related U.S. Application Data

(60) Provisional application No. 60/647,492, filed on Jan. 27, 2005, provisional application No. 60/615,179, filed on Oct. 1, 2004.

(51) **Int. Cl.**
G03B 13/00 (2006.01)
H04N 5/232 (2006.01)

(52) **U.S. Cl.** **348/349**; 348/350

(58) **Field of Classification Search** 348/345–356
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

725,567	A	4/1903	Ives
4,383,170	A	5/1983	Takagi et al.
4,661,986	A	4/1987	Adelson
4,694,185	A	9/1987	Weiss
5,076,687	A	12/1991	Adelson

(Continued)

FOREIGN PATENT DOCUMENTS

DE	19624421	A1	6/1996

(Continued)

OTHER PUBLICATIONS

Edward H. Adelson and John Y.A. Wang, "Single Lens Stereo with a Plenoptic Camera", Feb. 1992, IEEE, vol. 14, No. 2, pp. 99-106.*

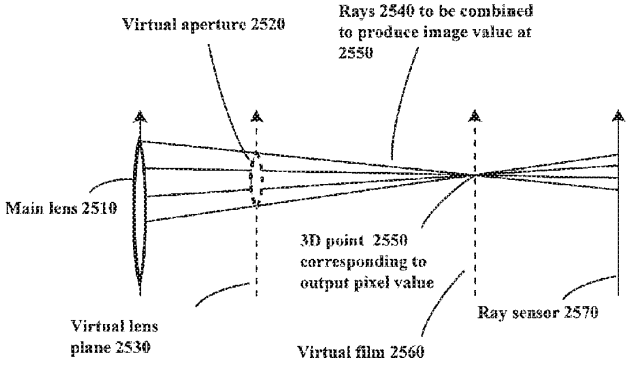
(Continued)

Primary Examiner — Tuan Ho
Assistant Examiner — Anthony J Daniels
(74) *Attorney, Agent, or Firm* — Courtney IP Law

(57) **ABSTRACT**

Image data is processed to facilitate focusing and/or optical correction. According to an example embodiment of the present invention, an imaging arrangement collects light data corresponding to light passing through a particular focal plane. The light data is collected using an approach that facilitates the determination of the direction from which various portions of the light incident upon a portion of the focal plane emanate from. Using this directional information in connection with value of the light as detected by photosensors, an image represented by the light is selectively focused and/or corrected.

14 Claims, 35 Drawing Sheets



U.S. PATENT DOCUMENTS

5,282,045	A		1/1994	Mimura et al.
5,610,390	A	*	3/1997	Miyano 250/216
5,748,371	A		5/1998	Cathey, Jr. et al.
5,757,423	A		5/1998	Tanaka et al.
6,023,523	A		2/2000	Cohen et al.
6,028,606	A		2/2000	Kolb et al.
6,097,394	A		8/2000	Levoy et al.
6,291,899	B1		3/2001	Bergen
6,320,979	B1		11/2001	Melen
6,483,535	B1		11/2002	Tamburrino et al.
6,577,342	B1		6/2003	Webster
6,842,297	B2		1/2005	Dowski, Jr. et al.
7,034,866	B1	*	4/2006	Colmenarez et al. 348/211.12
2002/0159030	A1		10/2002	Frey et al.
2003/0117511	A1		6/2003	Belz et al.
2003/0156077	A1		8/2003	Balogh
2005/0080602	A1		4/2005	Snyder et al.

FOREIGN PATENT DOCUMENTS

WO	WO 00/22566	4/2000
WO	WO 03/052465 A2	6/2003
WO	WO 2006/039486 A3	4/2006

OTHER PUBLICATIONS

Paul Haeberli, "A Multifocus Method for Controlling Depth of Field", Oct. 1994, http://www.graficaobscura.com/depth/index.html.*

J. Jackson et al. "Selection of a Convolution Function for Fourier Inversion Using Gridding." *IEEE Transactions on Medical Imaging*, Sep. 1991. vol. 10, No. 3, pp. 473-478.

T. Naemura et al. "3-D Computer Graphics based on Integral Photography." *Optics Express*, Feb. 12, 2001. vol. 8, No. 2, pp. 255-262.

F. Okano et al. Three-dimensional video system based on integral photography. *Optical Engineering*, Jun. 1999. vol. 38, No. 6, pp. 1072-1077.

E. Adelson et al. "Single Lens Stereo with a Plenoptic Camera." *IEEE Translation on Pattern Analysis and Machine Intelligence*, Feb. 1992. vol. 14, No. 2, pp. 99-106.

M. Levoy et al. "Light Field Rendering." *SIGGRAPH 96 Proceeding*, 1996. pp. 31-42.

A. Isaksen et al. "Dynamically Reparameterized Light Fields." *SIGGRAPH 2000*. Computer Graphics Proceedings. 10 pgs.

A. Agarwala et al. "Interactive Digital Montage." *ACM SIGGRAPH 2004*, vol. 23, No. 3, pp. 292-300.

P. Haeberli. "A Multifocus Method for Controlling Depth of Field." *GRAPHICAObscura*, 1994, pp. 1-3.

Herbert E. Ives, "Optical properties of a Lippman lenticulated sheet," J. Opt. Soc. Am. 21, 171 (1931).

Vaish et al., "Using plane + parallax for calibrating dense camera arrays", in Proceedings CVPR, 2004, pp. 2-9.

Wilburn et al., "High Performance Imaging using Large Camera Arrays", ACM Transactions on Graphics (TOG), vol. 24, Issue 3 (Jul. 2005), Proceedings of ACM SIGGRAPH 2005, pp. 7.

Jin-Xiang Chai et al., "Plenoptic Sampling", ACM SIGGRAPH 2000, Annual Conference Series, 2000, pp. 307-318.

Dowski et al., "Wavefront coding: A modern method of achieving high performance and/or low cost imaging systems" SPIE Proc. vol. 3779 (1999).

Tanida et al., "Thin observation module by bound optics (TOMBO): concept and experimental verification" Applied Optics 40, 11 (Apr. 2001), pp. 1806-1813.

Lippmann, "Reversible Prints", Communication at the French Society of Physics, Journal of Physics, 7, 4, Mar. 1908, pp. 821-825.

Sokolov, "Autostereoscopy and Integral Photography by Professor Lippmann's Method", 1911, pp. 23-29.

Gortler et al., "The lumigraph" SIGGRAPH 96, pp. 43-54 (1996).

* cited by examiner

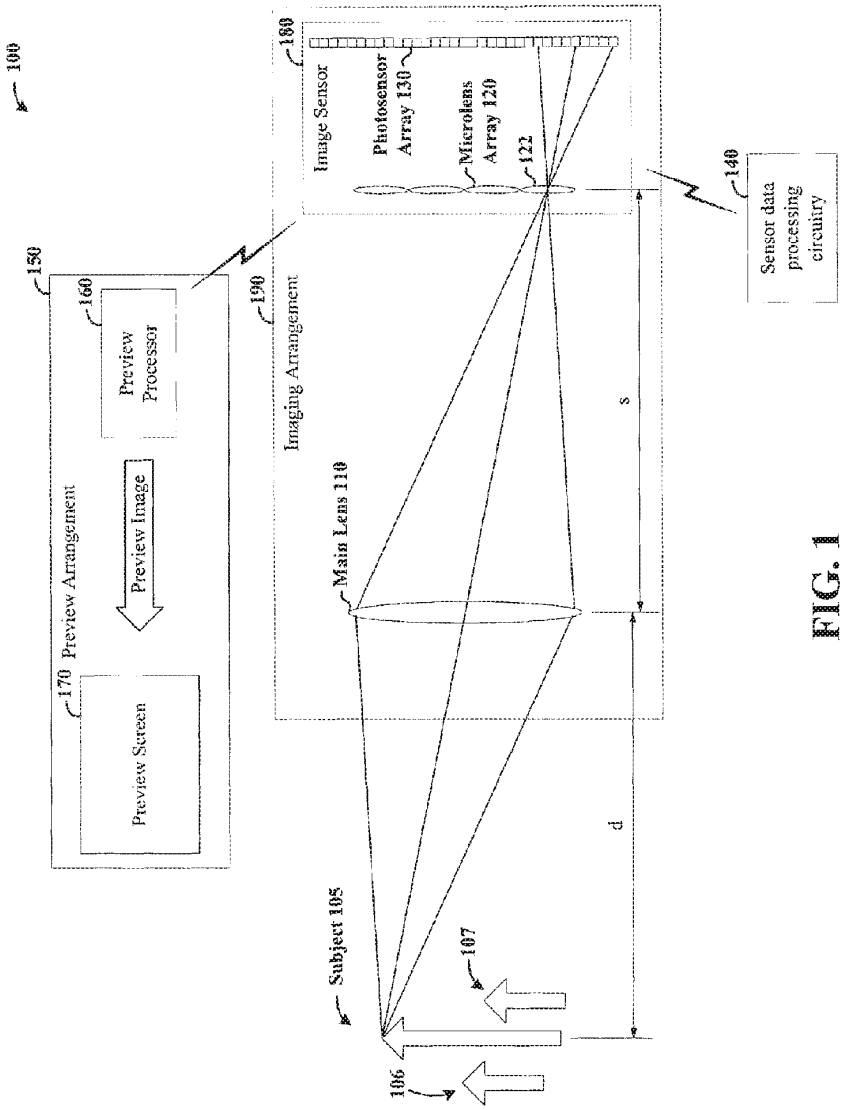

100
150
160
Preview Processor
Preview Image
170
Preview Screen
Preview Arrangement
190
Imaging Arrangement
180
Image Sensor
Photosensor Array 130
Microlens Array 120
122
140
Sensor data processing circuitry
Main Lens 110
s
d
Subject 105
107
106

FIG. 1

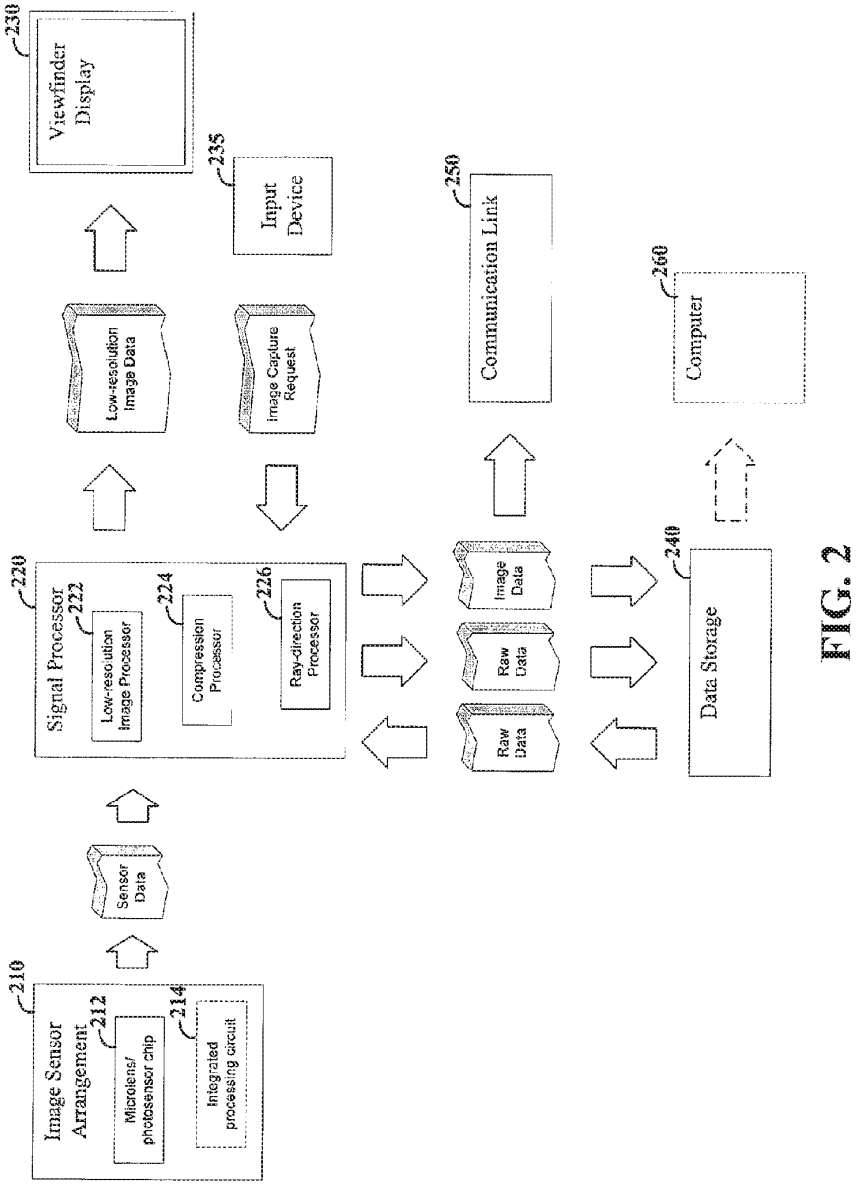

230
Viewfinder Display
235
Input Device
250
Communication Link
260
Computer
Low-resolution Image Data
Image Capture Request
220
Signal Processor
222
Low-resolution Image Processor
224
Compression Processor
226
Ray-direction Processor
Image Data
Raw Data
Raw Data
240
Data Storage
Sensor Data
210
Image Sensor Arrangement
212
Microlens/ photosensor chip
214
Integrated processing circuit

FIG. 2

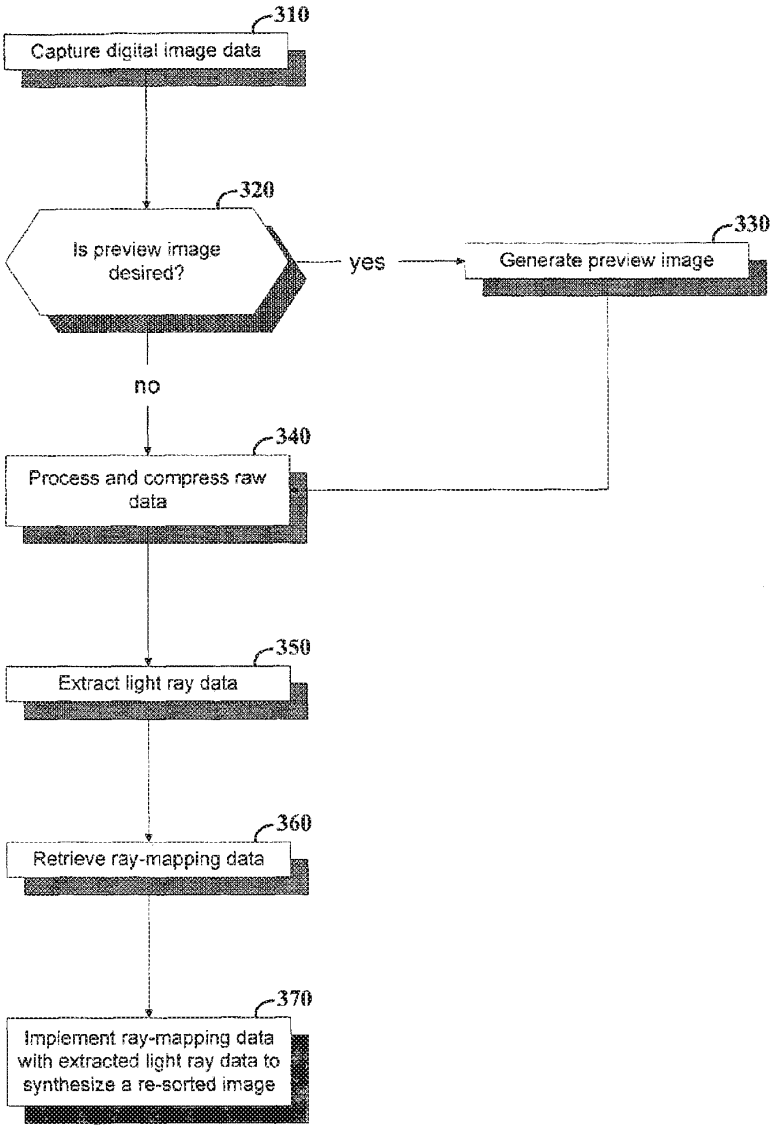

310
Capture digital image data
320
Is preview image desired?
yes
330
Generate preview image
no
340
Process and compress raw data
350
Extract light ray data
360
Retrieve ray-mapping data
370
Implement ray-mapping data with extracted light ray data to synthesize a re-sorted image

FIG. 3

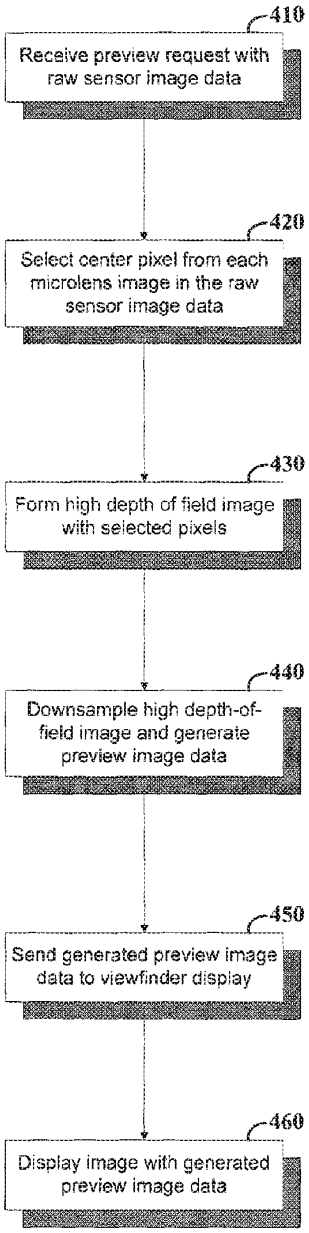

410
Receive preview request with raw sensor image data
420
Select center pixel from each microlens image in the raw sensor image data
430
Form high depth of field image with selected pixels
440
Downsample high depth-of-field image and generate preview image data
450
Send generated preview image data to viewfinder display
460
Display image with generated preview image data

FIG. 4

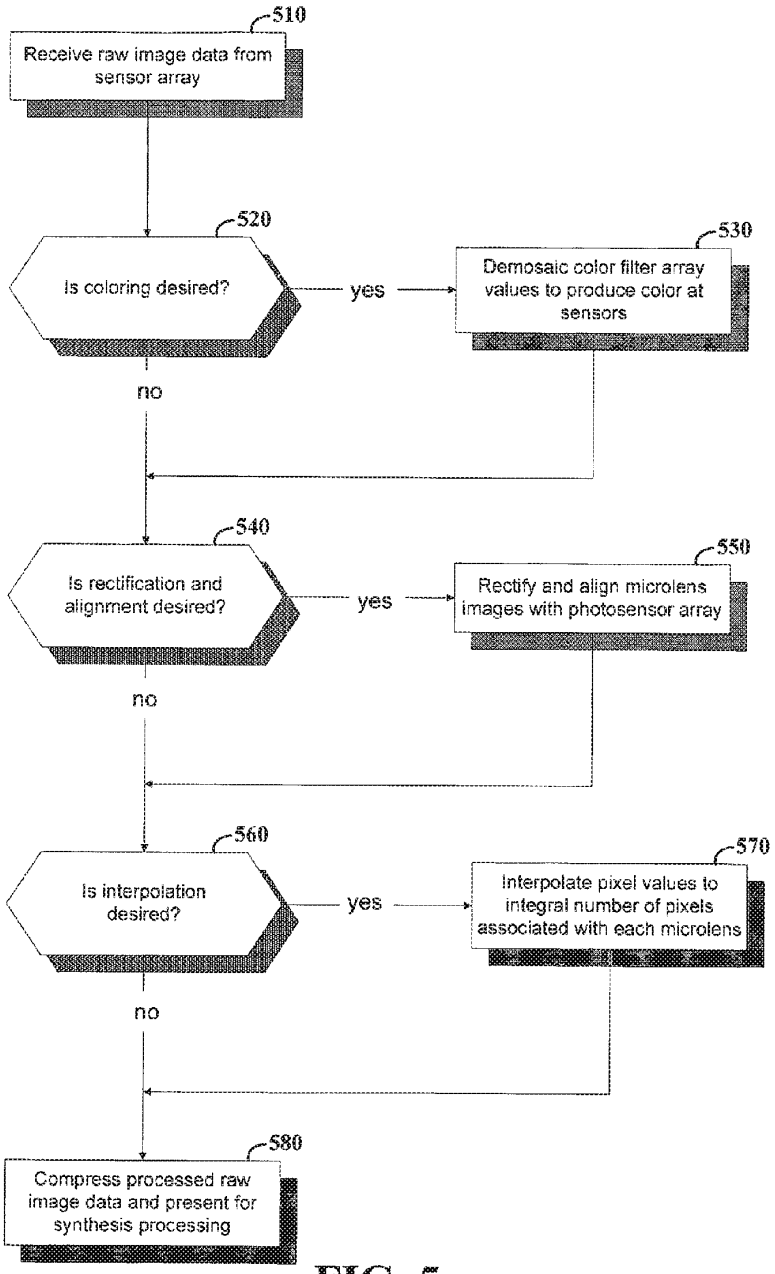

510
Receive raw image data from sensor array
520
Is coloring desired?
yes
530
Demosaic color filter array values to produce color at sensors
no
540
Is rectification and alignment desired?
yes
550
Rectify and align microlens images with photosensor array
no
560
Is interpolation desired?
yes
570
Interpolate pixel values to integral number of pixels associated with each microlens
no
580
Compress processed raw image data and present for synthesis processing

FIG. 5

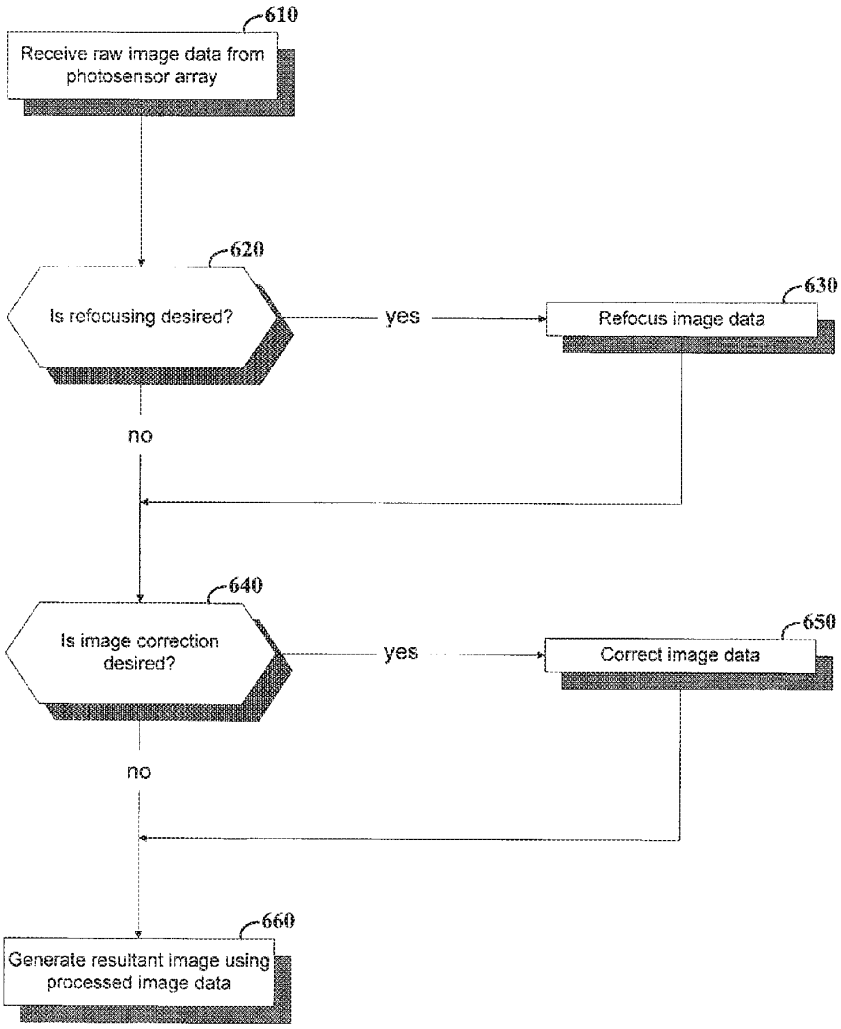
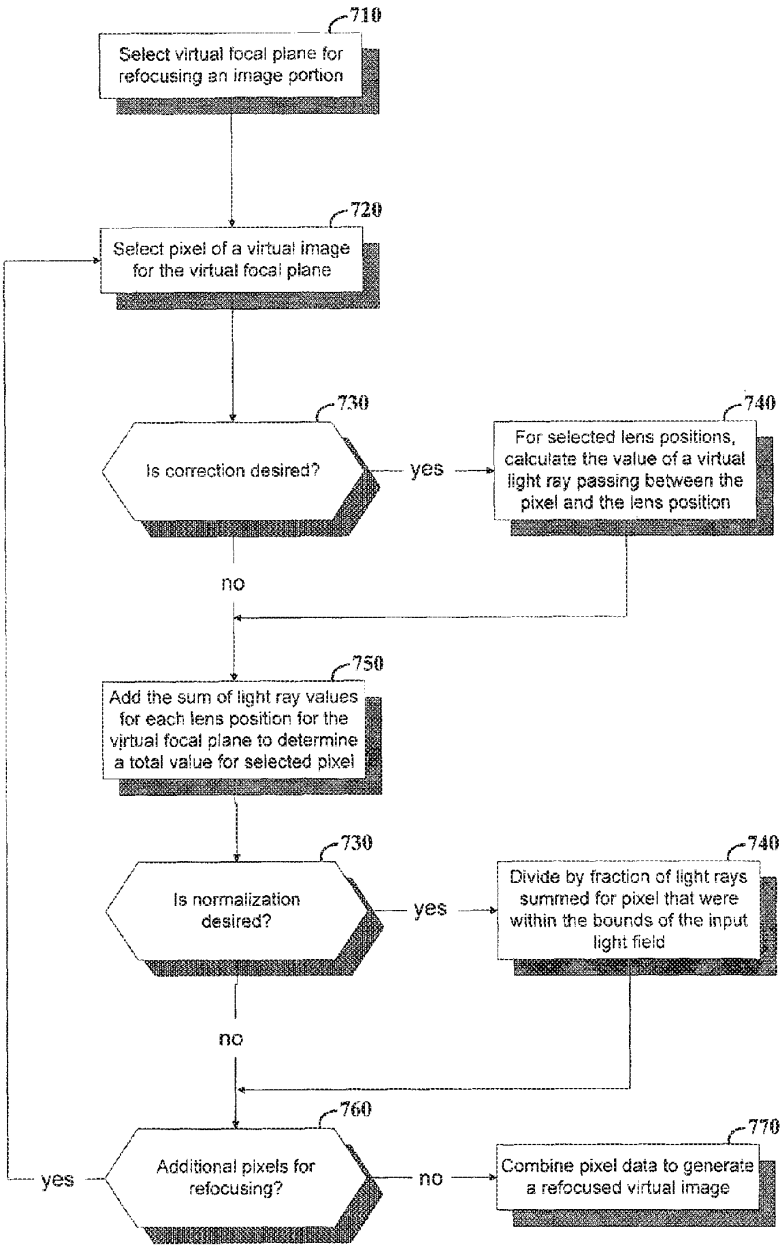

610
Receive raw image data from photosensor array
620
Is refocusing desired?
yes
630
Refocus image data
no
640
Is image correction desired?
yes
650
Correct image data
no
660
Generate resultant image using processed image data

FIG. 6

FIG. 7


710
Select virtual focal plane for refocusing an image portion
720
Select pixel of a virtual image for the virtual focal plane
730
Is correction desired?
yes
740
For selected lens positions, calculate the value of a virtual light ray passing between the pixel and the lens position
no
750
Add the sum of light ray values for each lens position for the virtual focal plane to determine a total value for selected pixel
730
Is normalization desired?
yes
740
Divide by fraction of light rays summed for pixel that were within the bounds of the input light field
no
760
Additional pixels for refocusing?
yes
no
770
Combine pixel data to generate a refocused virtual image

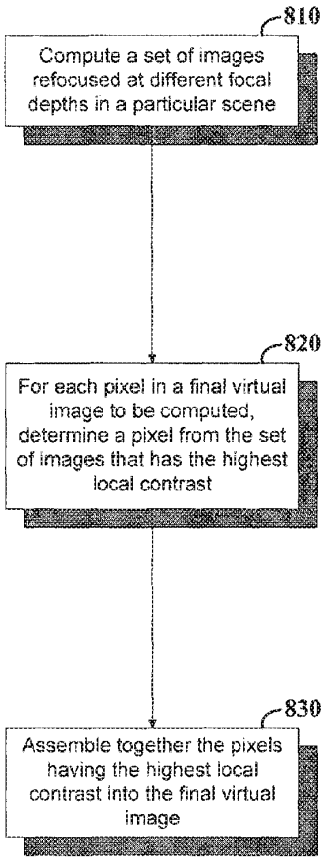

810
Compute a set of images refocused at different focal depths in a particular scene
820
For each pixel in a final virtual image to be computed, determine a pixel from the set of images that has the highest local contrast
830
Assemble together the pixels having the highest local contrast into the final virtual image

FIG. 8

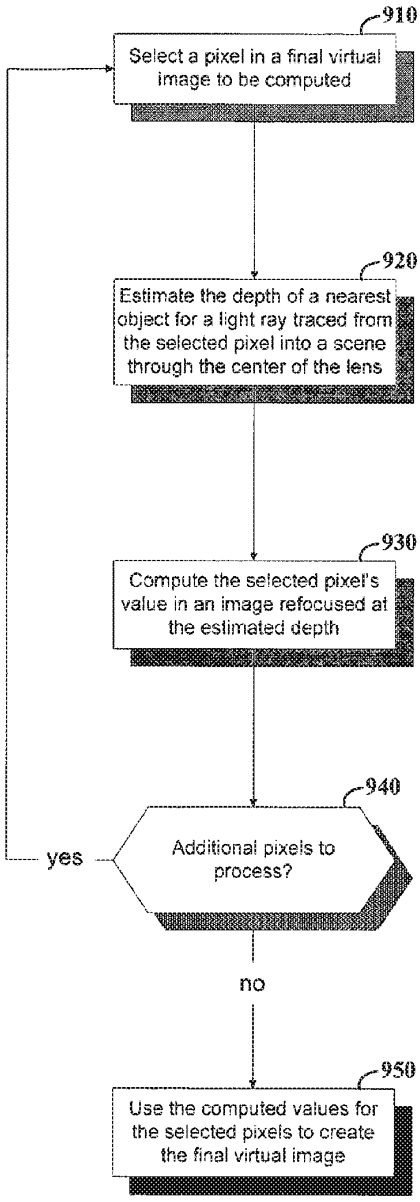

910
Select a pixel in a final virtual image to be computed
920
Estimate the depth of a nearest object for a light ray traced from the selected pixel into a scene through the center of the lens
930
Compute the selected pixel's value in an image refocused at the estimated depth
940
Additional pixels to process?
yes
no
950
Use the computed values for the selected pixels to create the final virtual image

FIG. 9

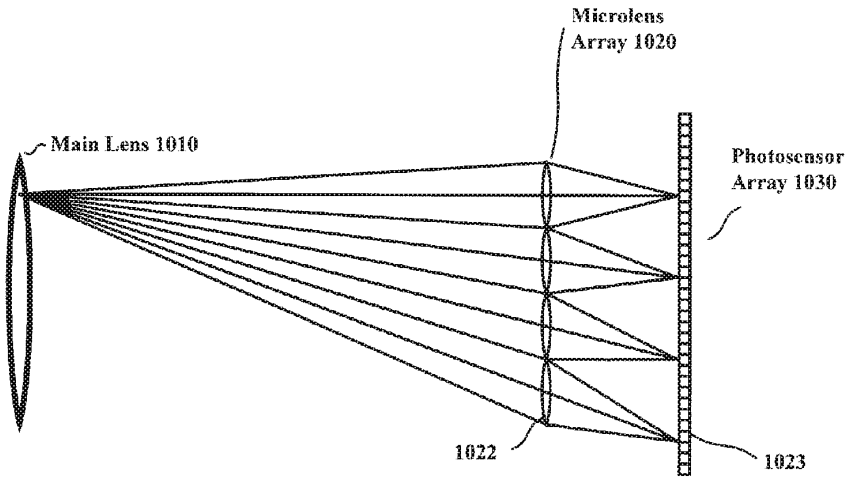

Microlens
Array 1020
Main Lens 1010
Photosensor
Array 1030
1022
1023

FIG. 10

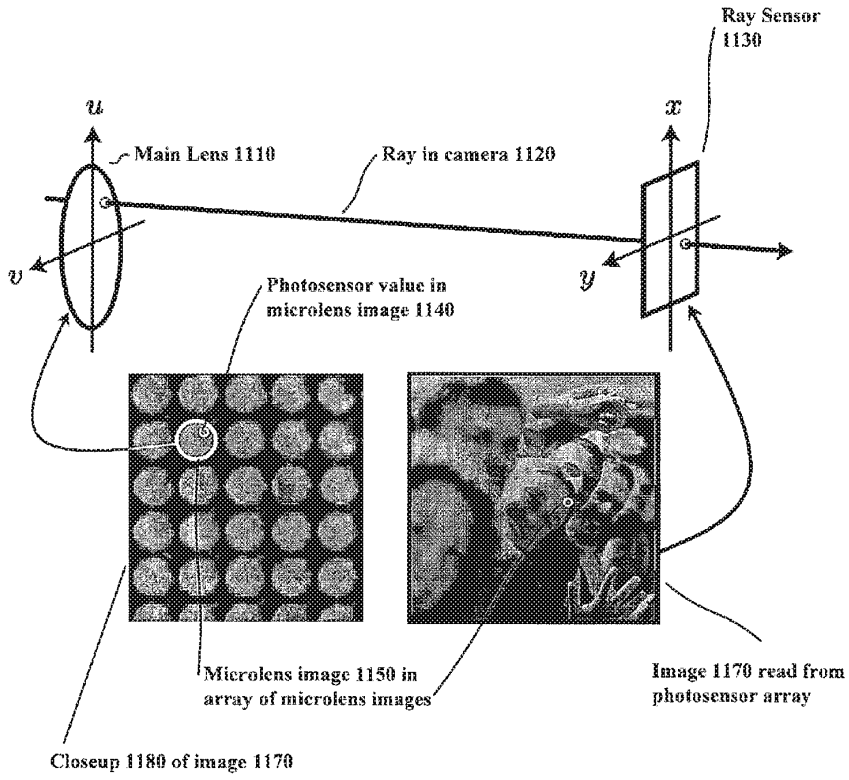

Ray Sensor
1130
u
x
Main Lens 1110
Ray in camera 1120
v
y
Photosensor value in
microlens image 1140
Microlens image 1150 in
array of microlens images
Image 1170 read from
photosensor array
Closeup 1180 of image 1170

FIG. 11

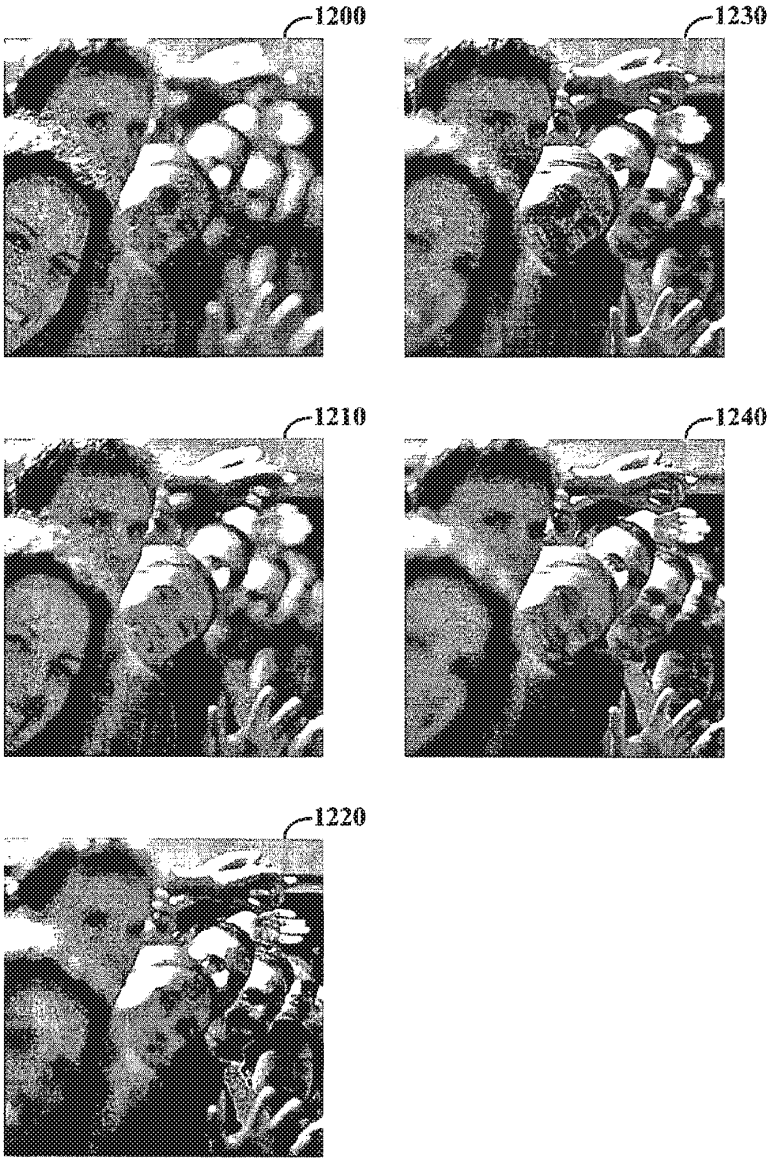


FIG. 12

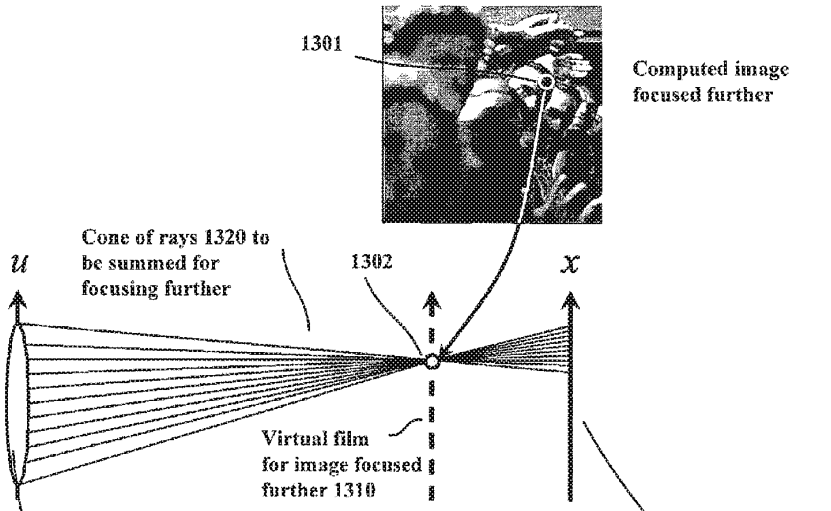


FIG. 13A

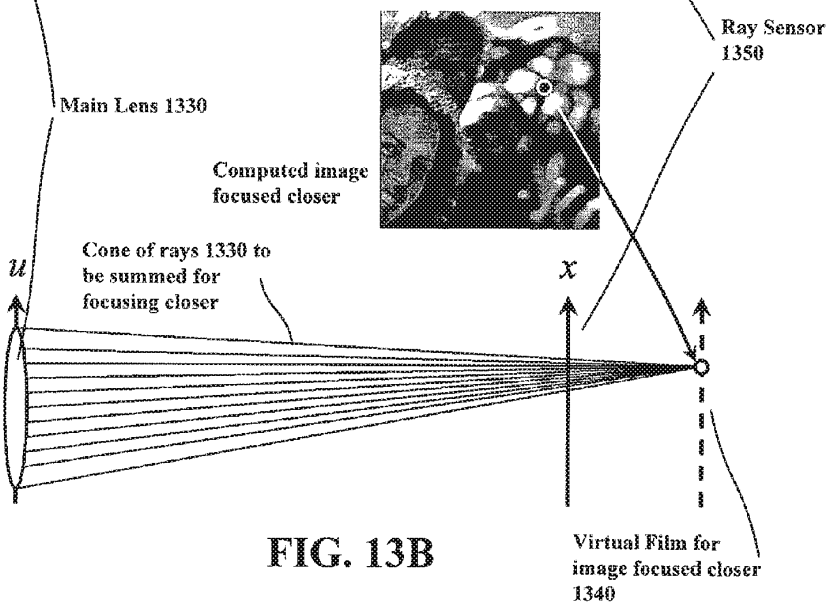
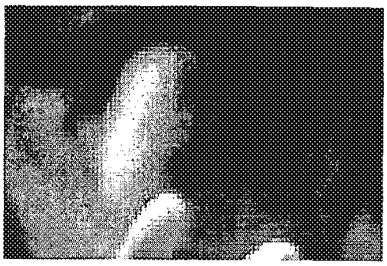


FIG. 13B

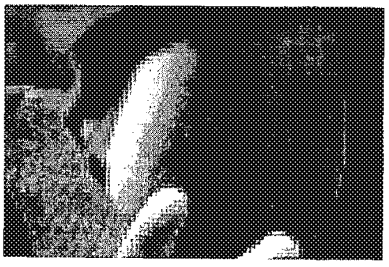


Closup

FIG. 14A

Closup

FIG. 14B



Closup

FIG. 14C

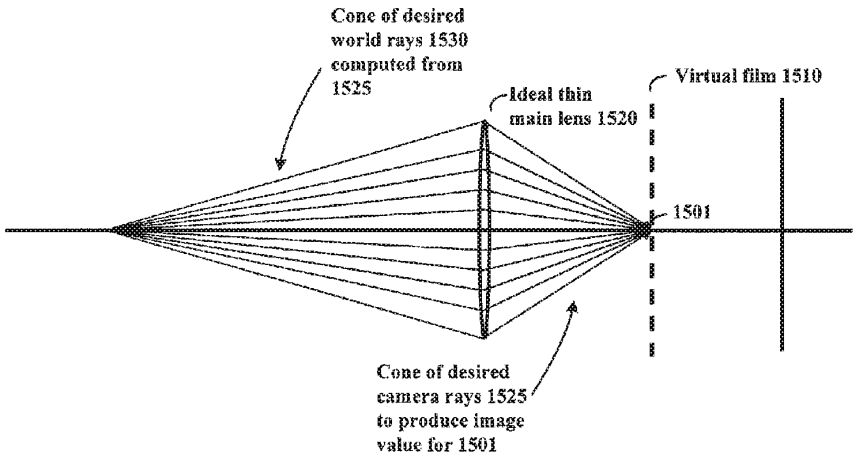

Cone of desired world rays 1530 computed from 1525
Ideal thin main lens 1520
Virtual film 1510
1501
Cone of desired camera rays 1525 to produce image value for 1501

FIG. 15

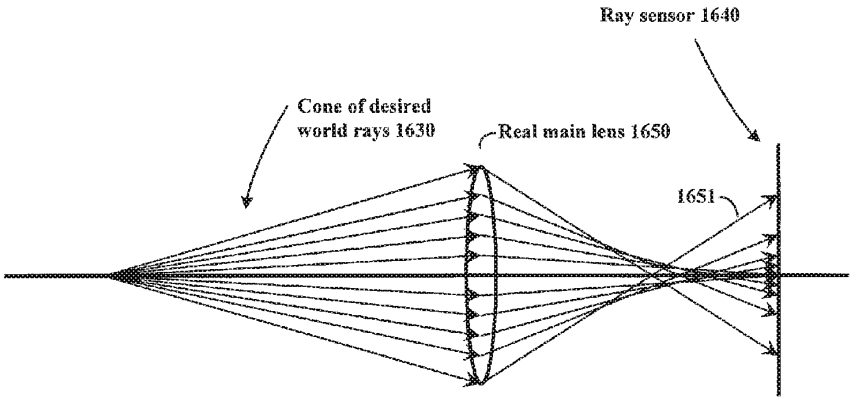

Ray sensor 1640
Cone of desired world rays 1630
Real main lens 1650
1651

FIG. 16

FIG. 17A

FIG. 17B

FIG. 17C

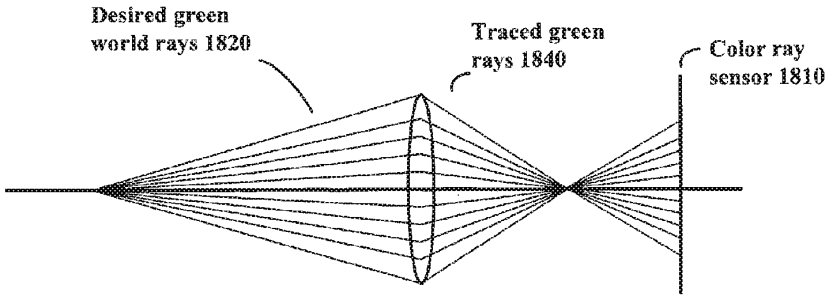


FIG. 18A

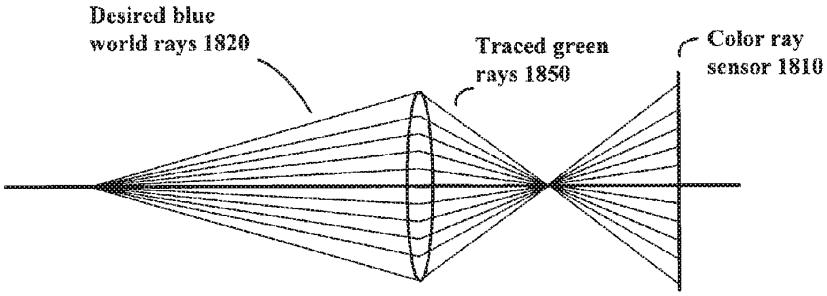


FIG. 18B

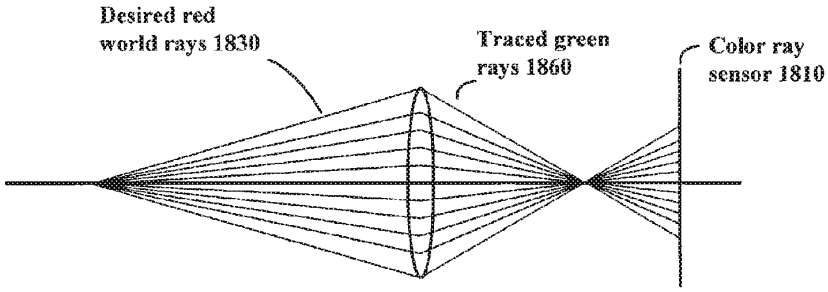


FIG. 18C

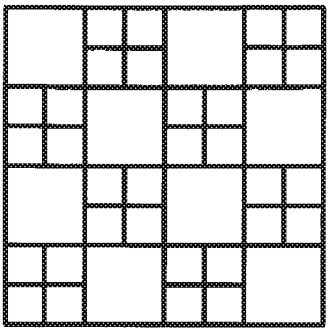


FIG. 19A

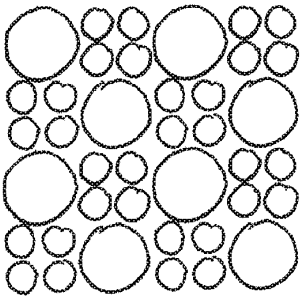


FIG. 19B

FIG. 19C

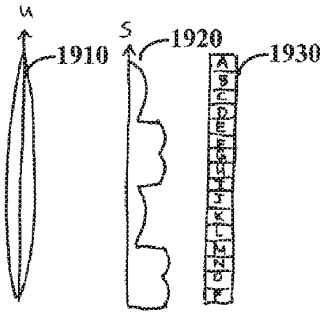


FIG. 19D

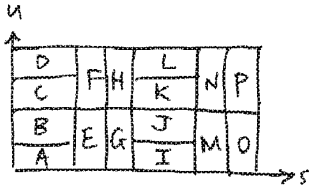


FIG. 19E

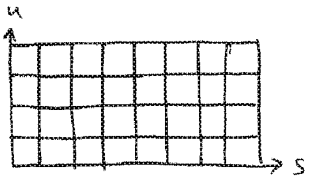


FIG. 19F

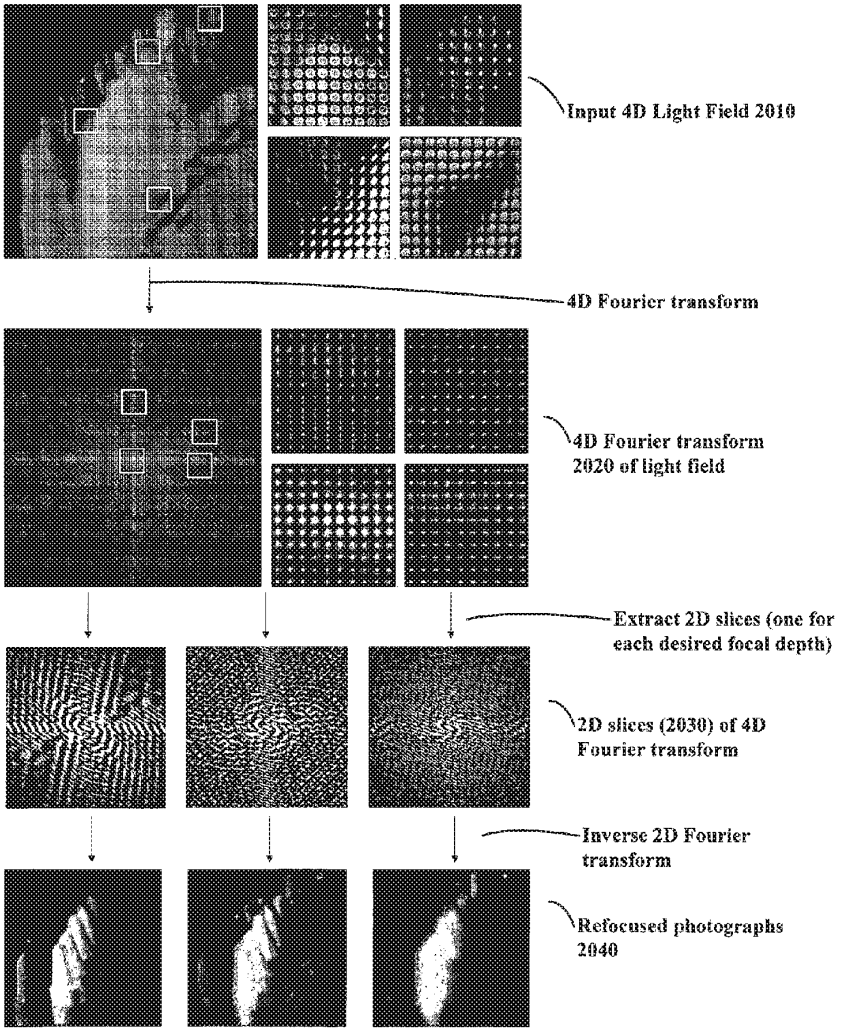

Input 4D Light Field 2010
4D Fourier transform
4D Fourier transform 2020 of light field
Extract 2D slices (one for each desired focal depth)
2D slices (2030) of 4D Fourier transform
Inverse 2D Fourier transform
Refocused photographs 2040

FIG. 20

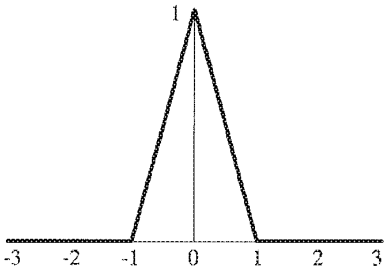


FIG. 21A

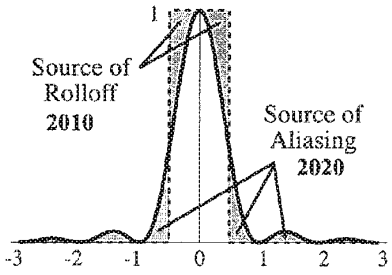


FIG. 21B

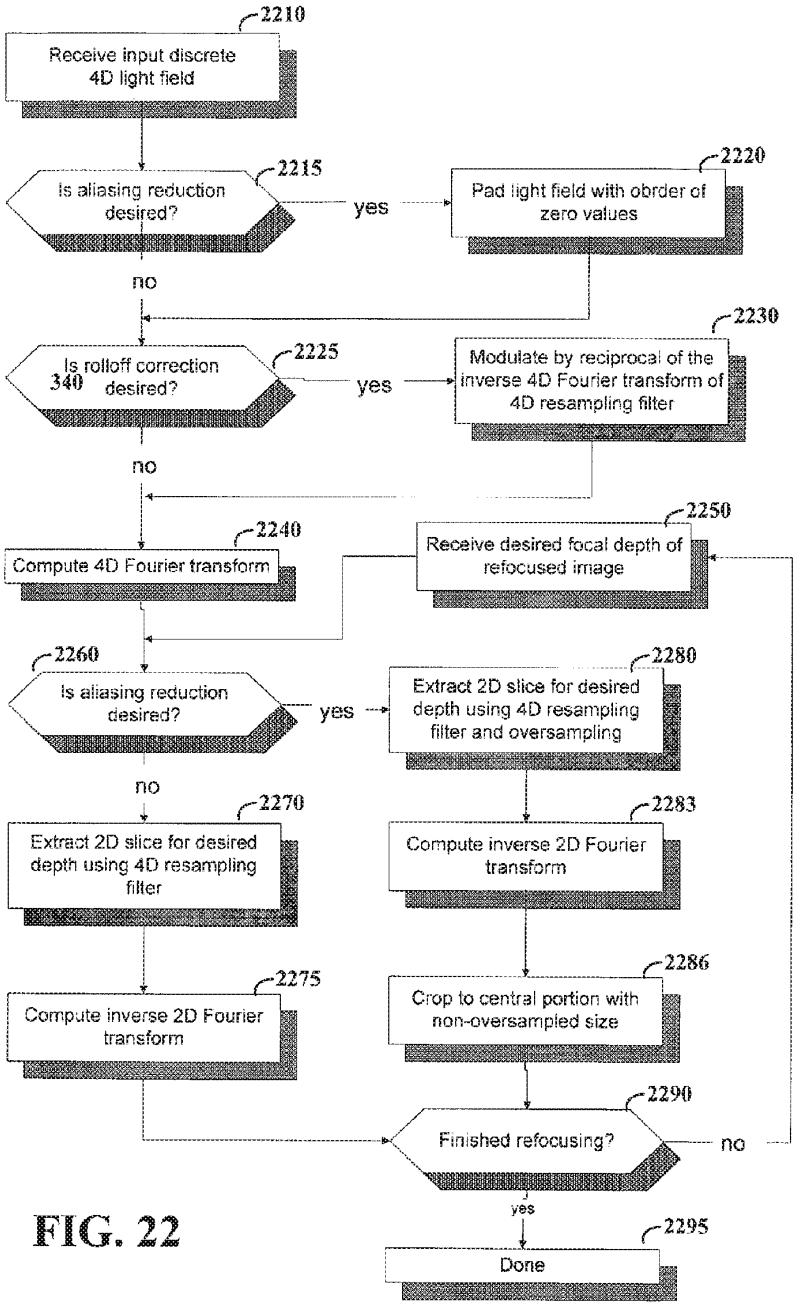

2210
Receive input discrete 4D light field
2215
Is aliasing reduction desired?
yes
2220
Pad light field with obrder of zero values
no
2230
Is rolloff correction desired?
340
2225
yes
Modulate by reciprocal of the inverse 4D Fourier transform of 4D resampling filter
no
2240
Compute 4D Fourier transform
2250
Receive desired focal depth of refocused image
2260
Is aliasing reduction desired?
yes
2280
Extract 2D slice for desired depth using 4D resampling filter and oversampling
no
2270
Extract 2D slice for desired depth using 4D resampling filter
2283
Compute inverse 2D Fourier transform
2275
Compute inverse 2D Fourier transform
2286
Crop to central portion with non-oversampled size
2290
Finished refocusing?
no
yes
2295
Done

FIG. 22

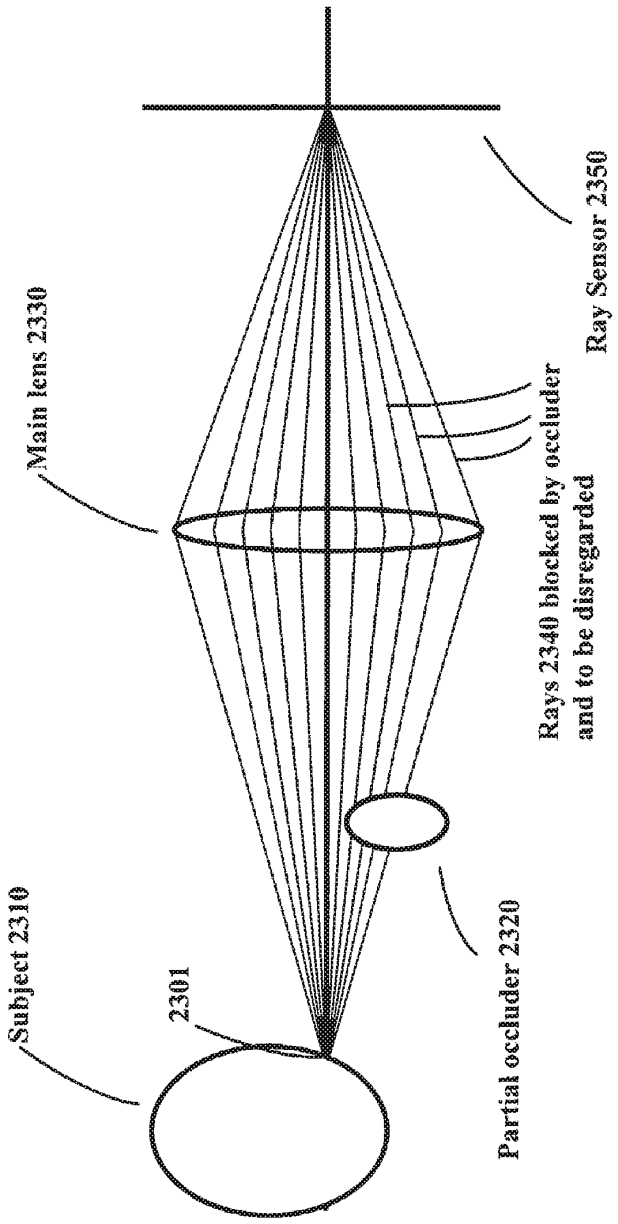

Ray Sensor 2350
Main lens 2330
Rays 2340 blocked by occluder and to be disregarded
Subject 2310
2301
Partial occluder 2320

FIG. 23

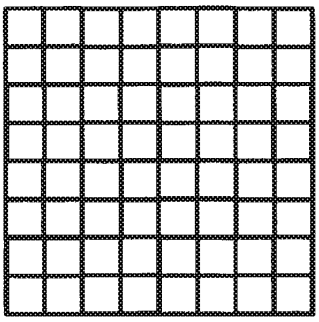


FIG. 24A

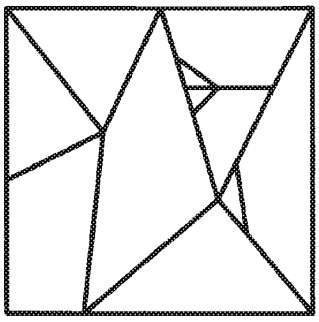


FIG. 24B

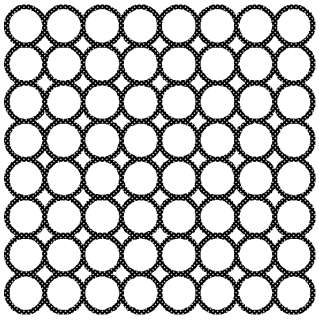


FIG. 24C

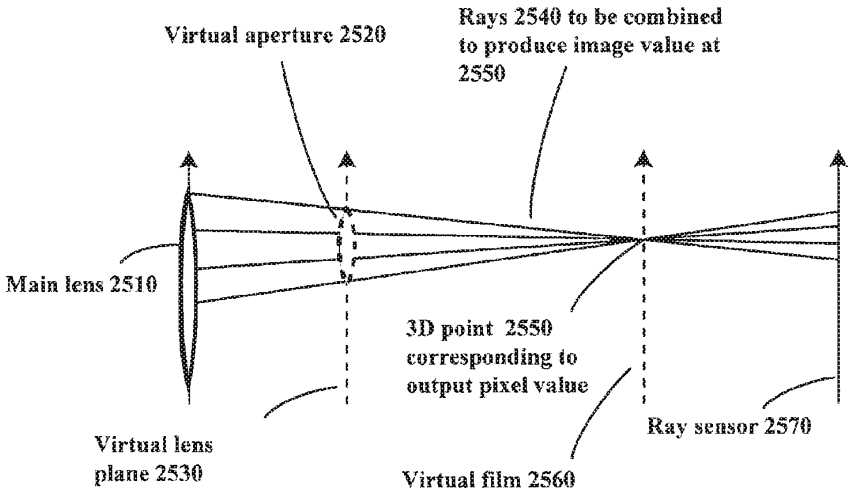

Virtual aperture 2520
Rays 2540 to be combined to produce image value at 2550
Main lens 2510
3D point 2550 corresponding to output pixel value
Ray sensor 2570
Virtual lens plane 2530
Virtual film 2560

FIG. 25

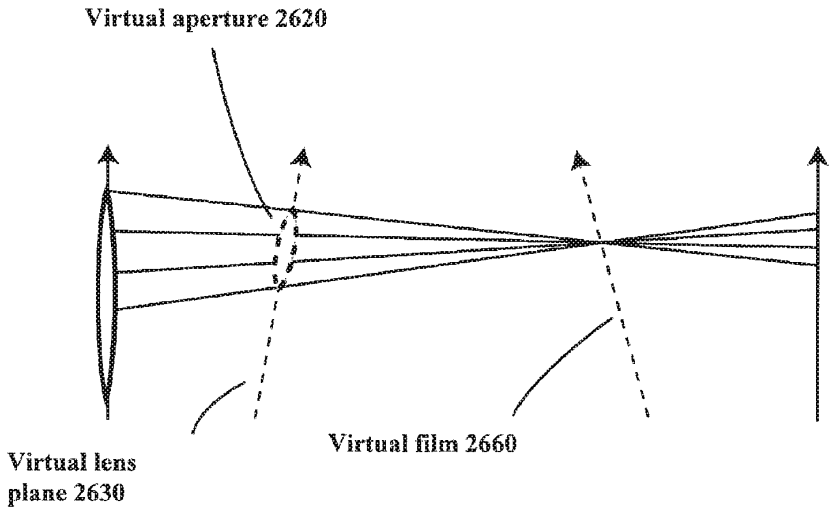

Virtual aperture 2620
Virtual film 2660
Virtual lens plane 2630

FIG. 26

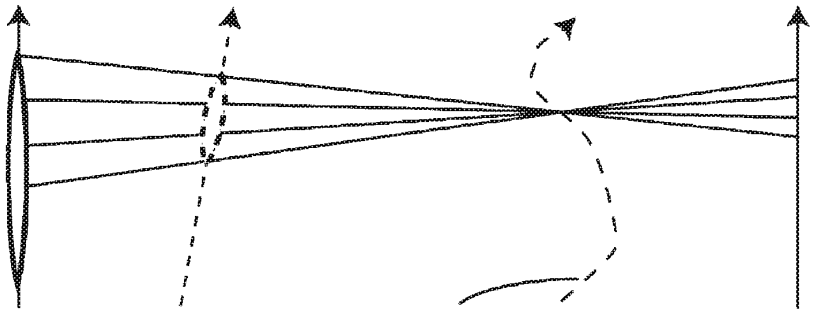


FIG. 27

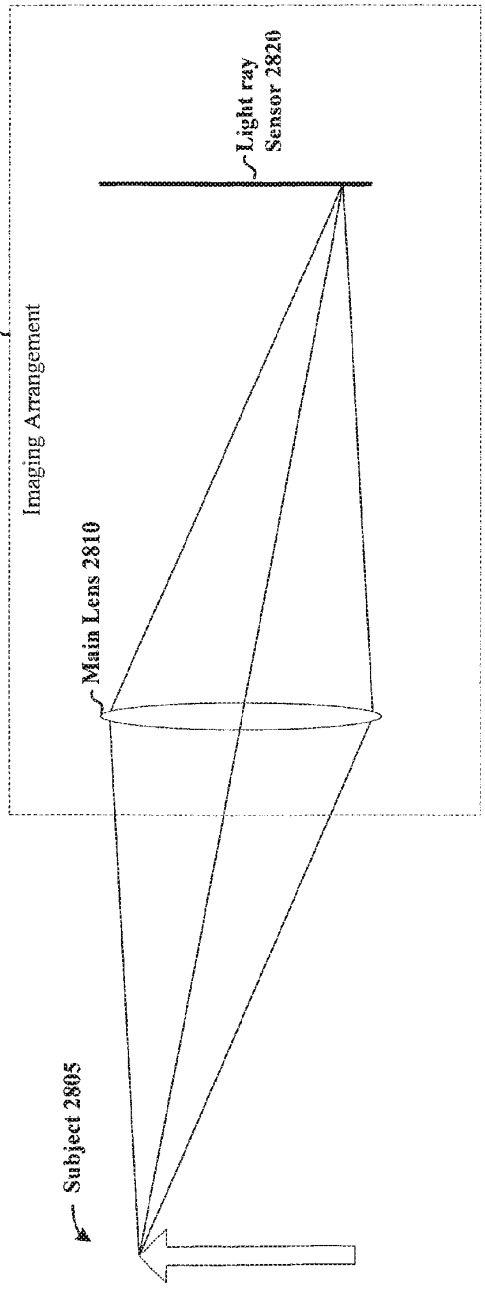

Light ray
Sensor 2820
2890
Imaging Arrangement
Main Lens 2810
Subject 2805

FIG. 28

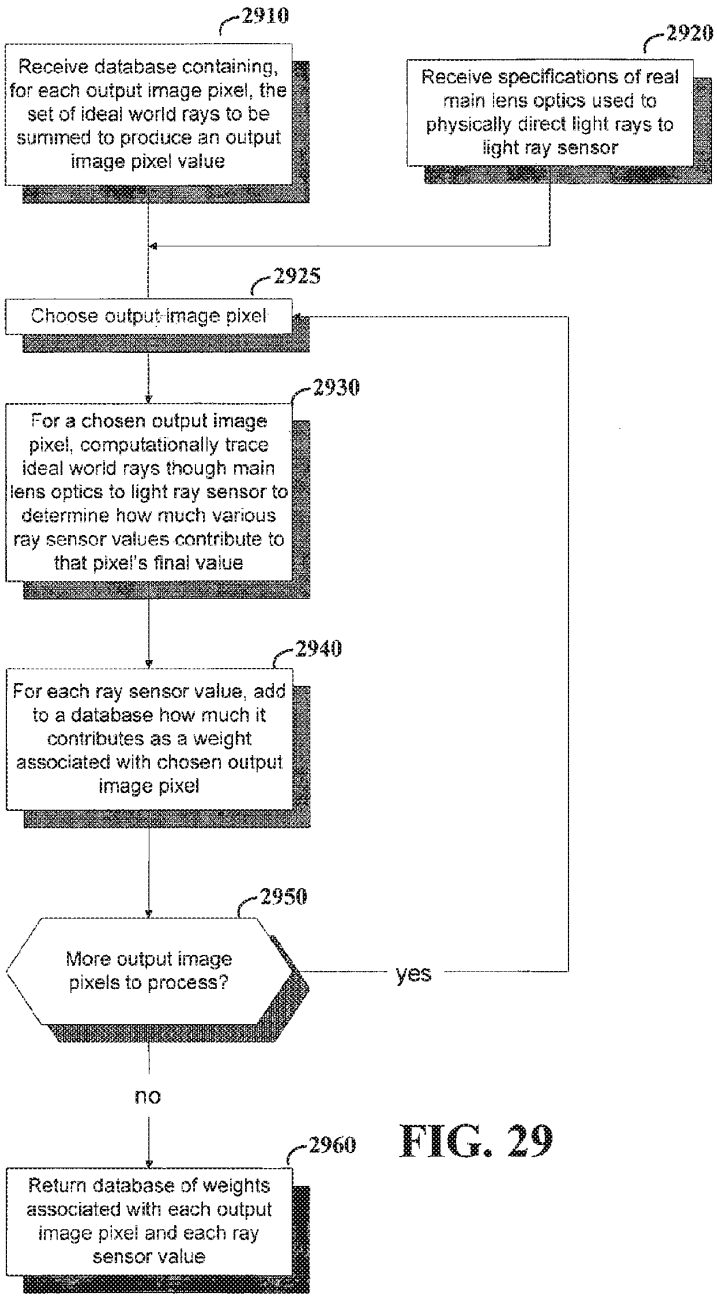

2910
Receive database containing, for each output image pixel, the set of ideal world rays to be summed to produce an output image pixel value
2920
Receive specifications of real main lens optics used to physically direct light rays to light ray sensor
2925
Choose output image pixel
2930
For a chosen output image pixel, computationally trace ideal world rays though main lens optics to light ray sensor to determine how much various ray sensor values contribute to that pixel's final value
2940
For each ray sensor value, add to a database how much it contributes as a weight associated with chosen output image pixel
2950
More output image pixels to process?
yes
no
2960
Return database of weights associated with each output image pixel and each ray sensor value

FIG. 29

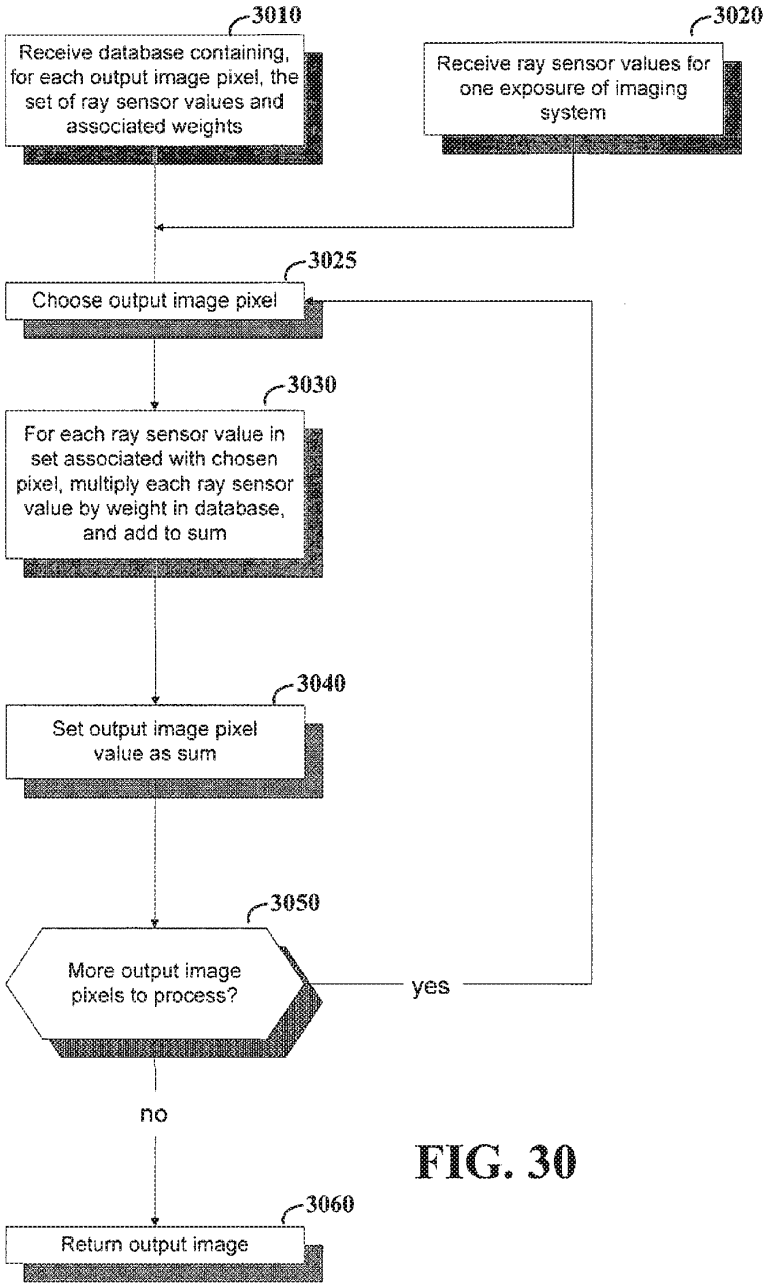

3010
Receive database containing, for each output image pixel, the set of ray sensor values and associated weights
3020
Receive ray sensor values for one exposure of imaging system
3025
Choose output image pixel
3030
For each ray sensor value in set associated with chosen pixel, multiply each ray sensor value by weight in database, and add to sum
3040
Set output image pixel value as sum
3050
More output image pixels to process?
yes
no
3060
Return output image

FIG. 30

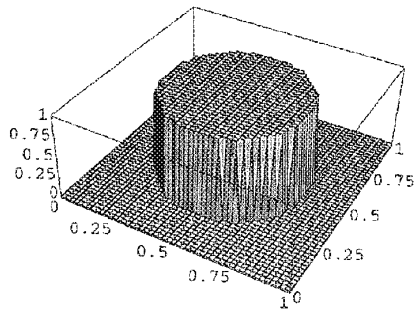


FIG. 31A

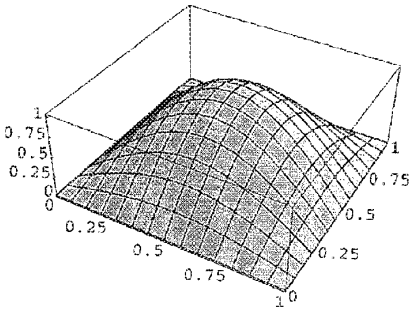


FIG. 31B

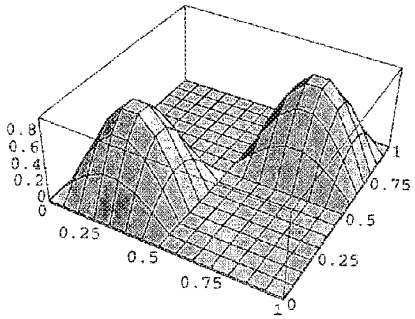


FIG. 31C

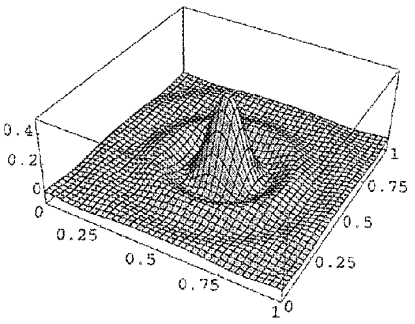


FIG. 31D

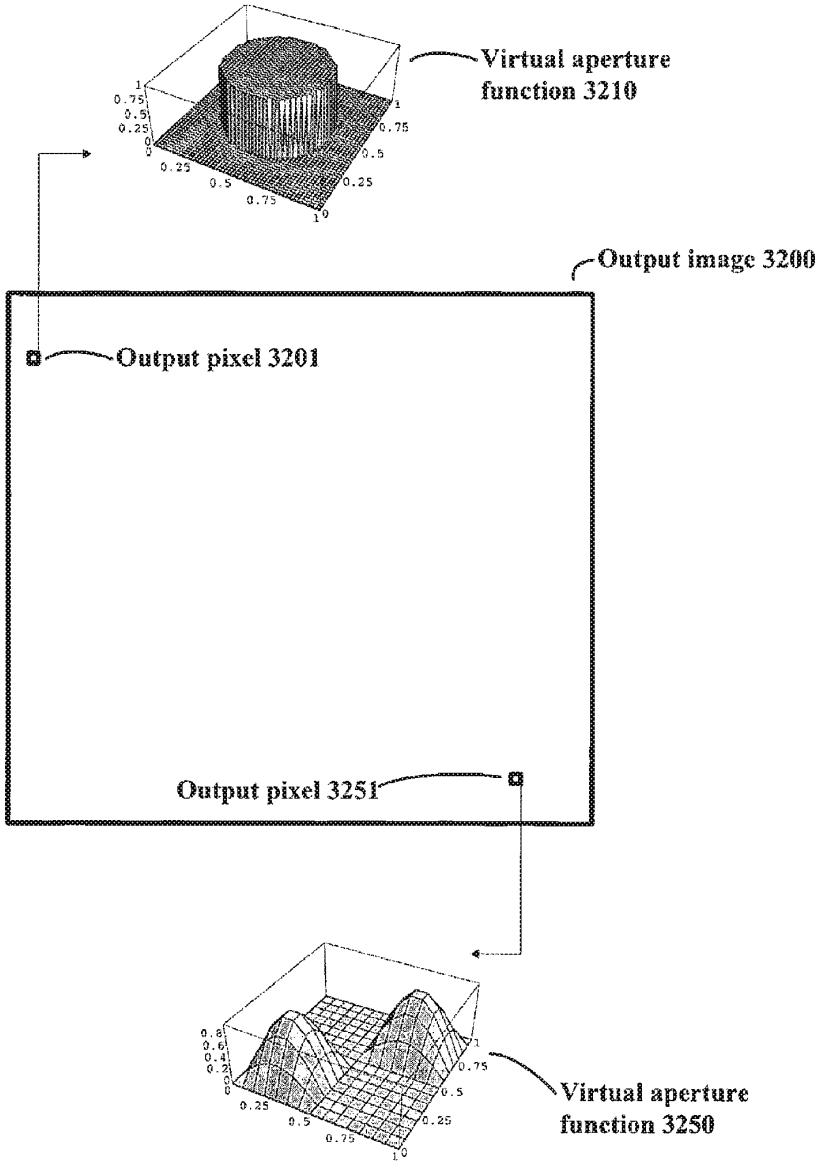

Virtual aperture function 3210
Output image 3200
Output pixel 3201
Output pixel 3251
Virtual aperture function 3250

FIG. 32

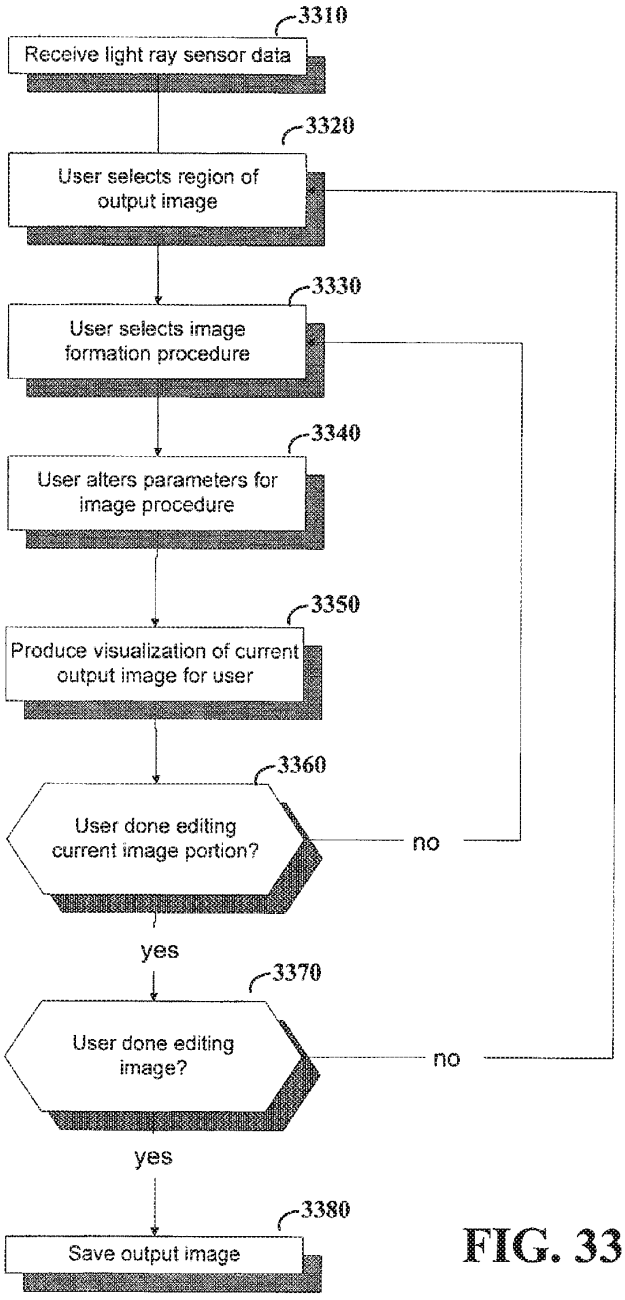

3310
Receive light ray sensor data
3320
User selects region of output image
3330
User selects image formation procedure
3340
User alters parameters for image procedure
3350
Produce visualization of current output image for user
3360
User done editing current image portion?
no
yes
3370
User done editing image?
no
yes
3380
Save output image

FIG. 33

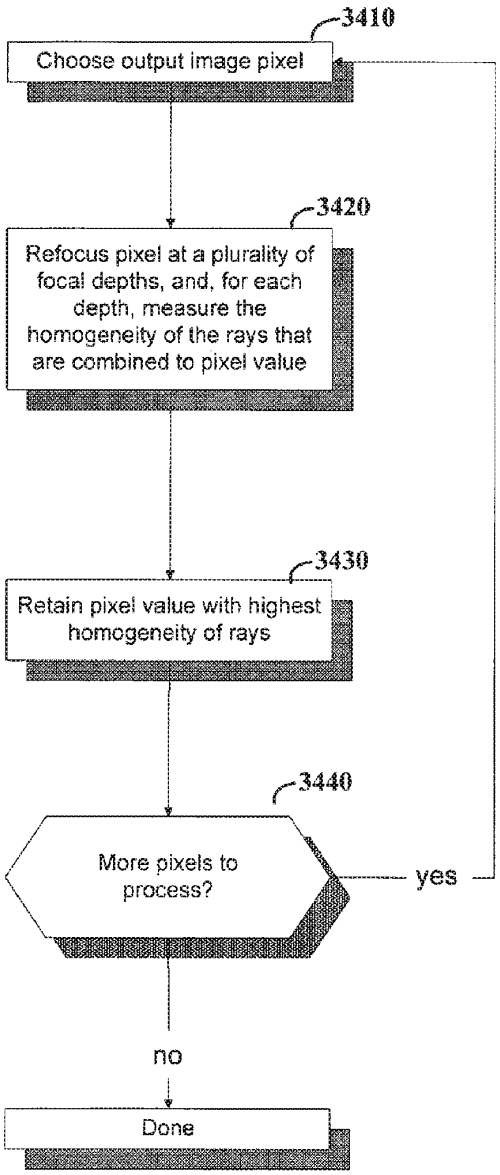

3410
Choose output image pixel
3420
Refocus pixel at a plurality of focal depths, and, for each depth, measure the homogeneity of the rays that are combined to pixel value
3430
Retain pixel value with highest homogeneity of rays
3440
More pixels to process?
yes
no
Done

FIG. 34

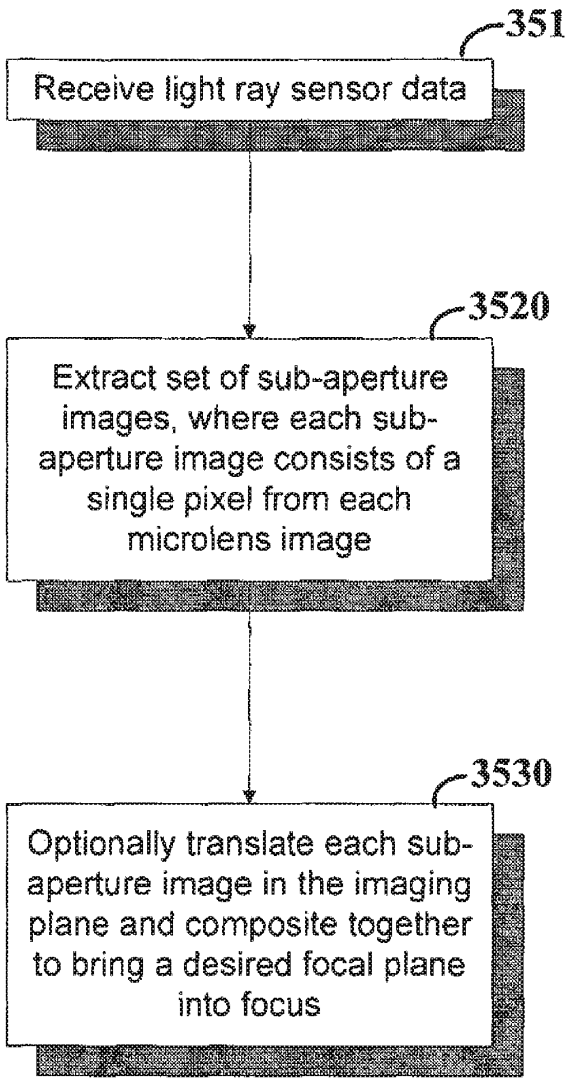

3510
Receive light ray sensor data
3520
Extract set of sub-aperture images, where each sub-aperture image consists of a single pixel from each microlens image
3530
Optionally translate each sub-aperture image in the imaging plane and composite together to bring a desired focal plane into focus

FIG. 35

IMAGING ARRANGEMENTS AND METHODS THEREFOR

RELATED PATENT DOCUMENTS

This patent application is the national stage filing under 35 U.S.C. 371 of International Application No. PCT/US2005/035189 filed on Sep. 30, 2005, which claims benefit under 35 U.S.C. §119(e) of U.S. Provisional Application Ser. No. 60/615,179 filed on Oct. 1, 2004; and of U.S. Provisional Application Ser. No. 60/647,492 filed on Jan. 27, 2005.

FEDERALLY-SPONSORED RESEARCH AND DEVELOPMENT

This invention was made with Government support under contract 0085864 awarded by the National Science Foundation. The U.S. Government has certain rights in this invention.

FIELD OF THE INVENTION

The present invention relates generally to imaging applications, and more specifically to processing image data to focus and/or correct the image data.

BACKGROUND

Imaging applications such as those involving cameras, video cameras, microscopes, telescopes and more have generally been limited in the amount of light that is collected. That is, most imaging devices do not record most of the information about light distribution entering the device. For example, conventional cameras such as digital still cameras and video cameras do not record most of the information about the light distribution entering from the world. In these devices, collected light is often not amenable to manipulation for a variety of approaches, such as for focusing at different depths (distances from the imaging device), correcting for lens aberrations or manipulating an angle of view.

For still-imaging applications, typical imaging devices capturing a particular scene generally focus upon a subject or object in the scene, with other parts of the scene left out of focus. For video-imaging applications, similar problems prevail, with a collection of images used in video applications failing to capture scenes in focus.

Many imaging applications suffer from aberrations with the equipment (lenses) used to collect light. Such aberrations may include, for example, spherical aberration, chromatic aberration, distortion, curvature of the light field, oblique astigmatism and coma. Correction for aberrations has typically involved the use of corrective optics, when tend to add bulk, expense and weight to imaging devices. In some applications benefiting from small-scale optics, such as camera phones and security cameras, the physical limitations associated with the applications make it undesirable to include additional optics.

Difficulties associated with the above have presented challenges to imaging applications, including those involving the acquisition and altering of digital images.

SUMMARY

The present invention is directed to overcoming the above-mentioned challenges and others related to imaging devices and their implementations. The present invention is exemplified in a number of implementations and applications, some of which are summarized below.

According to an example embodiment of the present invention, a light is detected with directional information characterizing the detected light. The directional information is used with the detected light to generate a virtual image, corresponding to one or both of a refocused image and a corrected image.

According to another example embodiment of the present invention, two or more subjects at different focal depths in a scene are imaged, with portions of the scene corresponding to each subject focused at different focal planes. Light from the scene is focused upon a physical focal plane and detected, together with information characterizing the direction from which the light arrived at particular locations on the physical focal plane. For at least one subject that is located at a depth of field that is not focused upon the physical focal plane, a virtual focal plane that is different than the physical focal plane is determined. Using the detected light and directional characteristics thereof, portions of the light corresponding to a focused image of the at least one subject upon the virtual focal plane are collected and added to form a virtual focused image of the at least one subject.

According to another example embodiment of the present invention, a scene is digitally imaged. Light from the scene that is passed to different locations on a focal plane is detected, and the angle of incidence of the light detected at the different locations on the focal plane is detected. A depth of field of a portion of the scene from which the detected light came is detected and used together with the determined angle of incidence to digitally re-sort the detected light. Depending upon the application, the re-sorting includes refocusing and/or correcting for lens aberrations.

The above summary of the present invention is not intended to describe each illustrated embodiment or every implementation of the present invention. The figures and detailed description that follow more particularly exemplify these embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be more completely understood in consideration of the detailed description of various embodiments of the invention that follows in connection with the accompanying drawings, in which:

FIG. **1** is a light ray capturing and processing arrangement, according to an example embodiment of the present invention;

FIG. **2** is an optical imaging device, according to another example embodiment of the present invention;

FIG. **3** is a process flow diagram for image processing, according to another example embodiment of the present invention;

FIG. **4** is a process flow diagram for generating a preview image, according to another example embodiment of the present invention;

FIG. **5** is a process flow diagram for processing and compressing image data, according to another example embodiment of the present invention;

FIG. **6** is a process flow diagram for image synthesis, according to another example embodiment of the present invention;

FIG. **7** is a process flow diagram for image refocusing, according to another example embodiment of the present invention;

FIG. **8** is a process flow diagram for extending the depth of field in an image, according to another example embodiment of the present invention;

FIG. **9** is a process flow diagram for another approach to extending the depth of field in an image, according to another example embodiment of the present invention;

FIG. **10** illustrates one example approach to separating light rays, according to another example embodiment of the present invention;

FIG. **11** illustrates an approach to the mapping of sensor pixel locations to rays in the L(u,v,s,t) space with respect to data collected, according to another example embodiment of the invention;

FIG. **12** illustrates several images refocused at different depths, according to another example embodiment of the present invention;

FIG. **13**A shows an imaging configuration in 2D, according to another example embodiment of the present invention;

FIG. **13**B shows a cone of rays from a 3D point summed for a pixel, according to another example embodiment of the present invention;

FIGS. **14**A-**14**C show an approach to computing images with different depths of field, according to another example embodiment of the present invention;

FIG. **15** illustrates an approach to the tracing of rays from a 3D point on a virtual film plane, according to another example embodiment of the present invention;

FIG. **16** shows an approach to finding the value of light, according to another example embodiment of the present invention;

FIG. **17**A shows an ideal 512×512 photograph, according to another example embodiment of the present invention;

FIG. **17**B shows an image that would be produced with an f/2 bi-convex spherical lens, according to another example embodiment of the present invention;

FIG. **17**C shows an image computed using an image correction approach, according to another example embodiment of the present invention;

FIGS. **18**A-**18**C illustrate the tracing of light rays common in color imaging systems, according to another example embodiment of the present invention;

FIGS. **19**A-**19**F illustrate approaches to implementing a mosaic array, according to another example embodiment of the present invention;

FIG. **20** is a process flow diagram of computational approaches to refocusing in a Fourier domain, according to another example embodiment of the present invention;

FIG. **21**A shows a triangle filter approach, according to another example embodiment of the present invention;

FIG. **21**B shows a Fourier transformation of the triangle filter approach; according to another example embodiment of the present invention;

FIG. **22** is process flow diagram of an approach to refocusing in a frequency domain, according to another example embodiment of the present invention;

FIG. **23** shows a set of rays which pass through a desired focal point, according to another example embodiment of the present invention;

FIGS. **24**A-B show differing views of a portion of a microlens array, according to another example embodiment of the present invention;

FIG. **24**C illustrates images that appear on a photosensor, according to another example embodiment of the present invention;

FIG. **25** illustrates an example embodiment of the present invention, in which a virtual image is computed as it would have appeared on virtual film;

FIG. **26** shows an approach to manipulating a virtual lens plane, according to another example embodiment of the present invention;

FIG. **27** illustrates that the virtual film may take any shape, according to another example embodiment of the present invention;

FIG. **28** shows an imaging arrangement; according to another example embodiment of the present invention;

FIG. **29** is a process flow diagram for pre-computing a database of weights associated with each output image pixel and each ray sensor value, according to another example embodiment of the present invention;

FIG. **30** is a process flow diagram for computing an output image using a database of weights, according to another example embodiment of the present invention;

FIGS. **31**A-D illustrate various scalar functions which are selectively implemented as a virtual aperture function, according to another example embodiment of the present invention;

FIG. **32** shows a virtual aperture function which varies from pixel to pixel; according to another example embodiment of the present invention;

FIG. **33** is a process flow diagram of a user selecting a region of an output image, editing an image portion and saving the output image, according to another example embodiment of the present invention;

FIG. **34** is a process flow diagram for extending the depth of field in an image, according to another example embodiment of the present invention; and

FIG. **35** is a process flow diagram for computing a refocused image from received light ray sensor data, according to another example embodiment of the present invention.

While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention.

DETAILED DESCRIPTION

The present invention is believed to be useful for a variety of different types of devices, and the invention has been found to be particularly suited for electronic imaging devices and applications. While the present invention is not necessarily limited to such applications, various aspects of the invention may be appreciated through a discussion of various examples using this context.

According to an example embodiment of the present invention, a four-dimensional (4D) light field (e.g., the light traveling along each ray in a region such as free space) is detected using an approach involving the determination of the amount and direction of light arriving at a sensor located at a focal plane. The two-dimensional position of light in the focal plane is detected, together with information characterizing the direction from which the light arrived at particular locations in the plane. With this approach, the directional lighting distribution arriving at different locations on the sensor are determined and used to form an image. In various discussions herein, the assembly or assemblies implemented for sensing and/or measuring of a light field are referred to as a "light ray sensor," or a "ray sensor."

In one application, an approach similar to the above is implemented using an imaging system having optics and sensors that sample the space of light rays that are incident on an imaging plane, with computational functionality that renders images from the set of measured rays in different ways. Each of the optics, sensors and computational functionality is

implemented using a variety of approaches, in combination or distinctly, depending upon the implementation. For example, a camera having lenses (optics) that focus an image upon a photosensor array (sensors) located at an imaging plane can be used to sample the space of light rays. An output from the photosensor array is used with computational functions (e.g., at a processor internal and/or external to the camera) to render images, such as by computing photographs that are focused at different depths or with different depths of field, and/or computationally correcting lens aberrations to produce higher quality images.

In another example embodiment, optics and sensor components of an imaging system direct rays of light onto sensor elements such that each sensor element senses a set of rays including rays emanating from specific directions. In many applications, this set of rays is a bundle of rays that is localized in both space and direction. For many applications, this bundle of rays will converge to a single geometric ray of light as the optics and sensor resolutions increase. In this regard, various portions of the description herein refer to the values sensed by the sensor elements as "rays of light" or "light rays" or simply "rays," even though in general they may not be limited to geometric rays.

Turning now to the figures, FIG. **28** shows an imaging arrangement **2890**, according to another example embodiment of the present invention. The imaging arrangement **2890** includes a main lens **2810**, and a light ray sensor that measures the value of light arriving at different locations on the sensor and from difference incident directions. In this context, measuring the value of light may be implemented by detecting light arriving at different locations at the sensor, together with characteristics of that light such as intensity to generate a value.

FIG. **1** shows an imaging system **100**, according to another example embodiment of the present invention. The imaging system **100** includes an imaging arrangement **190** having a main lens **110**, a microlens array **120** and a photosensor array **130**. In this case, the microlens array **120** and photosensor array **130** implement a light ray sensor. Although FIG. **1** illustrates a particular main lens **110** (single element) and particular microlens array **120**, those skilled in the art will recognize that a variety of lenses and/or microlens arrays (currently available or developed in the future) are selectively implemented with a similar approach by, for example, replacing the shown main lens and/or microlens array.

Rays of light from a single point on a subject **105** in an imaged scene are brought to a single convergence point on the focal plane of the microlens array **120**. For instance, when the imaged point on the subject **105** is at a distance from the main lens that is conjugate to the distance from the microlens array to the main lens, the dimension "d" is about equal to the dimension "s" as shown. A microlens **122** at this convergence point separates these rays of light based on the direction of the light, creating a focused image of the aperture of the main lens **110** on the photosensors underneath the microlens.

The photosensor array **130** detects light incident upon it and generates an output that is processed using one or more of a variety of components. In this application, the output light data is passed to sensor data processing circuitry **140**, which uses the data together with positional information about each photosensor providing the data in generating an image of the scene (e.g., including subjects **105**, **106** and **107**). The sensor data processing circuitry **140** is implemented, for example, with a computer or other processing circuit selectively implemented in a common component (e.g., a chip) or in different components. In one implementation, a portion of the sensor data processing circuitry **140** is implemented in the imaging arrangement **390**, with another portion of implemented in an external computer. Using the detected light (and, e.g., characteristics of the detected light) together with a known direction from which the light arrived at the microlens array (as computed using a known location of each photosensor), the sensor data processing circuitry **140** selectively refocuses and/or corrects light data in forming an image (where refocusing may be correcting). Various approaches to processing detected light data are described in detail below, with and without reference to other figures. These approaches may be selectively implemented with the sensor data processing circuitry **140** consistent with the above.

Different portions of the imaging system **100** are selectively implemented in a common or separate physical arrangement, depending upon the particular application. For example, when implemented with a variety of applications, the microlens array **120** and the photosensor array **130** are combined into a common arrangement **180**. In some applications, the microlens array **120** and the photosensor array **130** are coupled together on a common chip or other circuit arrangement. When implemented with a hand-held device such as a camera-like device, the main lens **110**, microlens array **120** and photosensor array **130** are selectively combined into a common imaging arrangement **190** integrated with the hand-held device. Furthermore, certain applications involve the implementation of some or all of the sensor data processing circuitry **140** in a common circuit arrangement with the photosensor array **130** (e.g., on a common chip).

In some applications, the imaging arrangement **100** includes a preview arrangement **150** for presenting a preview image to a user capturing images. The preview arrangement is communicatively coupled to receive image data from the photosensor array **130**. A preview processor **160** processes the image data to generate a preview image that is displayed on a preview screen **170**. In some applications, the preview processor **160** is implemented together with the image sensor **180**, on a common chip and/or in a common circuit. In applications where the sensor data processing circuitry **140** is implemented with the photosensor array **130** as discussed above, the preview processor **160** is selectively implemented with the sensor data processing circuitry **140**, with some or all of the image data collected by the photosensor array **130** used to generate the preview image.

The preview image may be generated using relatively fewer computational functions and/or less data than that used to generate a final image. For instance, when implemented with a hand-held imaging device such as a camera or cell phone, a preview image that does not effect any focusing or lens correction may be sufficient. In this regard, it may be desirable to implement processing circuitry that is relatively inexpensive and/or small to generate the preview image. In such applications, the preview processor generates the image at a relatively low-computational cost and/or using less data, for example by using the first extended depth of field computational method as described above.

The imaging system **100** is implemented in a variety of manners, depending upon the application. For instance, while the microlens array **120** is shown with several distinguishable microlenses by way of example, the array is generally implemented with a multitude (e.g., thousands or millions) of microlenses. The photosensor array **130** generally includes a relatively finer pitch than the microlens array **120**, with several photosensors for each microlens in the microlens array **120**. In addition, the microlenses in the microlens array **120** and the photosensors in the photosensor array **130** are gener-

ally positioned such that light passing via each microlens to the photosensor array does not overlap light passed via adjacent microlenses.

In various applications, the main lens **110** is translated along its optical axis (as shown in FIG. **1**, in a horizontal direction) to focus on a subject of interest at a desired depth "d" as exemplified between the main lens and an example imaging subject **105**. By way of example, light rays from a single point on the subject **105** are shown for purposes of this discussion. These light rays are brought to a single convergence point at microlens **122** on the focal plane of the microlens array **120**. The microlens **122** separates these rays of light based on direction, creating a focused image of the aperture of the main lens **110** on a set of pixels **132** in the array of pixels underneath the microlens. FIG. **10** illustrates one example approach to separating light rays, such that all rays emanating from a point on a main lens **1010** and arriving anywhere on the surface of the same microlens (e.g., **1022**) are directed by that microlens to converge at the same point on a photosensor (e.g., **1023**). This approach shown in FIG. **10** may, for example, be implemented in connection with FIG. **1** (i.e., with the main lens **1010** implemented for main lens **110**, with microlens array **1020** implemented for microlens array **120**, and with photosensor array **1030** implemented for photosensor array **130**).

The image that forms under a particular microlens in the microlens array **122** dictates the directional resolution of the system for that location on the imaging plane. In some applications, directional resolution is enhanced by facilitating sharp microlens images, with the microlenses focused on the principal plane of the main lens. In certain applications the microlenses are at least two orders of magnitude smaller than the separation between the microlens array and the main lens **110**. In these applications, the main lens **110** is effectively at the microlenses' optical infinity; to focus the microlenses, the photosensor array **130** is located in a plane at the microlenses' focal depth.

The separation "s" between the main lens **110** and the microlens array **120** is selected to achieve a sharp image within the depth of field of the microlenses. In many applications, this separation is accurate to within about $\Delta x_p \cdot (f_m / \Delta x_m)$, where Δx_p is the width of a sensor pixel, f_m is the focal depth of the microlenses and Δx_m is the width of the microlenses. In one particular application, Δx_p is about 9 microns, f_m is about 500 microns and. Δx_m is about 125 microns, with the separation between the microlens array **120** and the photosensor array **130** being accurate to about 36 microns.

The microlens array **120** is implemented using one or more of a variety of microlenses and arrangements thereof. In one example embodiment, a plane of microlenses with potentially spatially varying properties is implemented as the microlens array **120**. For example, the microlens array may include lenses that are homogeneous and/or inhomogeneous, square in extent or non-square in extent, regularly distributed or non-regularly distributed, and in a pattern than is repeating or non-repeating, with portions that are optionally masked. The microlenses themselves may be convex, non-convex, or have an arbitrary profile to effect a desired physical direction of light, and may vary in profile from microlens to microlens on the plane. Various distributions and lens profiles are selectively combined. These various embodiments provide sampling patterns that are higher spatially (correspondingly lower angularly) in some regions of the array, and higher angularly (correspondingly lower spatially) in other regions. One use of such data facilitates interpolation to match desired spatial and angular resolution in the 4D space.

FIG. **24**A illustrates a view (line of sight perpendicular to the plane) of a portion of a microlens array, according to another example embodiment of the present invention. The microlenses are square-shaped and regularly distributed in an array.

FIG. **24**B illustrates a view of a portion of a microlens array, according to another example embodiment of the present invention. The microlens plane distribution is not regular or repeating, and the microlenses are arbitrarily shaped.

FIG. **24**C illustrates images that appear on the photosensor in connection with another example embodiment of the present invention, using a distribution such as that shown in FIG. **24**A with a convex profile and a main lens having a circular aperture.

In other example embodiments, a regular mosaic of larger and smaller microlenses is used. In one implementation, the resulting photosensor data is interpolated to provide a homogeneous sampling that has the maximum spatial and angular resolutions of a microlens or microlenses in the mosaic.

FIGS. **19**A-**19**F illustrate approaches to implementing a mosaic array such as that described above, in connection with one or more example embodiments of the present invention. FIG. **19**A is an overhead view of a plane showing example relative sizes and arrangement of the microlenses. FIG. **19**B is an illustration of the shape of the images that form on the photosensor array after projection through each microlens in FIG. **19**A. FIG. **19**C is a cross-sectional view of the array in FIG. **19**A, illustrating that the microlenses have the same f-number and their focal points share a common plane. This requires that the smaller microlenses are positioned closer to the focal plane than the larger ones. This causes the images of the main lens that appear underneath each microlens to be large without overlapping, and all appear in-focus on a photosensor that is placed at the plane containing the focal points.

FIG. **19**D shows a cross-sectional view of the microlenses shown in FIGS. **19**A and **19**C implemented in a full imaging arrangement containing a main lens **1910**, a mosaic microlens array **1920** and photosensor arrangement **1930**, according to another example embodiment of the present invention. Note that although the diagram has been shown with several microlenses and several pixels per microlens, the actual number of microlenses and pixels is selected using a variety of approaches, such as by determining the resolution requirements of the given application and implementing appropriate numbers of each.

FIG. **19**E is a Cartesian ray diagram representing the space of rays starting at u on the main lens **1910** and terminating at s on the microlens array **1920** (the space of rays is shown in 2D for clarity, although the full space of rays is 4D). The set of rays that are summed by each photosensor (labeled A-P) in FIG. **19**C is shown on the Cartesian ray diagram in FIG. **19**D. In the full 4D space of rays, each photosensor integrates a 4D box of rays. The 4D boxes for photosensors under the larger microlenses have half the width (twice the resolution) in the (u, v) directional axes, and twice the width (half the resolution) in the (x, y) spatial axes compared to photosensors under the smaller microlenses.

In another example embodiment, photosensor values are interpolated to a regular grid so that the resolution in all axes matches the maximum resolution in all axes. FIG. **19**F illustrates such an approach, wherein the boxes of rays that represent each photosensor value are split by interpolating nearby box values. In the 2D ray space illustrated, each box is split into two, but in the 4D space, each box is split into four (split into two along each of its two longer sides). In some embodiments, the interpolated values are computed by ana-

lyzing the nearby values. In another embodiment, the interpolation is implemented as a weighted sum of the values of the original, unsplit boxes in a neighborhood of the desired value.

In some applications, the weighting is implemented in a manner that depends on a decision function based on the values in a neighborhood. For example, the weighting may interpolate along the axes that are least likely to contain an edge in the 4D function space. The likelihood of an edge near that value can be estimated from the magnitude of the gradient of the function values at those locations, as well as the components of the Laplacian of the function.

In another example embodiment, each of the microlenses (e.g., in the array **1920** of FIG. **19**D or similar) is tilted inwards so that their optical axes are all centered on the main lens aperture. This approach reduces aberrations in the images that form under microlenses towards the edges of the array.

Referring again to FIG. **1**, the aperture sizes of the main lens **110** and of the microlenses in the microlens array **120** (e.g., the effective sizes of the opening in the lenses) are also selected to meet specific applications in which the imaging arrangement **100** is implemented. In many applications, the relative aperture sizes are selected so that collected images are as large as possible without overlapping (i.e., such that light does not undesirably overlap onto an adjacent photosensor). This approach is facilitated by matching the f-numbers (focal ratios; i.e., the ratio of the aperture to the effective focal length of the lens) of the main lens and the microlenses. In this instance, the effective focal length, in terms of the f-number, for the main lens **110** is the ratio of the diameter of the aperture of the main lens to the distance "s" between the main lens **110** and the microlens array **120**. In applications in which the principal plane of the main lens **110** is translated relative to the plane at which the microlens array **120** is located, the aperture of the main lens is selectively modified so as to maintain the ratio and thus the size of the images forming under each microlens in the microlens array. In some applications, different main lens aperture shapes such as a square aperture are used to achieve desirable (e.g., efficient) packing of the array of images under the microlens array on the photosensor surface.

The following discussion refers to a general application of the imaging arrangement **100** of FIG. **1**, in connection with one or more example embodiments of the present invention. Considering a two-plane light field "L" inside the imaging arrangement **100**, L(u,v,s,t) denotes the light traveling along a light ray that intersects the main lens **110** at (u, v) and that intersects the plane of the microlens array **120** at (s,t). Assuming ideal microlenses in the microlens array **120** and ideal photosensors (e.g., pixels) on aligned grids in the photosensor array **130**, all the light that passes to a photosensor also passes through its square parent microlens in the microlens array **120**, and through the photosensor's conjugate square on the main lens **110**. These two square regions on the main lens **110** and microlens specify a small four-dimensional box in the light field, and the photosensor measures the total amount of light in the set of rays represented by this box. Correspondingly, each photosensor detects such a four-dimensional box in the light field; the light field detected by the photosensor array **130** thus is a box-filtered, rectilinear sampling of L(u, v,s,t).

FIG. **11** illustrates an approach to the mapping of sensor pixel locations to rays in the L(u,v,s,t) space with respect to data collected, according to another example embodiment of the invention. The approach shown in FIG. **11** and discussed herein may be applicable, for example, to FIG. **1** with each photosensor in the photosensor array **130** corresponding to a sensor pixel. Image **1170** in the bottom right is a downsampling of raw data read from a ray sensor (photosensor) **1130**, with the circular image **1150** that forms under one microlens circled. Image **1180** in the bottom left is a close-up representation of a portion of the raw data around the circled microlens image **1150**, with one photosensor value **1140** circled within the microlens image. Since this circular image **1150** is an image of the lens aperture, the location of the selected pixel within the disk provides the (u, v) coordinates of the starting position of the illustrated ray **110** on the main lens. The location of the microlens image **1150** within the sensor image **1170** provides the (x, y) coordinates of the ray **1120**.

Although the mapping of sensor elements to rays is discussed with respect to the figures (and other example embodiments), values associated with the various sensor elements are selectively represented by the value of the set of rays that is directed through optics to each particular sensor element. In the context of FIG. **1**, each photosensor in the photosensor array can thus be implemented to provide a value that represents a set of light rays directed via the main lens **110** and microlens array **120** to the photosensor. That is, each photosensor generates an output in response to the light incident upon the photosensor, and the position of each photosensor, relative to the microlens array **120**, is used to provide directional information about the incident light.

In one example embodiment, the resolution of the microlens array **120** is selected to match a particular application's desired resolution for final images. The resolution of the photosensor array **130** is selected so that each microlens covers as many photosensors as required to match the desired directional resolution of the application, or the finest resolution of photosensors that may be implemented. In this regard, the resolution of the imaging system **100** (and other systems discussed herein) is selectively tailored to particular applications, with considerations such as the type of imaging, cost, complexity and available equipment used to arrive at a particular resolution.

Once image data is captured via optics and sensors (e.g., using imaging arrangement **190** in FIG. **1**), a variety of computational functions and arrangements are implemented to selectively process the image data. In one example embodiment of the present invention, different sets of photosensors capture these separated light rays from each microlens and pass information about the captured light rays to a computational component such as a processor. Images of the scene are computed from the set of measured light rays.

In the context of FIG. **1**, sensor data processing circuitry **140** is implemented to process the image data and compute images of the scene including subjects **105**, **106** and **107**. In some applications, a preview arrangement **150** is also implemented to generate a preview image using a preview processor **160**, with the preview image displayed on a preview screen **170**. The previous processor **160** is selectively implemented with the sensor data processing circuitry **140**, with a preview image generated in a manner not inconsistent, for example, with approaches discussed below.

In another embodiment, for each pixel in an image output from a sensor arrangement, the computational component weights and sums a subset of the measured rays of light. In addition, the computational component may analyze and combine a set of images computed in the manner described above, for example, using an image compositing approach. Although the present invention is not necessarily limited to such applications, various aspects of the invention may be appreciated through the discussion of several specific example embodiments of such a computational component.

In connection with various example embodiments, image data processing involves refocusing at least a portion of an image being captured. In some embodiments, an output image is generated in the context of a photograph focused on desired elements of a particular scene. In some embodiments, the computed photograph is focused at a particular desired depth in the world (scene), with misfocus blur increasing away from the desired depth as in a conventional photograph. Different focal depths are selected to focus upon different subjects in the scene.

FIG. **12** illustrates several images **1200**-**1240** refocused at different depths, computed from a single light field measured in accordance with another example embodiment of the present invention. The approach shown in FIG. **12** may, for example, be implemented using an imaging arrangement such as that shown in FIG. **1**.

FIGS. **13**A and **13**B show a refocusing approach, according to another example embodiment of the present invention. This approach may be implemented, for example, with a computational/processor component of an imaging system, such as the sensor data processing circuitry **140** in FIG. **1**. Each output pixel (e.g., **1301**) from an imaging arrangement corresponds to a three-dimensional (3D) point (e.g., **1302**) on a virtual film plane **1310**. This virtual film plane **1310** is located behind a main lens **1330**, where the plane **1310** is optically conjugate to the desired focal plane in the world (not shown). That is, the virtual film plane **1310** is located at a position at which a film plane would desirably be located to capture a simple two-dimensional (2D) image (e.g., the position is comparable to the position at which a photographic film would be located with a conventional camera in order to capture a 2D image). By separating light by direction (e.g., using the microlens array **120** of FIG. **1**), the light arriving at the virtual film plane **1310** can be selectively computed. In this regard, the value for the output pixel **1301** is computed by summing the cone of light rays **1320** that converge on the corresponding 3D point **1302**. Values for these rays are gleaned from the data collected by the ray sensor **1350**. FIG. **13**A shows an imaging configuration in 2D for visual simplicity. In FIG. **13**B, a cone of rays **1330** from the 3D point **1340** is summed for the same pixel **1301**, with the chosen world focal depth if closer to the main lens.

In some embodiments, the required light ray values do not correspond exactly to the discrete sample locations captured by the ray sensor. In some embodiments, the light ray value is estimated as a weighted sum of selected close sample locations. In some implementations, this weighting approach corresponds to a four-dimensional filter kernel that reconstructs a continuous four-dimensional light field from the discrete sensor samples. In some implementations, this four-dimensional filter is implemented with a four-dimensional tent function corresponding to quadrilinear interpolation of the 16 nearest samples in the four dimensional space.

FIG. **35** is a process flow diagram for computing a refocused image from received light ray sensor data, according to another example embodiment of the present invention. At block **3520** a set of sub-aperture images is extracted from light ray sensor data **3510**, where each sub-aperture image consists of a single pixel under each microlens image where the pixels are at the same relative position under its microlens. At block **3530**, the set of sub-aperture images is combined to produce the final output image. The sub-aperture images are optionally translated relative to one another and composited to bring a desired plane into focus.

In another example embodiment, darkening associated with pixels near a border of an output image is mitigated. For instance, with the pixels near the border of an output image, some required rays may not have been captured in the measured light field (they may exceed the spatial or directional bounds of the imaging arrangement, such as the microlens array **120** and photosensor array **130** in FIG. **1**). For applications in which this darkening is undesirable, the pixel values are normalized by dividing a value associated with the pixels (e.g., as captured by a photosensor array) by the fraction of rays that are actually found in the measured light field.

As discussed above, a variety of different computational approaches are chosen for different applications. The following discussion addresses various such approaches. In some applications, reference is made to figures, and in other applications, the approaches are discussed generally. In each of these applications, the particular approaches may be implemented using a computational-type component, such as the sensor data processing circuitry **140** shown in FIG. **1**.

In another example embodiment, an imaging methodology for each output pixel for a particular imaging system corresponds to a virtual camera model in which a virtual film is rotated or deformed, arbitrarily and/or selectively, and a virtual main lens aperture is correspondingly moved and modified in size as appropriate. By way of example, FIG. **25** illustrates an example embodiment in which a virtual image is computed as it would have appeared on virtual film **2560** if it had been present behind a virtual lens aperture **2520** of arbitrary size on a virtual lens plane **2530** that is permitted to be non-coincident with the physical main lens plane **2510**. The value of the pixel corresponding to point **2550** on the virtual film **2560** is computed by summing the rays passing through the virtual aperture **2520** and converging on point **2550**, which are found by their intersection point and incident direction on ray sensor **2570**.

FIG. **26** shows an approach to manipulating a virtual lens plane, according to another example embodiment of the present invention. A virtual lens plane **2630** and/or virtual film plant **2660** selectively tilted, relative to a physical main lens or other reference. An image computed using this approach has a resulting world focal plane that is not parallel to the imaging plane.

In another example embodiment, as exemplified in FIG. **27**, the virtual film **2560** need not be planar, but may take any shape.

A variety of approaches involve selective implementation of different apertures. In one example embodiment, the virtual aperture on the virtual lens plane is a generally circular hole, and in other example embodiments, the virtual aperture is generally non-circular and/or is implemented with multiple distinct regions of any shape. In these and other embodiments, the notion of "virtual aperture" can be generalized, and in some applications, corresponds to an approach involving the processing of light data to correspond to light that would be received via a selected "virtual" aperture.

In various embodiments, a virtual aperture approach is implemented with a pre-determined but arbitrary function on a virtual lens plane. FIGS. **31**A-**31**D illustrate various scalar functions that are selectively implemented as the virtual aperture function in connection with one or more example embodiments. The various functions include, for example, smoothly varying values (as exemplified in FIG. **31**B), implementing a plurality of distinct regions (as exemplified in FIG. **31**A), and taking on negative values (as exemplified in FIG. **31**D). To compute the value of a point on a virtual film, all rays that start at different points on the virtual lens and converge on the point on the virtual film are weighted by the virtual aperture function and summed. In various other embodiments, the final value is computed with an arbitrary computational function that depends on the ray values. For example, the compu-

tational function may not correspond to a weighting by a virtual aperture function, but may contain discontinuous program branches depending on the value of test functions computed on the ray values.

In other example embodiments, as may be implemented in combination with the other example embodiments described herein, a method of computing output pixels is chosen independently. For example, in one example embodiment, parameters including the orientation of a virtual lens plane and the size of the virtual aperture are varied continuously for each output pixel. In another example, as illustrated in FIG. **32**, the virtual aperture function used to integrate rays for each output pixel is varied from pixel to pixel. In an output image **3200**, pixel **3201** uses virtual aperture function **3210** and pixel **3251** uses virtual aperture function **3250**.

In another example embodiment, a virtual aperture function varies from pixel to pixel. In one specific embodiment, the function is chosen to mask out rays from undesired portions of a particular scene, such as an undesired object in the foreground.

In another example embodiment, a human user chooses virtual aperture parameters interactively, with light data processed in accordance with the selections. FIG. **33** is a process flow diagram showing one such example embodiment. In the first block **3310**, the process receives data from a light ray sensor. In block **3320**, a user selects a region of an output image; in block **3330** a user selects an image formation method; and in block **3340**, the user alters parameters for the selected method and visually examines a computed image of the scene at block **3350** (for example on a computer monitor). Block **3360** checks if the user is done editing the image portion, and if not returns to block **3330**. Block **3370** checks whether the user is done choosing portions of the image to edit, and if not returns to block **3320**. If editing is complete, block **3380** saves the final edited image.

In another example embodiment, an image with extended depth of field is computed by focusing on more than one subject at the same time. In one implementation, the depth of field of the output image is extended by simulating conventional photographic imaging with a stopped-down (reduced size) main lens aperture. For each output pixel, an evaluation is performed using the rays of light that would have converged at the output pixel through an aperture (on the virtual lens plane) that is smaller than the aperture used in ray sensing.

In one implementation involving the example system **100** shown in FIG. **1**, the depth of field is extended by extracting a photosensor value under each microlens image, where each photosensor is located at the same relative position within each microlens image. With respect to FIG. **1**, extending the depth of field produces an image in which not only the subject **105** is in focus (due to the correlation between the distances "d" and "s") but also objects at a different depth, such as subjects **106** and **107**, which may otherwise be blurry due to misfocus. This approach to extending the depth of field, coupled with optional downsampling of the resulting image, is computationally efficient. This approach is selectively implemented in applications where noise generated with the image is tolerable, such as where the image generated is for preview purposes (e.g., for display at the preview screen **170** in FIG. **1**). FIG. **4**, discussed below, is further directed to approaches to the generation of a preview image.

FIGS. **14**A and **14**B illustrate an approach to computing images with different depths of field, in connection with one or more example embodiments. FIG. **14**A shows an image and close-up computed with refocusing. Note that the face in the close-up is blurry due to shallow depth of field. The middle row of FIG. **14**B shows the final image computed with an extended depth of field approach such as that described in the previous paragraph.

FIG. **8** is a process flow diagram for another computational approach to extending the depth of field in an image, according to another example embodiment of the present invention. At block **810**, a set of images refocused at all focal depths in a particular scene is refocused. At block **820** and for each pixel, a pixel is determined from a set of images that has the highest local contrast. At block **830**, the pixels having the highest local contrast are assembled into a final virtual image. With this approach, a desirable signal-to-noise ratio (SNR) can be obtained, using a relatively high number of pixels (e.g., relative to selecting a single pixel (photosensor) for each microlens in a microlens array). Referring to FIG. **14**C, the example image shown is produced using an approach similar to that described in connection with FIG. **8** and exhibits relatively low image noise.

In one alternative embodiment, a minimum set of refocused images to compute is defined as follows, in terms of the distance between a virtual film plane for each refocused image and the principal plane of the main lens via which the light for the image is passed to the virtual film plane. A minimum distance is set at the focal length of the main lens, and the maximum distance set at the conjugate depth for the closest object in the scene. The separation between each virtual film plane is no more than $\Delta x_m f/A$, where Δx_m is the width of a microlens, f is the separation between the main lens and the microlens array, and A is the width of the lens aperture.

In another example embodiment, refocused images are combined to produce an extended depth of field image at each final pixel to retain the pixel that is best focused in any of the set of refocused images. In another embodiment pixels to retain are chosen by enhancing the local contrast and coherence with neighboring pixels. For general information regarding imaging, and for specific information regarding approaches to imaging involving enhancing local contrast, reference may be made to Agarwala, A., Dontcheva, M., Agrawala, M., Drucker, S., Colburn, A., Curless, B., Salesin, D., Cohen, M., Interactive Digital Photomontage, in ACM Transactions on Graphics, 23, 3 (2004), 292-300, which is fully incorporated herein by reference.

In another example embodiment of the present invention, an extended depth of field image is computed as follows. For each output image pixel, a refocusing computation is performed at the pixel to focus at different depths. At each depth, a measure of the homogeneity of the rays that converge is computed. The depth that produces the (relative) maximum homogeneity is chosen and kept for that pixel value. With this approach, where an image pixel is in focus, all of its rays originate from the same point in the scene and thus are likely to have similar color and intensity.

Although the measure of homogeneity can be defined in various ways, for many applications, the following measure of homogeneity is used: for each color component of each ray, the squared difference of that color intensity is computed from the corresponding color component of the central ray (the ray that arrives at the pixel at an angle closest to the optical axis of the main lens). All of these squared differences are summed, and the homogeneity is taken to be the reciprocal of the sum.

FIG. **34** is a process flow diagram for extending the depth of field in an image, according to another example embodiment of the present invention. At block **3410**, a pixel is selected in a virtual image to be computed. At block **3420**, the pixel is refocused at a plurality of focal depths, and the homo-

geneity of the rays that are combined to refocus at each depth is computed. At block **3430**, the refocused pixel value associated with the highest homogeneity of rays that are combined is retained as the final output image pixel value. The process continues at block **3440** until all pixels are processed.

In another example embodiment, the above process is adapted so that the selection of final pixel values takes into account the neighboring pixel values, and the homogeneity of the associated rays that are combined to compute those pixel values.

In other example embodiments of the present invention, the depth of field is extended by focusing each pixel on the depth of the closest object in that direction. FIG. **9** is a process flow diagram for extending the depth of field in an image, according to one such example embodiment. At block **910**, a pixel is selected in a final virtual image to be computed. At block **920**, the depth of a nearest object is estimated for a light ray (or set of light rays) traced from the selected pixel into a scene through the center of the lens.

At block **930**, the selected pixel's value is computed in an image refocused at the estimated depth. If additional pixels are desirably processed at block **940**, another pixel is selected at block **910** and the process continues at block **920** for the newly-selected pixel. When no additional pixels are desirably processed at block **940**, the computed values for each selected pixel are used to create the final virtual image.

In some embodiments involving the extension of the depth of field, a value at each output pixel is computed by disregarding light rays that originate at depths closer than the depth of a desired object to mitigate or eliminate artifacts such as those generally referred to as "blooming" or "halo" artifacts around the borders of objects closer to the lens. By way of example, FIG. **23** illustrates the set of rays that pass through a desired focal point **2301** in the world on a subject of interest **2310**. Some of these rays are occluded from the main lens by object **2320**, and these correspond to the light rays **2340** that are detected by ray sensor **2350** but disregarded in computing an image value for point **2301**. In some embodiments, rays to be disregarded are detected by a mismatch with the color of the central ray. In some embodiments the resulting pixel value is normalized by dividing by the fraction of rays that are not disregarded. These embodiments may be used in isolation or combination with each other and any other embodiments, including those directed to extending the depth of field.

As discussed above, light data is processed in accordance with various example embodiments to focus and/or correct images. A variety of approaches to the latter correction approach are discussed as follows. In some of these embodiments, aberrations are corrected by tracing rays through the actual optical elements of the optics (e.g., lens or lenses) used in capturing the rays, and mapping the traced rays to particular photosensors capturing the light. Light data is rearranged, using knownd defects exhibited by the optics as well as the known position of the sensors detecting the light.

In one correction-type embodiment, the world of rays that contribute to each pixel as formed through idealized optics is computed for each pixel on a film of a synthesized photograph. In one implementation, these rays are computed by tracing rays from the virtual film location back through the ideal optics into the world. FIG. **15** illustrates an approach to the tracing of rays from a 3D point **1501** on a virtual film plane **1510** through an ideal thin main lens **1520** out into a cone of world rays **1530**, in connection with one such example embodiment. In some implementations, the set of desired rays **1525** may not necessarily correspond to direction through a real lens, but may correspond to any set of rays that are to be weighted and summed to produce a desired image value.

FIG. **16** shows an approach to finding the value of light traveling along ideal rays for a particular application, in connection with another example embodiment. These values are computed by tracing desired ideal world rays **1630** through a real main lens **1650**, having a single element with spherical interfaces, used to physically direct the real world light rays to the ray sensor **1640** at the time the rays are measured (detected). In this embodiment, the rays that ideally converge to a single 3D point (**1601**) do not converge, representing a defect of lenses with spherical interfaces called spherical aberration. The ray sensor **1640** provides individual values for each of the aberrated rays (such as **1651**), which are used to correct for the spherical aberration.

FIGS. **17A-17C** illustrate example results using a computer simulation with an approach to lens correction. The image in FIG. **17A** is an ideal 512×512 photograph (as seen through perfect optics). The image in FIG. **17B** is an image that would be produced with a real f/2 bi-convex spherical lens, which has loss in contrast and blurring. The image in FIG. **17C** is a photograph computed using an approach to image correction described above, using an optics and sensor arrangement facilitating 10×10 directional (u, v) resolution at each of 512×512 microlenses.

In another example embodiment of the present invention, chromatic aberrations are corrected in a main lens used to capture an image. Chromatic aberration is caused by the divergence of rays of light as they are physically directed through optics because of differences in the physical direction dependent on the wavelength of light. The incoming rays are traced through the actual optics, taking into account the wavelength-dependent refraction of light that occurs in the actual optics. In some applications, each color component of the system is traced separately based on the primary wavelength.

In another example embodiment, each of the red, green and blue components common in color imaging systems is traced separately, as illustrated in FIG. **18A**. The green world light rays are computationally traced back into the imaging system to produce green rays **1830**, and to determine where they intersect a color ray sensor **1810** and at what direction they intersect the color ray sensor **1810**. Similarly, FIG. **18B** illustrates computationally tracing the desired blue world light rays **1820**, which are refracted to a greater extent than the green light rays. FIG. **18C** illustrates computationally tracing the desired red world light rays **1830**, which are refracted to a lesser extent than the green light rays. The values for each ray are computed from the values from the ray sensor **1810** using, for example, approaches discussed in connection with other example embodiments described herein. The light field values for each ray are integrated to calculate the corrected image value for each particular film pixel. For some applications, chromatic aberration is ameliorated by refocusing each color channel on the plane at which its wavelengths best come into focus.

The desired light rays may not converge exactly on one of the discrete ray values sampled by the ray sensor. In some embodiments, the value to be used for such rays is computed as a function of the discrete ray values. In some embodiments, this function corresponds to a weighted sum of the value of discrete rays in a neighborhood of the desired light ray. In some implementations, this weighted sum corresponds to a 4D convolution of the discrete sample values with a predetermined convolution kernel function. In other implementations, the weighting may correspond to a quadrilinear interpolation from the 16 nearest neighbors. In still other

implementations, the weighting may correspond to a cubic or bicubic interpolation from the 16 nearest neighbors.

It is worth noting that example correction processes have been described in terms of ray-tracing for conceptual simplicity; a variety of other approaches are implemented with correction. In one embodiment, for each desired output pixel, the set of photosensor values that contribute are pre-computed along with their relative weights. As described above, these weights are a property of a number of factors that may include the optics, sensor, desired set of rays to be weighted and summed for each output pixel and desired light field reconstruction filter. These weights are pre-computed, selectively using ray-tracing, and stored. A corrected image is formed by weighting and adding the appropriate sensed light field values for each output pixel.

FIG. **29** and FIG. **30** illustrate other example embodiments for use in connection with the above correction approach. FIG. **29** is a process flow diagram for pre-computing a database of weights associated with ray (light) sensors and an output pixel value associated with each ray sensor. In the first two blocks **2910** and **2920**, a data set (e.g., in a database) is received for a desired image formation process consisting (for each output image pixel) of a set of ideal world light rays to be summed to produce an output image pixel value, and a specification for real main lens optics used to physically direct light rays to a light ray sensor. At block **2925**, an image pixel is chosen. For the output value of this pixel, the associated set of world rays is computationally traced at block **2930** through a virtual representation of the main lens optics to the ray sensor. This results in a set of weights to be applied to each ray sensor value to compute the output pixel value. These values are stored in an output database in block **2940**. Block **2950** checks whether all pixels have been processed, returning to block **2925** if not. If all pixels have been processed, the final block **2960** saves the completed database.

FIG. **30** is a flow diagram for a process that computes an output image using a database of weights that may have been computed by a process as in FIG. **29**. In block **3010** and **3020**, the process receives the database and a set of ray sensor values captured with the main lens optics used in computing the database. At block **3025**, a pixel in the output image is selected, so that its final image value may be computed. For the selected pixel, block **3030** uses the database to find the set of ray sensor that contributes and their weights. In block **3040**, each sensor value given in **3020** is weighted and added to a sum for that image pixel value. At block **3050**, a check is performed to see whether all image pixels have been processed. If not, the process returns to block **3025**, and if so, the output image is saved at block **3060**.

In a variety of example embodiments, light data is processed in the frequency domain, with certain approaches directed to computational approaches to refocusing that operate in the Fourier domain. FIG. **20** is a flow diagram illustrating one such approach, in connection with another example embodiment. The input to the algorithm is a discrete 4D light field **2010**, which we will refer to as L(s,t,u,v), representing the ray starting at (u, v) on a main lens and terminating at (s, t) on a microlens plane (e.g., from the main lens **110** and terminating at a plane of the microlens array **120** of FIG. **1**). The first step is to compute the discrete 4D Fourier transform **2020** of the light field. The 4D Fourier transform value at (k_s, k_t, k_u, k_v), let us call this value M(k_s, k_t, k_u, k_v) is defined by the following equation:

$$M(k_s,k_t,k_u,k_v)=\iiint L(s,t,u,v)\exp(-2\pi\sqrt{-1}\cdot(sk_s+tk_t+uk_u+vk_v))\,ds\,dt\,du\,dv; \quad (1)$$

where the exp function is the exponential function, $\exp(x)=e^x$. In some embodiments the discrete light field is sampled on a rectilinear grid in the 4D space, and the Fourier transform is computed with the Fast Fourier Transform (FFT) algorithm.

The next step, which is executed once for each depth at which we wish to refocus the image, is to extract appropriate 2D slices **2030** of the 4D Fourier transform, and compute the inverse 2D Fourier transforms of the extracted slices, which are photographs focused at different depths **2040**. The inverse 2D Fourier transform, g(x, y), for a function G(k_x, k_y) is defined by the following equation:

$$g(x,y)=\iint G(k_x,k_y)\exp(2\pi\sqrt{-1}\cdot(xk_x+yk_y))\,dk_x\,dk_y. \quad (2)$$

The values on the extracted 2D slice are determined by the depth at which we want to refocus. Considering the conjugate plane (on the image-side of the lens) for the desired world focal plane, when the separation between this conjugate plane and the main lens is D and the separation between the microlens plane and the main lens is F, then the value of the extracted 2D slice at coordinates (k_x,k_y) is given by

$$G(k_x,k_y)=1/F^2\cdot M(k_x(1-D/F),k_y(1-D/F),k_xD/F,k_yD/F). \quad (3)$$

Using various approaches, artifacts that result from discretization, resampling and Fourier transformation are selectively ameliorated. In general signal-processing terms, when we sample a signal it is replicated periodically in the dual domain. When we reconstruct this sampled signal with convolution, it is multiplied in the dual domain by the Fourier transform of the convolution filter. In this regard, the original, central replica is isolated, eliminating all other replicas. A desirable filter is a 4D sinc function, sinc(s)sinc(t)sinc(u)sinc(v), where $\mathrm{sinc}(x)=\sin(\pi x)/(\pi x)$; however, this function has infinite extent.

In various approaches, finite-extent filters are used with frequency-domain processing; such filters may exhibit defects, which are selectively mitigated. FIG. **21**A illustrate these defects with respect to a specific 1D filter, with corresponding discussion below directed to mitigation or such defects. FIG. **21**A represents a triangle filter approach implemented with in linear interpolation in 1D (or as the basis for a 4D quadrilinear filter). FIG. **21**B shows the Fourier transform of the triangle filter approach, which is not of unit value within the band-limit (see **2010**), and which gradually decays to smaller fractional values as the frequency increases. In addition, the filter is not truly band-limited, containing energy at frequencies outside the desired stop-band (**2020**).

The first defect described above leads to "rolloff artifacts," which can lead to a darkening of the borders of computed photographs. Decay in the filter's frequency spectrum with increasing frequency means that the spatial light field values, which are modulated by this spectrum, also "roll off" to fractional values towards the edges.

The second defect described above involves aliasing artifacts in computed photographs, which are related to energy at frequencies above the band-limit. The non-zero energy that extends beyond the band-limit means that the periodic replicas are not fully eliminated, leading to two kinds of aliasing. First, the replicas that appear parallel to the slicing plane appear as 2D replicas of the image encroaching on the borders of the final photograph. Second, the replicas positioned perpendicular to this plane are projected and summed onto the image plane, creating ghosting and loss of contrast.

In an example embodiment, correction for rolloff-type defects as described above is eliminated by multiplying the input light field by the reciprocal of the filter's inverse Fourier spectrum, to nullify the effect introduced during resampling. In this example embodiment, multiplication is performed

prior to taking the 4D Fourier transform in the pre-processing step of the algorithm. While it corrects rolloff error, pre-multiplication may accentuate the energy of the light field near its borders, maximizing the energy that folds back into the desired field of view as aliasing.

Three methods of suppressing aliasing artifacts—oversampling, superior filtering and zero-padding—are used individually or in combination in various example embodiments described below. Oversampling within the extracted 2D slice increases the replication period in the spatial domain. This means that less energy in the tails of the in-plane replicas will fall within the borders of the final photograph. Increasing the sampling rate in one domain leads to an increase in the field of view in the other domain. Aliasing energy from neighboring replicas falls into these outer regions, which is cropped away to isolate the original, central image of interest.

Another approach to mitigating aliasing is directed to a finite-extent filter that approximates a perfect spectrum (as would be exhibited via use of an ideal filter) as closely as possible. In an example embodiment, a 4D Kaiser-Bessel separable function, kb4(s,t,u,v)=kb(s)kb(t)kb(u)kb(v), is used as the filter, where

$$kb(x)=1/W\cdot I_0(P\sqrt{1-(2x/W)^2}) \quad (4)$$

In this equation, I_0 is the standard zero-order modified Kaiser-Bessel function of the first kind, W is the width of the desired filter, and P is a parameter that depends on W. In this example embodiment, W values are 5, 4.5, 4.0, 3.5, 3.0, 2.5, 2.0 and 1.5, and the P values are, respectively, 7.4302, 6.6291, 5.7567, 4.9107, 4.2054, 3.3800, 2.3934, and 1.9980. For general information regarding aliasing, and for specific information regarding approaches to mitigating aliasing in connection with one or more example embodiments of the present invention, reference may be made to Jackson J. I., Meyer C. H., Nishimura, D. G. and Macovski, A., 1997, Selection of convolution function for Fourier inversion using gridding. IEEE Transactions on Medical Imaging, 10, 3, 473-478, which is fully incorporated herein by reference. In one implementation, widths "W" of less than about 2.5 are implemented to achieve desirable image quality.

In another example embodiment, aliasing is mitigated by padding a light field with a small border of zero values before pre-multiplication and taking its Fourier transform. This pushes energy slightly further from the borders, and minimizes the amplification of aliasing energy by the pre-multiplication for rolloff correction.

FIG. **22** is a flow diagram showing an approach to refocusing in the frequency domain using various corrections described above, according to another example embodiment of the present invention. At block **2210**, a discrete 4D light field is received. In the pre-processing phase, which occurs once per input light field, block **2215** checks if aliasing reduction is desired, and if so executes block **2220**, which pads the light field with a small border (e.g., 5% of the width in that dimension) of zero values. At block **2225** a check is performed to determine whether rolloff correction is desired, and if so, the light field is modulated at block **2230** by the reciprocal of the Fourier transform of the resampling filter. In the final block of the pre-processing phase, the 4D Fourier transform of the light field is computed at block **2240**.

In the refocusing phase, which occurs once per desired focal depth, the process receives a desired focal depth of refocused image at block **2250**, such as through the direction of a user. At block **2260**, a check is performed to determine whether aliasing reduction is desired. If not, block **2270** extracts a 2D slice of the Fourier transform of the light field, with a desired 4D rsampling filter, where the trajectory of the 2D slice corresponds to the desired focal depth; and block **2275** computes an inverse 2D Fourier transform of the extracted slice and moves to block **2290**. If aliasing reduction was desired at block **2260**, the process moves to block **2280**, at which a 2D slice with desired 4D resampling filter and oversampling (e.g. 2× oversampling in each of the two dimensions) is extracted. At block **2283**, the slice's inverse 2D Fourier transform is computed, and the resulting image is cropped to the original size without oversampling at block **2286**, after which the process moves to block **2290**. At block **2290**, a check is performed to determine whether refocusing is complete. If not, another focal depth is chosen at block **2250** and the process proceeds as described above. If refocusing is complete, the process exits at block **2295**.

The asymptotic computational complexity of this frequency-domain algorithm is less than refocusing by explicitly summing rays as described for the alternate embodiment above. Assume that the input discrete light field has N samples in each of its four dimensions. Then the computational complexity of the algorithm that explicitly sums rays is O (N^8) for refocusing at each new depth. The computational complexity of the frequency-domain algorithm is O (N^4 log N) for refocusing at each new depth, dominated by the cost of the inverse 2D Fourier transform. However, the pre-processing step costs O (N^4 log N) for each new light field dataset.

In another example embodiment, the captured light rays are optically filtered. Although not limited to such applications, some examples of such filters are neutral density filters, color filters, polarizing filters. Any filter currently existing or that may be developed in the future may be used to effect a desired filtering of the rays of light. In one implementation, the light rays are optically filtered in groups or individually, so that each group or individual ray is filtered differently. In another implementation, a filtering is applied by the use of a spatially-varying filter attached to a main lens. In one example application, a gradient filter such as a neutral-density gradient filter is used to filter light. In another implementation, spatially varying filters are used in front of one or more of a ray sensor, a microlens array or a photosensor array. Referring to FIG. **1** by way of example, one or more such filters are selectively placed in front of one or more of the main lens **110**, microlens array **120** and photosensor array **130**.

In another example embodiment of the present invention, a computational component such as a processor is programmed to selectively choose rays to combine in computing output pixels in order to effect a desired net filtering for that pixel value. By way of example, consider embodiments involving an optical neutral gradient density filter at the main lens, each image of the lens aperture that appears under a microlens is weighted by the filter gradient across its extent. In one implementation, output images are computed by selecting a photosensor under each microlens at the point of the gradient that matches the desired level of neutral-density filtering for that output image pixel. For example, to produce an image in which every pixel is filtered to a large extent, every pixel value is set to the value of the photosensor under the corresponding microlens that is at the extreme end of the gradient corresponding to maximum filtering.

FIG. **2** is a data-flow diagram showing an approach to processing images in connection with other example embodiments of the present invention. An image sensor arrangement **210** collects image data using microlens/photosensor chip arrangement **212** in a manner similar, for example, to the microlens array **120** and photosensor array **130** shown in FIG. **1** and described above. The image sensor arrangement **210**

optionally includes an integrated processing circuit **214** bearing certain processing circuitry to prepare collected image data for transfer.

Sensor data created at the image sensor arrangement **210** is passed to a signal processor **220**. The signal processor includes a low-resolution image processor **222** and one or both of a compression processor **224** and a (light) ray-direction processor **226**; each of these processors is selectively implemented separately or functionally with a common processor, depending upon the application. Furthermore, each of the processors shown in FIG. **2** is selectively programmed with one or more processing functions described in connection with other figures or elsewhere herein. The signal processor **220** is optionally implemented in a common device or component with the image sensor arrangement **210**, such as on a common circuit and/or in a common image device.

The low-resolution image processor **222** uses sensor data received from the image sensor arrangement **210** to generate low-resolution image data, which is sent to a viewfinder display **230**. An input device **235**, such as a pushbutton on a camera or video camera, sends an image capture request to the signal processor **220** requesting, for example, the capture of a particular image displayed in the viewfinder display **230** and/or to initiate video imaging where so implemented.

In response to the image capture request or as otherwise directed, the signal processor **220** uses the sensor data captured by the image sensor arrangement **210** to generate processed sensor data. In some applications, the compression processor **224** is implemented to generate compressed raw data for transfer to a data storage arrangement **240** (e.g., memory). Such raw data is then selectively processed at the signal processor **220** and/or at an external computer **260** or other processing device, implementing ray-direction processing such as that implemented with the ray-direction processor **226**, which is discussed further below.

In certain applications, the ray-direction processor **226** is implemented to process the sensor data received at the signal processor **220** to rearrange the sensor data for use in generating focused and/or corrected image data. The ray-direction processor **226** uses one or both of sensor data received from the image sensor arrangement **210** and raw data sent to the data storage arrangement **240**. In these applications, the ray-direction processor **226** uses ray-mapping characteristics of the particular imaging device (e.g., camera, video camera or mobile telephone) in which the image sensor arrangement **210** is implemented to determine a rearrangement of light rays sensed with the microlens/photosensor chip **212**. Image data created with the ray-direction processor **226** is sent to the data storage arrangement **240** and/or to a communication link **250** for use in a variety of applications, such as in streaming image data or otherwise sending image data to a remote location.

In some applications, the integrated processing circuit **214** includes some or all of the processing functionality of the signal processor **220** by implementing, for example, a CMOS-type processor or other processor with appropriate functionality. For instance, the low-resolution image processor **222** is selectively included with the integrated processing circuit **214**, with the low-resolution image data sent directly to the viewfinder display **230** from the image sensor arrangement **210**. Similarly, the compression processor **224**, or functionality similar thereto, is selectively implemented with the integrated processing circuit **214**.

In some applications, computation of final images may be performed on the integrated processing circuit **214** (e.g., in some digital still cameras that output only final images). In other applications, the image sensor arrangement **210** may simply transmit the raw light ray data, or a compressed version of these data, to an external computational device, such as a desktop computer. Computation of final images from these data is then performed on the external device.

FIG. **3** is a flow diagram for a method for processing image data, according to another example embodiment of the present invention. At block **310**, image data is captured at a camera or other imaging device, using a main lens or a lens stack with a microlens/photosensor array such as that shown in FIG. **1**. If a preview image is desired at block **320**, the preview image is generated at block **330** using, for example, a viewfinder or other type of display. The preview image is displayed, for example, in a viewfinder of a camera or video camera, using a subset of the captured image data.

Raw data from the photosensor array is processed and compressed for use at block **340**. Light ray data is extracted from the processed and compressed data at block **350**. This extraction involves, for example, detecting a bundle or set of light rays incident upon a particular photosensor in the photosensor array. Ray mapping data is retrieved at block **360** for the imaging arrangement in which the image data is captured. The ray-mapping data and the extracted light ray data is used to synthesize a re-sorted image at block **370**. For example, the extraction, mapping and synthesis blocks **350-370** are selectively implemented by determining a bundle of light rays for a particular pixel of a scene for which the light rays were collected, and integrating the energy of the light rays to synthesize a value for the particular pixel. In some applications, the ray mapping data is used to trace light rays for each particular pixel through actual lenses used to acquire the image data. For example, by determining an appropriate set of rays to add together in order to focus upon a selected subject at a particular focal depth at block **370**, the rays can be re-sorted to arrive at a focused image. Similarly, by determining a proper arrangement of rays to correct for conditions such as lens aberrations in the imaging device, the rays can be re-sorted to generate an image relatively free of characteristics relating to the aberrations or other condition.

A variety of approaches are selectively used to generate preview images for camera-type and other applications. FIG. **4** is a process flow diagram for generating such a preview image, according to another example embodiment of the present invention. The approach shown in FIG. **4** and discussed below may be implemented, for example, in connection with the generation of a preview image at block **330** of FIG. **3**.

A preview instruction with raw sensor image data is received at block **410**. At block **420**, a center pixel is selected from each microlens image in the raw sensor image data. The selected center pixels are collected to form a high depth-of-field image at block **430**. At block **440**, the high depth-of-field image is downsampled to a resolution amenable for use in a viewfinder display. Referring to FIG. **2** by way of example, such downsampling is selectively performed at one or more of the image sensor arrangement **210** or the signal processor **220**. The generated preview image data is sent to the viewfinder display at block **450**, and at block **460**, the viewfinder displays an image with the preview image data.

FIG. **5** is a process flow diagram for processing and compressing image data, according to another example embodiment of the present invention. The approach shown in FIG. **5** and discussed below may be implemented, for example, in connection with the processing and compressing of image data at block **340** of FIG. **3**. When implemented with an arrangement as shown in FIG. **2**, the approach shown in FIG. **5** may, for example, be implemented at one or both of the image sensor arrangement **210** and the signal processor **220**.

At block **510**, raw image data is received from a sensor array. If coloring is desired at block **520**, color filter array values are demosiaced at block **530** to produce color at the sensors. If rectification and alignment is desired at block **540**, microlens images are rectified and aligned with the photosensor array at block **550**. If interpolation is desired at block **560**, pixel values are interpolated at block **570** to an integral number of pixels associated with each microlens. At block **580**, the processed raw image data is compressed and presented for synthesis processing (e.g., to form a refocused and/or corrected image).

FIG. **6** is a process flow diagram for image synthesis, according to another example embodiment of the present invention. The approach shown in FIG. **6** and discussed below may be implemented, for example, in connection with the image synthesis approach shown at block **370** of FIG. **3** and discussed further below.

At block **610**, raw image data is received from a photosensor array. If refocusing is desired at block **620**, image data is refocused at block **630** using, e.g., approaches discussed herein for selectively re-sorting light represented by the raw image data. If image correction is desired at block **640**, image data is corrected at block **650**. In various applications, image correction at block **650** is carried out before or concurrently with refocusing at block **630** in applications where both refocusing and image correction is desirable. A resultant image is generated at block **660** using processed image data including refocused and corrected data, where applicable.

FIG. **7**A is a process flow diagram for image refocusing with a lens arrangement, according to another example embodiment of the present invention. The approach shown in FIG. **7** and discussed below may be implemented, for example, in connection with the refocusing of image data at block **630** in FIG. **6**.

At block **710**, a virtual focal plane for refocusing an image portion is selected. At block **720**, a pixel of a virtual image for the virtual focal plane is selected. If correction (e.g., for lens aberration) is desired at block **730**, the value of a virtual light ray (or virtual set of light rays) passing between the selected pixel and each particular lens position is calculated at block **740**. In one application, this calculation is facilitated by computing the conjugate light ray that would fall upon the selected pixel and tracing that ray through the path in the lens arrangement.

At block **750**, the sum of light ray (or virtual set of light ray) values for each lens position for the particular focal plane are added to determine a total value for the selected pixel. In some applications, the sum added at block **750** is a weighted sum, wherein certain light rays (or set of light rays) are given greater weight than others. If there are additional pixels for refocusing at block **760**, another pixel is selected at block **720** and the process continues until no further pixels are desirably refocused. After the pixels have been refocused, the pixel data is combined at block **770** to generate a refocused virtual image at the virtual focal plane selected in block **710**. The refocusing approaches involving some or all of blocks **720**, **730**, **740** and **750** in FIG. **7** are carried out via more specific functions for a variety of applications.

The sensor data processing circuitry implemented with one or more example embodiments described herein includes one or more microprocessors, Application-Specific Integrated Circuits (ASICs), digital signal processors (DSPs), and/or programmable gate arrays (for example, field-programmable gate arrays (FPGAs)), depending upon the implementation. In this regard, sensor data processing circuitry may be any type or form of circuitry whether now known or later developed. For example, the sensor data processing circuitry may include a single component or a multiplicity of components (microprocessors, ASICs and DSPs), either active and/or passive, which are coupled together to implement, provide and/or perform a desired operation/function/application.

In various applications, the sensor data processing circuitry performs or executes one or more applications, routines, programs and/or data structures that implement particular methods, tasks or operations described and/or illustrated herein. The functionality of the applications, routines or programs are selectively combined or distributed in certain applications. In some applications, the applications, routines or programs are implemented by sensor (or other) data processing circuitry using one or more of a variety of programming languages, whether now known or later developed. Such programming languages include, for example, FORTRAN, C, C++, Java and BASIC, whether compiled or uncompiled code, selectively implemented in connection with one or more aspects of the present invention.

The various embodiments described above are provided by way of illustration only and should not be construed to limit the invention. Based on the above discussion and illustrations, those skilled in the art will readily recognize that various modifications and changes may be made to the present invention without strictly following the exemplary embodiments and applications illustrated and described herein. For instance, such changes may include implementing the various optical imaging applications and devices in different types of applications, increasing or decreasing the number of rays collected per pixel (or other selected image area), or implementing different algorithms and/or equations than the examples described to assemble or otherwise process image data. Other changes may involve using coordinate representations other than or in addition to Cartesian coordinates, such as polar coordinates. Such modifications and changes do not depart from the true spirit and scope of the present invention.

What is claimed is:

1. A method for digitally imaging a scene, the method comprising: generating photosensor image data in response to detecting light rays incident on a physical focal plane using a photosensor array, having a plurality of photosensors, wherein the plurality of photosensors simultaneously detect the light rays from the scene that are incident on a microlens array and passed to different locations on the physical focal plane; determining an angle of incidence of the light rays incident at different locations on the physical focal plane using the photosensor image data; and generating a virtual output image which corresponds to the scene by selectively combining the photosensor image data based on the angle of incidence of the light rays, such that at least a selected portion of the image is refocused via the selective combination of photosensor image data representing different ones of the light rays.

2. The method of claim **1**, wherein generating a virtual an output image comprises forming an image having at least a portion thereof focused at a virtual focal plane that is different than the physical focal plane.

3. The method of claim **2**, wherein generating a virtual output image further comprises:

determining a set of light rays from the detected light rays that make up the at least a portion of the image focused at a virtual focal plane that is different than the physical focal plane; and

combining the determined set of light rays to form the portion of the output image focused at the virtual focal plane.

4. The method of claim 1, wherein combining the determined set of light rays further comprises correcting for conditions of optics used in detecting the light.

5. The method of claim 1, wherein combining the determined set of light rays further comprises correcting for lens aberration.

6. A digital imaging system for generating a virtual image of a scene, wherein the virtual image includes a plurality of pixels, the system comprising:

a photosensor array, having a plurality of photosensors, configured to detect light including a plurality of light rays from the scene, wherein each photosensor, in response to detecting the light incident thereon, generates light data, the photosensor array further configured to detect a set of the plurality of light rays that concurrently arrive at the particular portion of the physical focal plane at different angles of incidence;

an optics arrangement, having a physical focus, configured to direct light rays from the scene to the photosensor array via a physical focal plane; and

processing circuitry to compute a pixel value of each pixel of the virtual image by combining light data from selected photosensors based on angles of incidence of the light rays detected by each photosensor, as characterized by the location of each photosensor relative to the physical focal plane, the virtual image having a virtual focus and a virtual focal plane that are respectively different from the physical focus and the physical focal plane.

7. The system of claim 6, wherein the optics arrangement includes a microlens array, the microlens array including a plurality of microlenses, each microlens being configured to separate light rays incident upon the microlens and to direct the separated rays to a predetermined plurality of photosensors in the photosensor array.

8. The system of claim 7, wherein the processing circuitry further determines the angles of incidence of light upon each photosensor using a position of each photosensor relative to the microlens.

9. The system of claim 6, wherein the processing circuitry further determines a focus depth of a subject in the scene from which the light rays emanate, and uses the focus depth and the angles of incidence to compute the virtual image focused upon a virtual focal plane that is different from the physical focal plane.

10. The system of claim 6, wherein the processing circuitry is further configured to:

determine an angle of incidence of the detected light rays as characterized by the location of each photosensor detecting the light, and

map a path of the detected light rays through the system using the angles of incidence of the detected light rays.

11. The system of claim 6, wherein the optics arrangement includes a microlens array having a plurality of microlenses, each microlens being associated with a plurality of the photosensors and configured to direct light rays from the optics arrangement onto the associated plurality of photosensors.

12. The system of claim 6, wherein the processing circuitry is configured to combine the light data from selected photosensors based on data indicative of a virtual focal plane and the angles of incidence of the light rays detected by each photosensor, to generate a virtual image of the scene having the virtual focus at the virtual focal plane.

13. The system of claim 6, wherein:

the optics arrangement is configured to project light from the scene onto the physical focal plane with a physical depth of field, and

the processing circuitry is configured to generate the virtual image of the scene by combining light data from selected photosensors, based on a selected virtual depth of field and the angles of incidence of the light rays detected by each photosensor, to generate a virtual image of the scene having the selected virtual depth of field, the selected virtual depth of field being different from the physical depth of field.

14. The system of claim 6, wherein:

the optics arrangement is configured to project light from the scene onto the physical focal plane with a physical depth of field, and

the processing circuitry is configured to generate the virtual image of the scene by combining light data from selected photosensors, based on a selected virtual depth of field and the angles of incidence of the light rays detected by each photosensor, to provide a virtual image of the scene having the selected virtual depth of field, the selected virtual depth of field being greater than the physical depth of field.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	: 7,936,392 B2
APPLICATION NO.	: 11/576438
DATED	: May 3, 2011
INVENTOR(S)	: Ng et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 25, line 1 and line 4, the claim reference numeral "1", each occurrence, should read -3-.

Signed and Sealed this
First Day of May, 2012

David J. Kappos
Director of the United States Patent and Trademark Office

US 20020135688A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2002/0135688 A1

Niikawa (43) Pub. Date: Sep. 26, 2002

(54) IMAGE PROCESSING APPARATUS

(75) Inventor: Masahito Niikawa, Sakai-Shi (JP)

Correspondence Address:
SIDLEY AUSTIN BROWN & WOOD LLP
717 NORTH HARWOOD
SUITE 3400
DALLAS, TX 75201 (US)

(73) Assignee: MINOLTA CO., LTD.

(21) Appl. No.: 10/102,146

(22) Filed: Mar. 19, 2002

(30) Foreign Application Priority Data

Mar. 26, 2001 (JP) 2001-088015

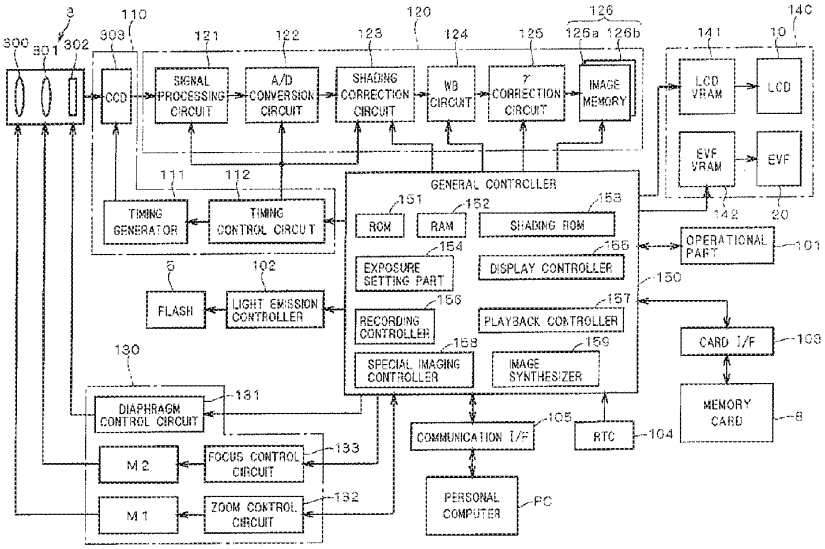
Publication Classification

(51) Int. Cl.[7] H04N 9/64

(52) U.S. Cl. 348/251

(57) ABSTRACT

A digital camera which is an image processing apparatus is controlled so that a first image and a second image are acquired for the same subject in different timings. A plurality of correction tables for use in shading correction are prepared in advance in a shading ROM of the digital camera. When a first image and a second image are acquired, multiplication of one correction table is performed on both images by a shading correction circuit. As a result of this, a shading correction is effected on both images. The first image and the second image that have been subjected to the shading correction are taken into respective image memories, and after being subjected to a positioning process by a general controller, they are synthesized to generate a synthesized image.



PE

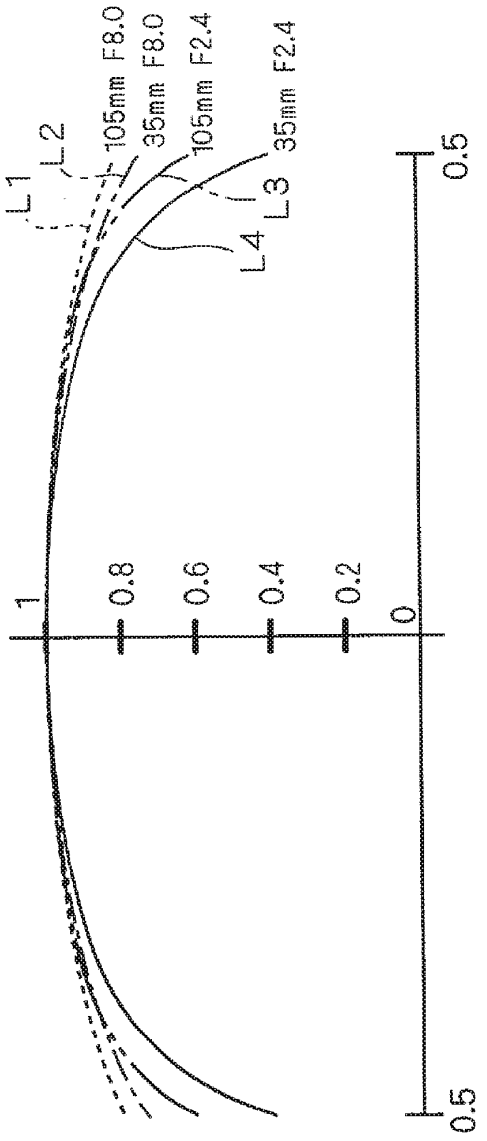

105mm F8.0
35mm F8.0
105mm F2.4
35mm F2.4
L1
L2
L3
L4
1
0.8
0.6
0.4
0.2
0
0.5
0.5

FIG. 1

PE

FIG. 2

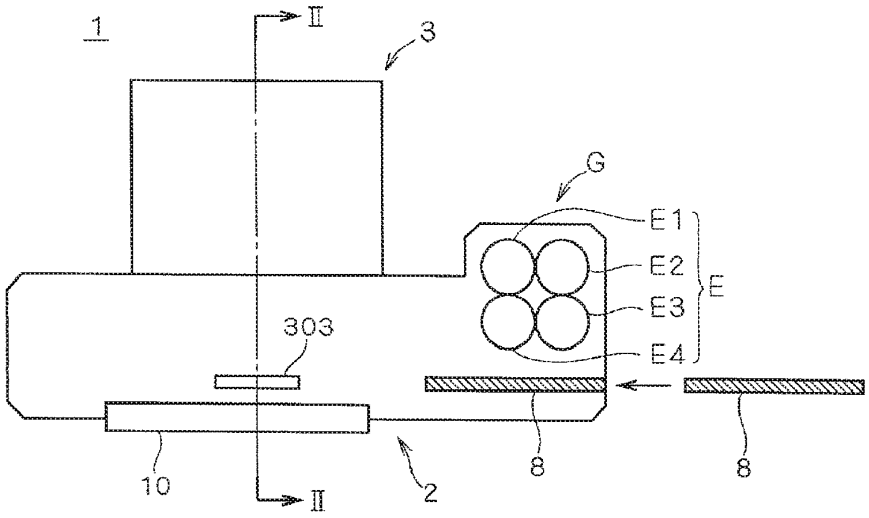
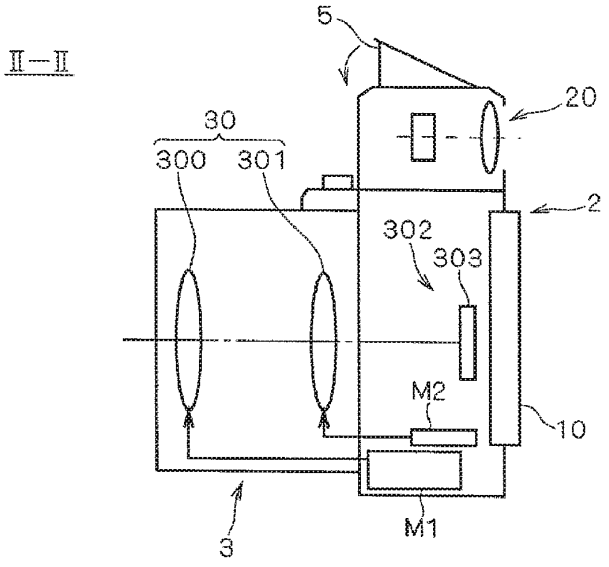
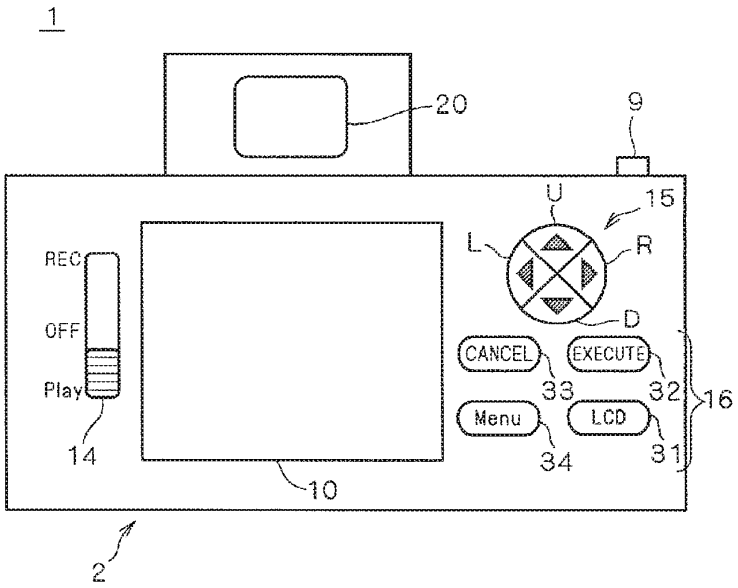


FIG. 3



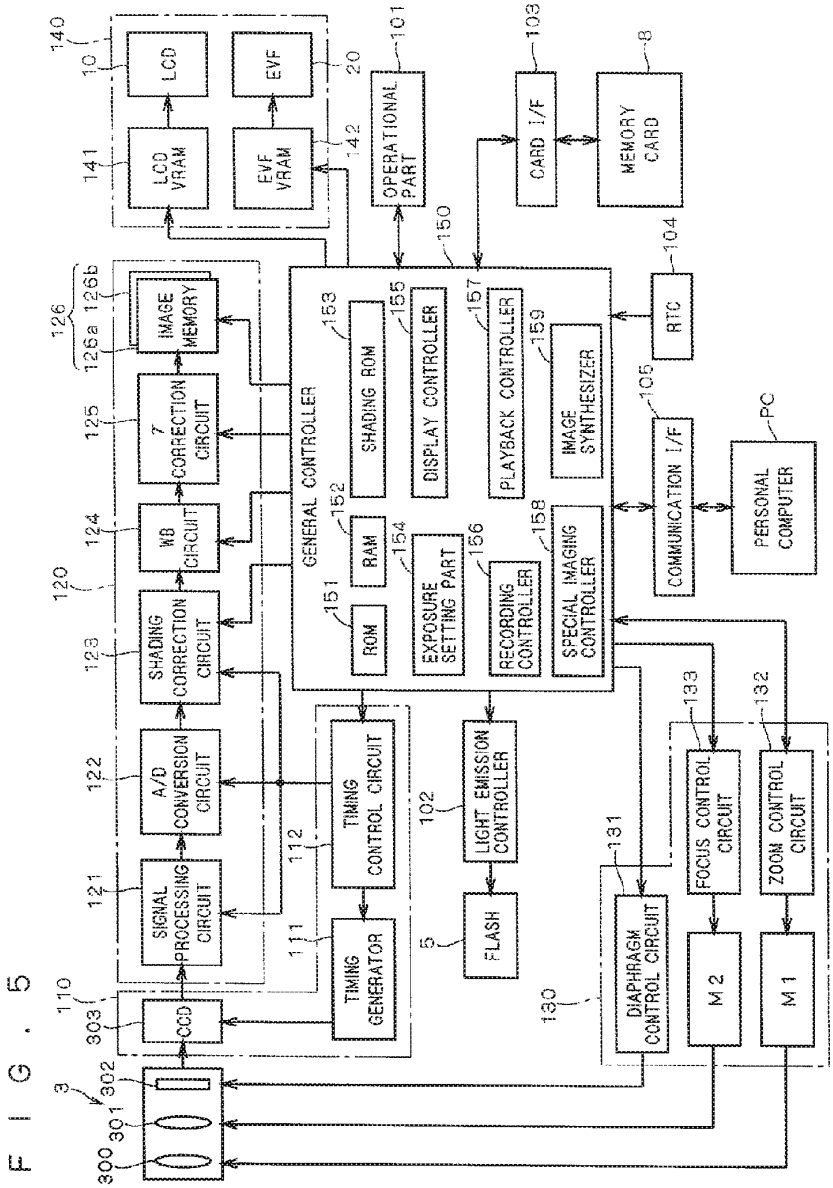
PE

F I G . 4


1
20
9
U
15
L
R
D
REC
OFF
Play
14
CANCEL
EXECUTE
33
32
16
Menu
LCD
34
31
10
2

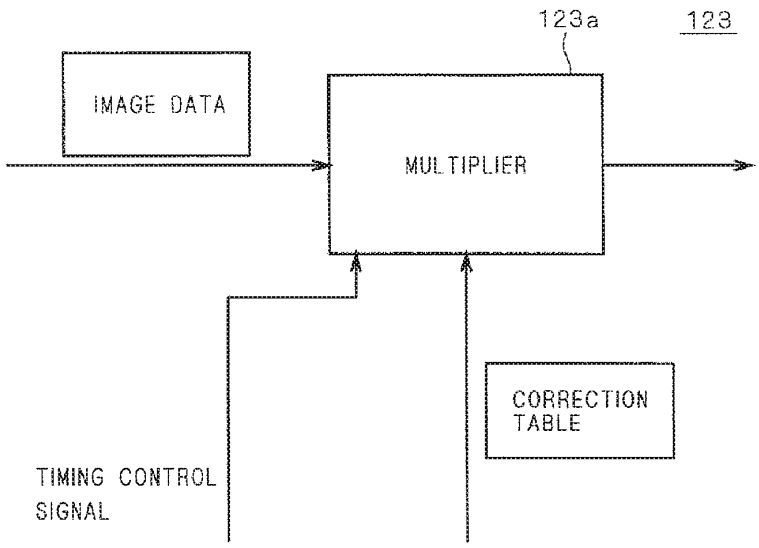
PE

FIG. 5


LCD
EVF
LCD VRAM
EVF VRAM
OPERATIONAL PART
CARD I/F
MEMORY CARD
IMAGE MEMORY
γ CORRECTION CIRCUIT
WB CIRCUIT
SHADING CORRECTION CIRCUIT
A/D CONVERSION CIRCUIT
SIGNAL PROCESSING CIRCUIT
CCD
TIMING GENERATOR
TIMING CONTROL CIRCUIT
LIGHT EMISSION CONTROLLER
FLASH
GENERAL CONTROLLER
ROM
RAM
SHADING ROM
EXPOSURE SETTING PART
DISPLAY CONTROLLER
RECORDING CONTROLLER
PLAYBACK CONTROLLER
SPECIAL IMAGING CONTROLLER
IMAGE SYNTHESIZER
RTC
COMMUNICATION I/F
PERSONAL COMPUTER
PC
DIAPHRAGM CONTROL CIRCUIT
FOCUS CONTROL CIRCUIT
ZOOM CONTROL CIRCUIT
M2
M1

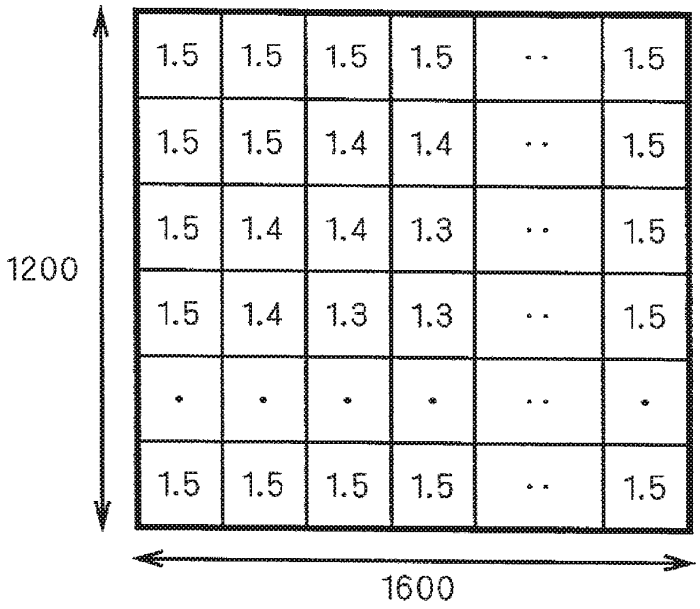
PE

FIG. 6


123a
123
IMAGE DATA
MULTIPLIER
CORRECTION TABLE
TIMING CONTROL SIGNAL

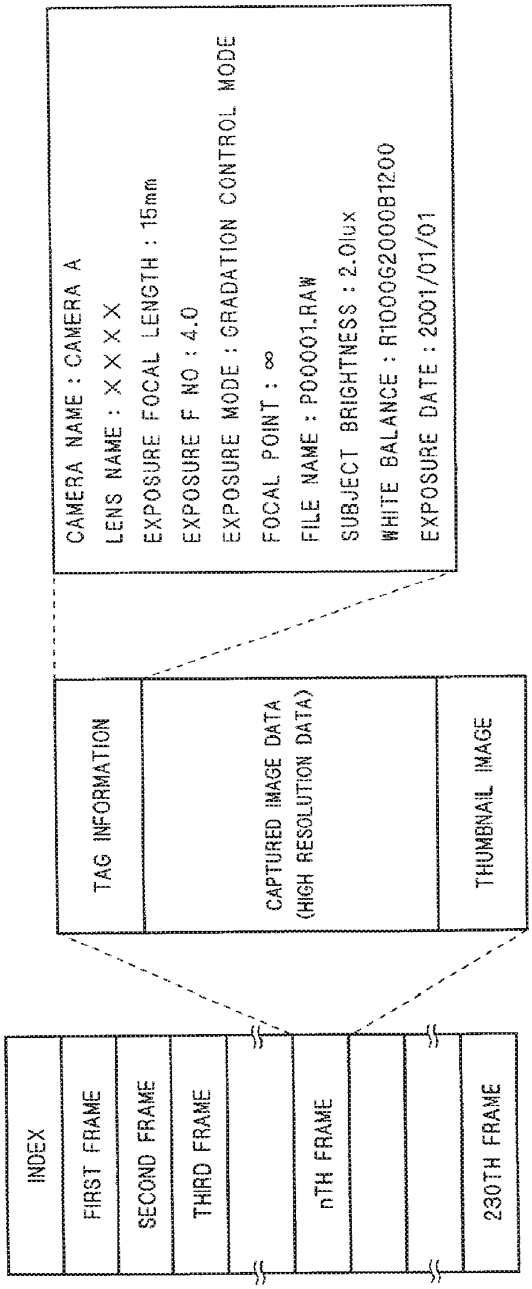
PE

FIG. 7


1.5 1.5 1.5 1.5 .. 1.5
1.5 1.5 1.4 1.4 .. 1.5
1.5 1.4 1.4 1.3 .. 1.5
1.5 1.4 1.3 1.3 .. 1.5
. . . .
1.5 1.5 1.5 1.5 .. 1.5
1200
1600

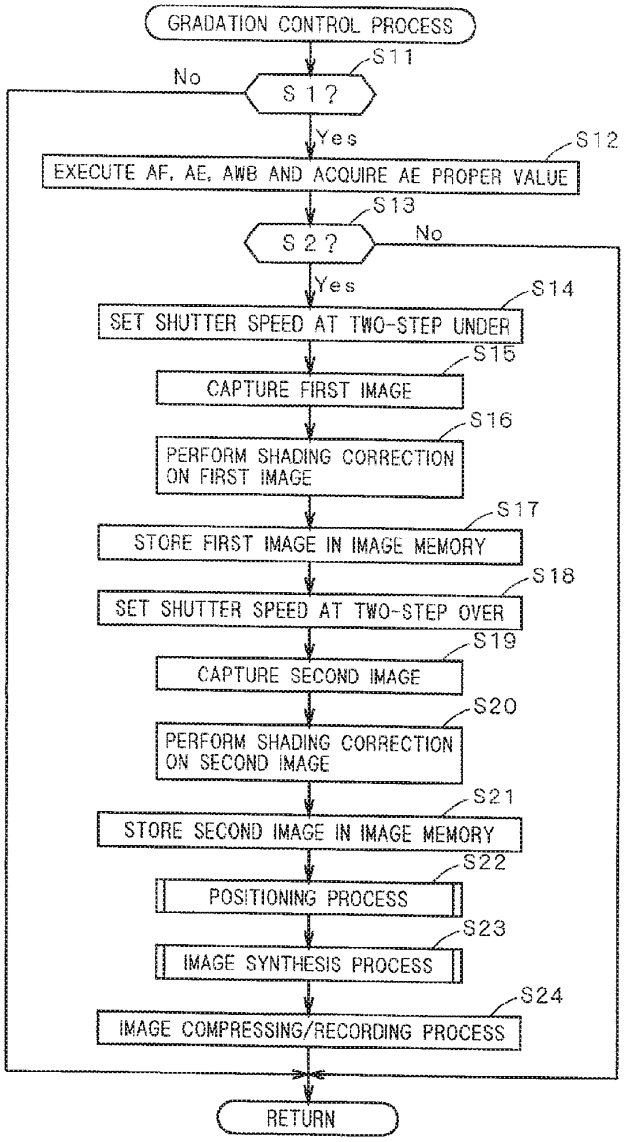
PE

FIG. 8


INDEX
FIRST FRAME
SECOND FRAME
THIRD FRAME
nTH FRAME
230TH FRAME
TAG INFORMATION
CAPTURED IMAGE DATA
(HIGH RESOLUTION DATA)
THUMBNAIL IMAGE
CAMERA NAME : CAMERA A
LENS NAME : XXXX
EXPOSURE FOCAL LENGTH : 15mm
EXPOSURE F NO : 4.0
EXPOSURE MODE : GRADATION CONTROL MODE
FOCAL POINT : ∞
FILE NAME : P00001.RAW
SUBJECT BRIGHTNESS : 2.0lux
WHITE BALANCE : R1000G2000B1200
EXPOSURE DATE : 2001/01/01

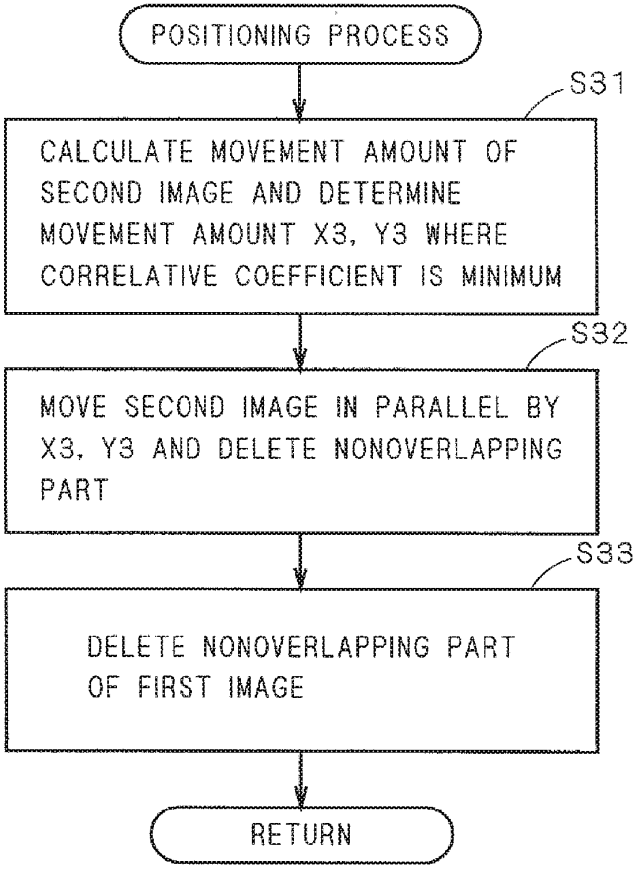
PE

FIG. 9


GRADATION CONTROL PROCESS
S11
No
S1?
Yes
S12
EXECUTE AF, AE, AWB AND ACQUIRE AE PROPER VALUE
S13
S2?
No
Yes
S14
SET SHUTTER SPEED AT TWO-STEP UNDER
S15
CAPTURE FIRST IMAGE
S16
PERFORM SHADING CORRECTION ON FIRST IMAGE
S17
STORE FIRST IMAGE IN IMAGE MEMORY
S18
SET SHUTTER SPEED AT TWO-STEP OVER
S19
CAPTURE SECOND IMAGE
S20
PERFORM SHADING CORRECTION ON SECOND IMAGE
S21
STORE SECOND IMAGE IN IMAGE MEMORY
S22
POSITIONING PROCESS
S23
IMAGE SYNTHESIS PROCESS
S24
IMAGE COMPRESSING/RECORDING PROCESS
RETURN

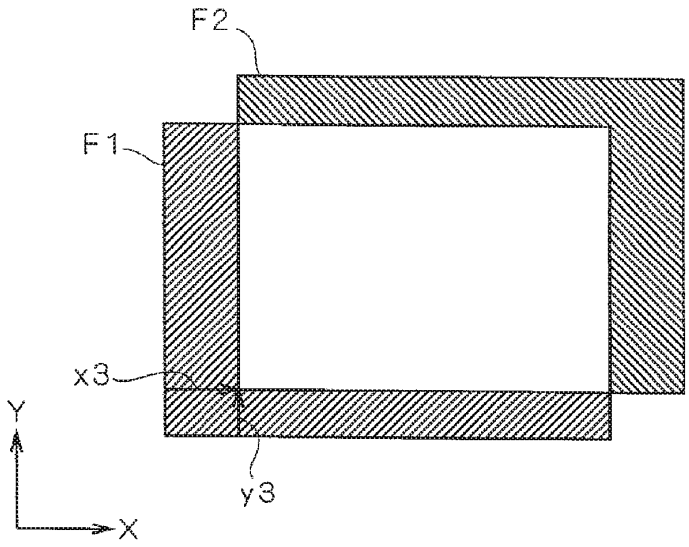
PE

FIG. 10


POSITIONING PROCESS
S31
CALCULATE MOVEMENT AMOUNT OF SECOND IMAGE AND DETERMINE MOVEMENT AMOUNT X3, Y3 WHERE CORRELATIVE COEFFICIENT IS MINIMUM
S32
MOVE SECOND IMAGE IN PARALLEL BY X3, Y3 AND DELETE NONOVERLAPPING PART
S33
DELETE NONOVERLAPPING PART OF FIRST IMAGE
RETURN

PE

FIG. 11



PE

FIG. 12A

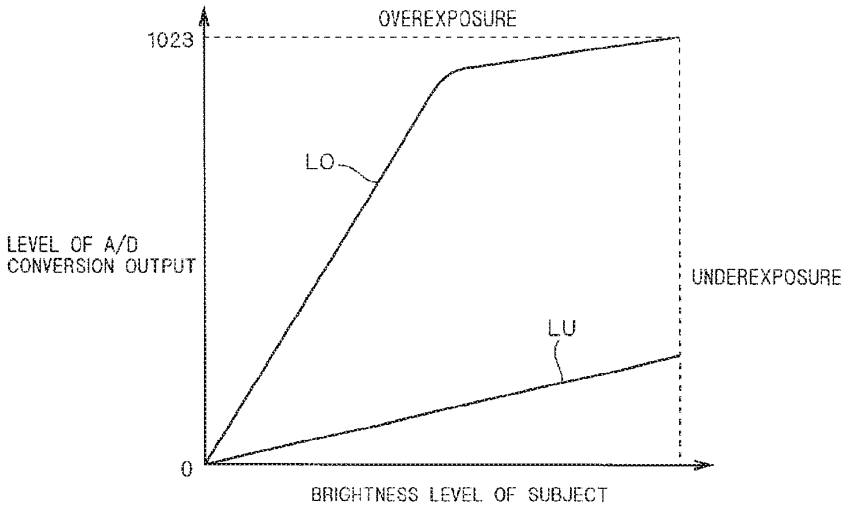
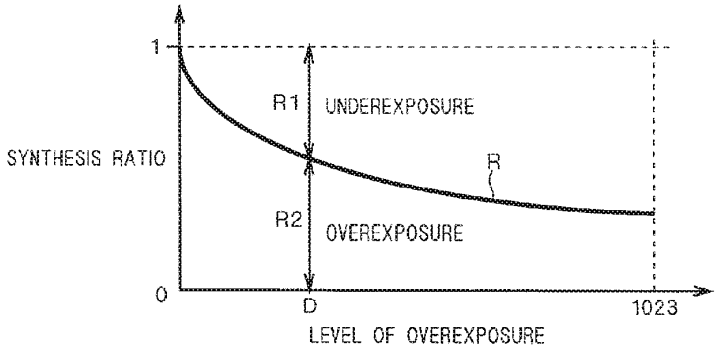
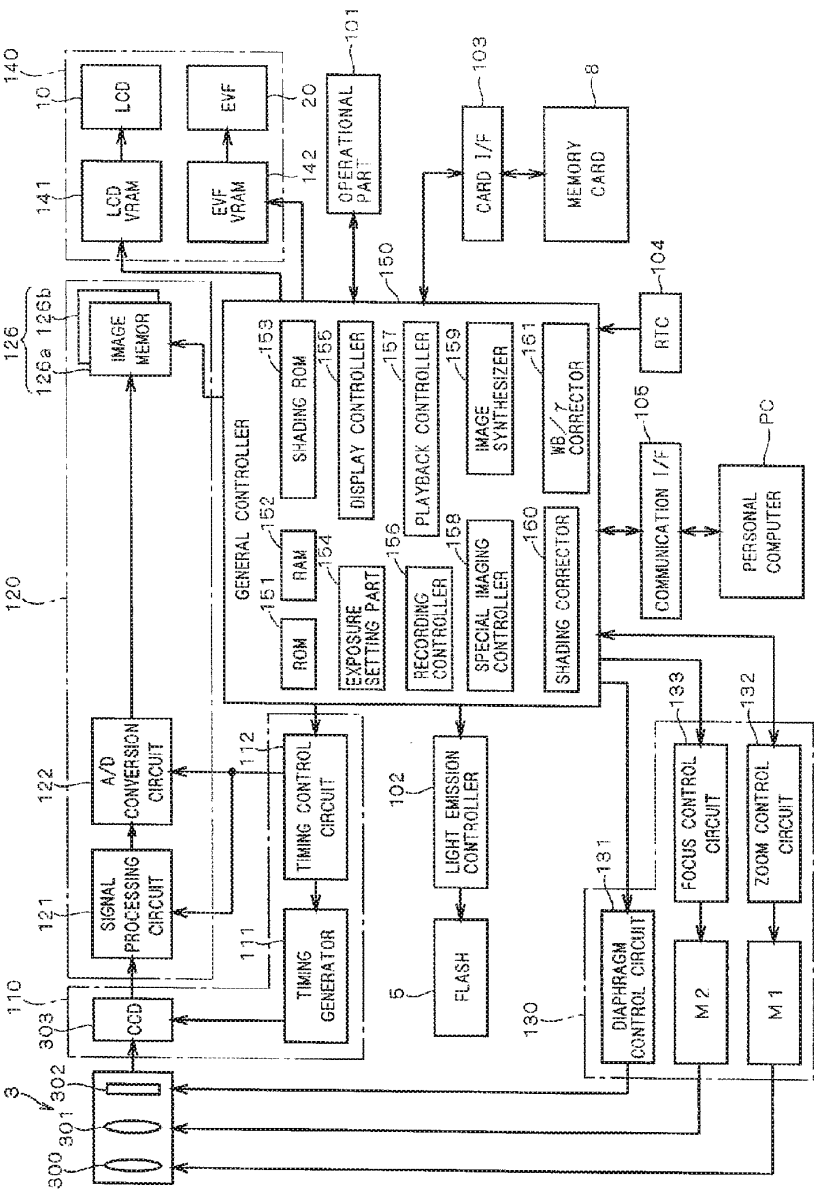


FIG. 12B



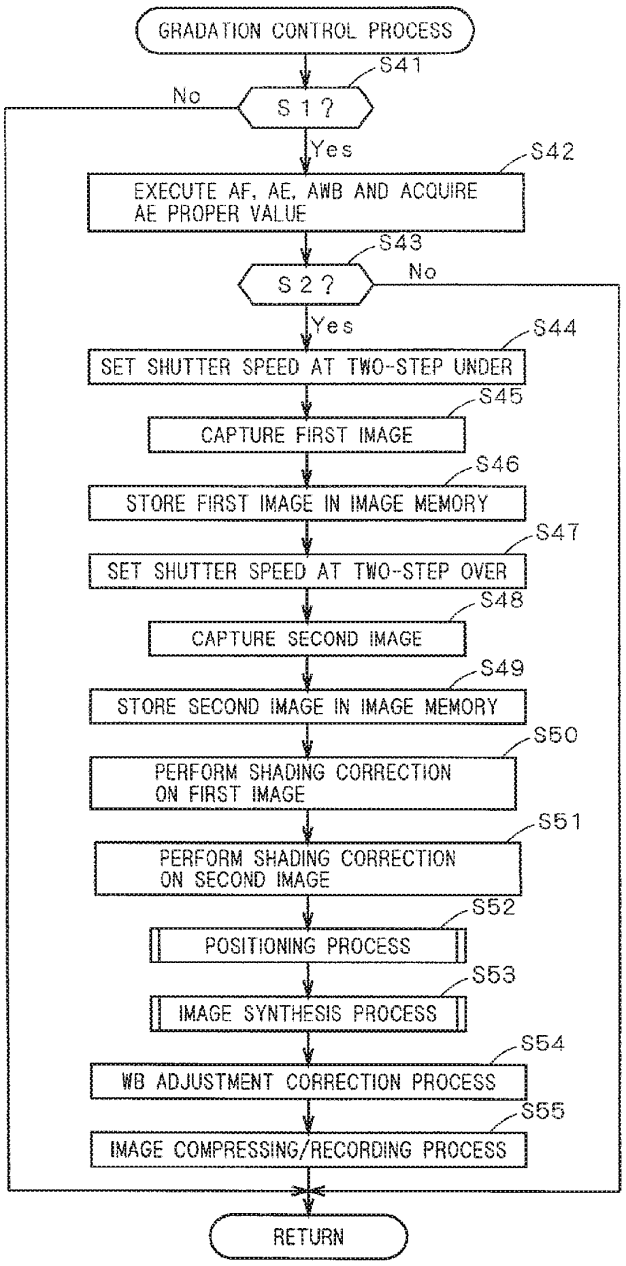
PE

FIG. 13


LCD
EVF
OPERATIONAL PART
CARD I/F
MEMORY CARD
LCD VRAM
EVF VRAM
IMAGE MEMOR
GENERAL CONTROLLER
SHADING ROM
DISPLAY CONTROLLER
PLAYBACK CONTROLLER
IMAGE SYNTHESIZER
WB/γ CORRECTOR
RTC
ROM
RAM
EXPOSURE SETTING PART
RECORDING CONTROLLER
SPECIAL IMAGING CONTROLLER
SHADING CORRECTOR
COMMUNICATION I/F
PERSONAL COMPUTER
A/D CONVERSION CIRCUIT
SIGNAL PROCESSING CIRCUIT
TIMING CONTROL CIRCUIT
LIGHT EMISSION CONTROLLER
FOCUS CONTROL CIRCUIT
ZOOM CONTROL CIRCUIT
TIMING GENERATOR
FLASH
DIAPHRAGM CONTROL CIRCUIT
M2
M1
CCD

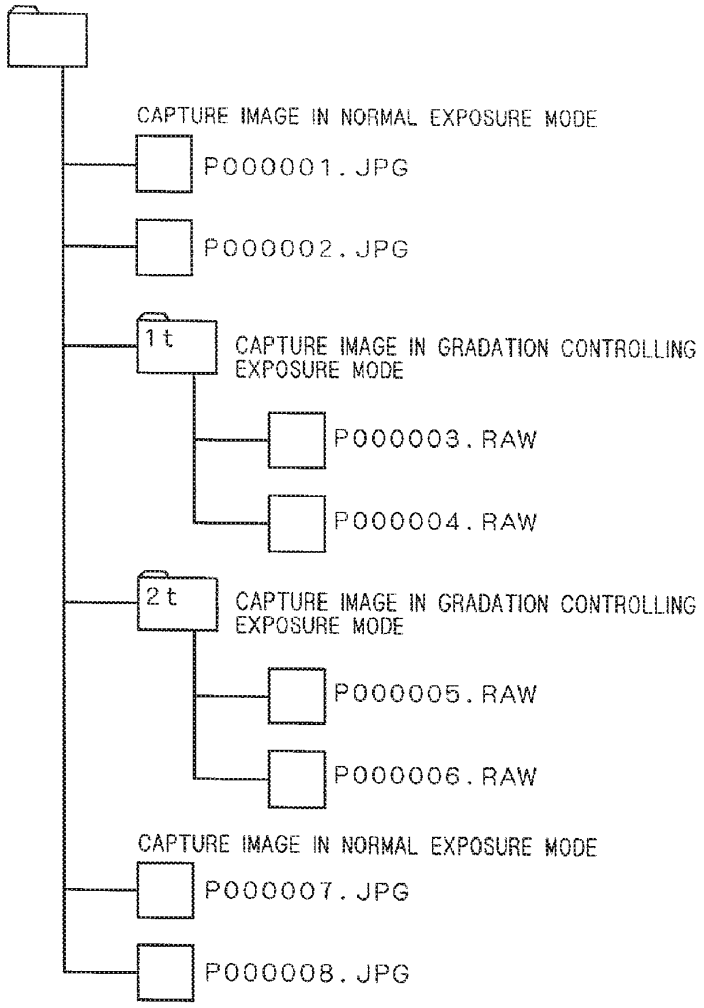
PE

FIG. 14


GRADATION CONTROL PROCESS
S41
S1?
No
Yes
S42
EXECUTE AF, AE, AWB AND ACQUIRE AE PROPER VALUE
S43
S2?
No
Yes
S44
SET SHUTTER SPEED AT TWO-STEP UNDER
S45
CAPTURE FIRST IMAGE
S46
STORE FIRST IMAGE IN IMAGE MEMORY
S47
SET SHUTTER SPEED AT TWO-STEP OVER
S48
CAPTURE SECOND IMAGE
S49
STORE SECOND IMAGE IN IMAGE MEMORY
S50
PERFORM SHADING CORRECTION ON FIRST IMAGE
S51
PERFORM SHADING CORRECTION ON SECOND IMAGE
S52
POSITIONING PROCESS
S53
IMAGE SYNTHESIS PROCESS
S54
WB ADJUSTMENT CORRECTION PROCESS
S55
IMAGE COMPRESSING/RECORDING PROCESS
RETURN

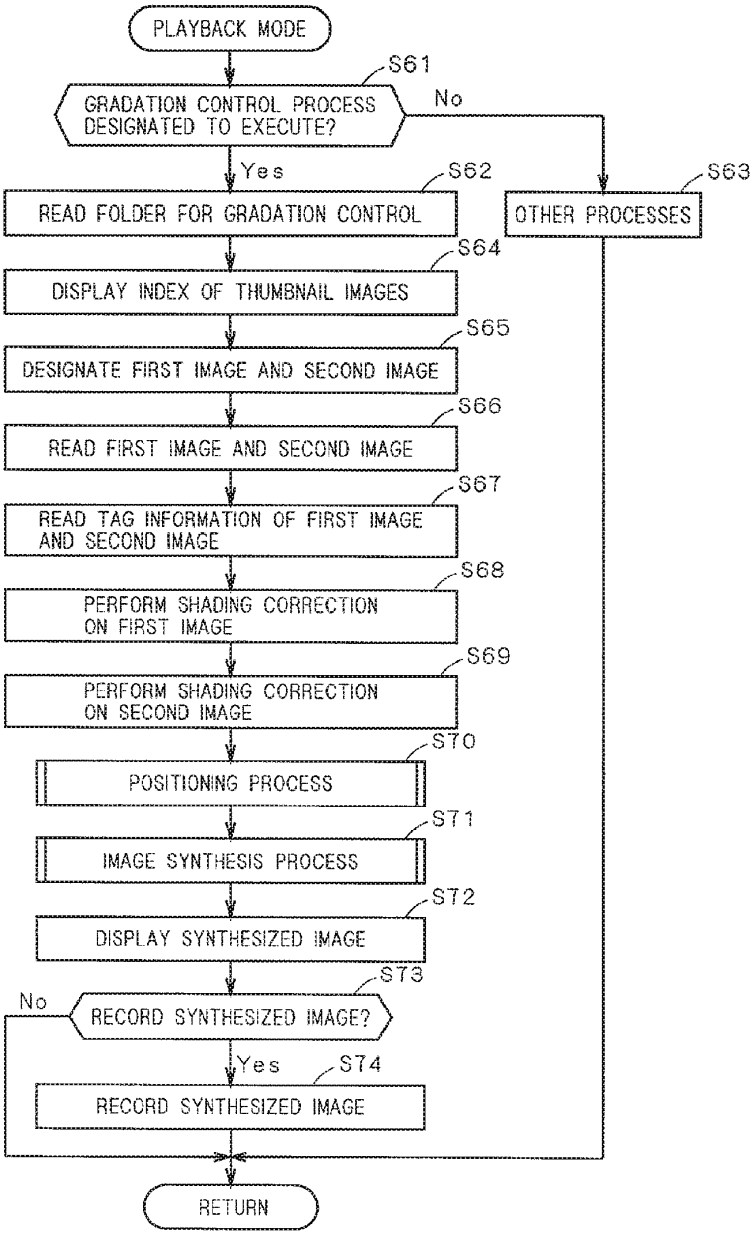
PE

FIG. 15


CAPTURE IMAGE IN NORMAL EXPOSURE MODE
P000001.JPG
P000002.JPG
1t
CAPTURE IMAGE IN GRADATION CONTROLLING EXPOSURE MODE
P000003.RAW
P000004.RAW
2t
CAPTURE IMAGE IN GRADATION CONTROLLING EXPOSURE MODE
P000005.RAW
P000006.RAW
CAPTURE IMAGE IN NORMAL EXPOSURE MODE
P000007.JPG
P000008.JPG

PE

FIG. 16


PLAYBACK MODE
S61
GRADATION CONTROL PROCESS DESIGNATED TO EXECUTE?
No
Yes
S62
READ FOLDER FOR GRADATION CONTROL
S63
OTHER PROCESSES
S64
DISPLAY INDEX OF THUMBNAIL IMAGES
S65
DESIGNATE FIRST IMAGE AND SECOND IMAGE
S66
READ FIRST IMAGE AND SECOND IMAGE
S67
READ TAG INFORMATION OF FIRST IMAGE AND SECOND IMAGE
S68
PERFORM SHADING CORRECTION ON FIRST IMAGE
S69
PERFORM SHADING CORRECTION ON SECOND IMAGE
S70
POSITIONING PROCESS
S71
IMAGE SYNTHESIS PROCESS
S72
DISPLAY SYNTHESIZED IMAGE
S73
No
RECORD SYNTHESIZED IMAGE?
Yes
S74
RECORD SYNTHESIZED IMAGE
RETURN

PE

FIG. 17A

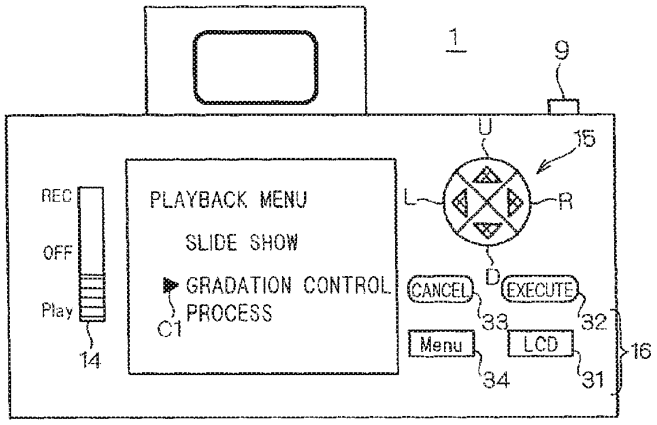
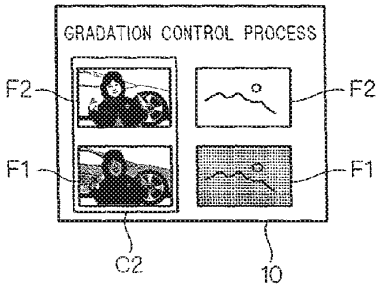
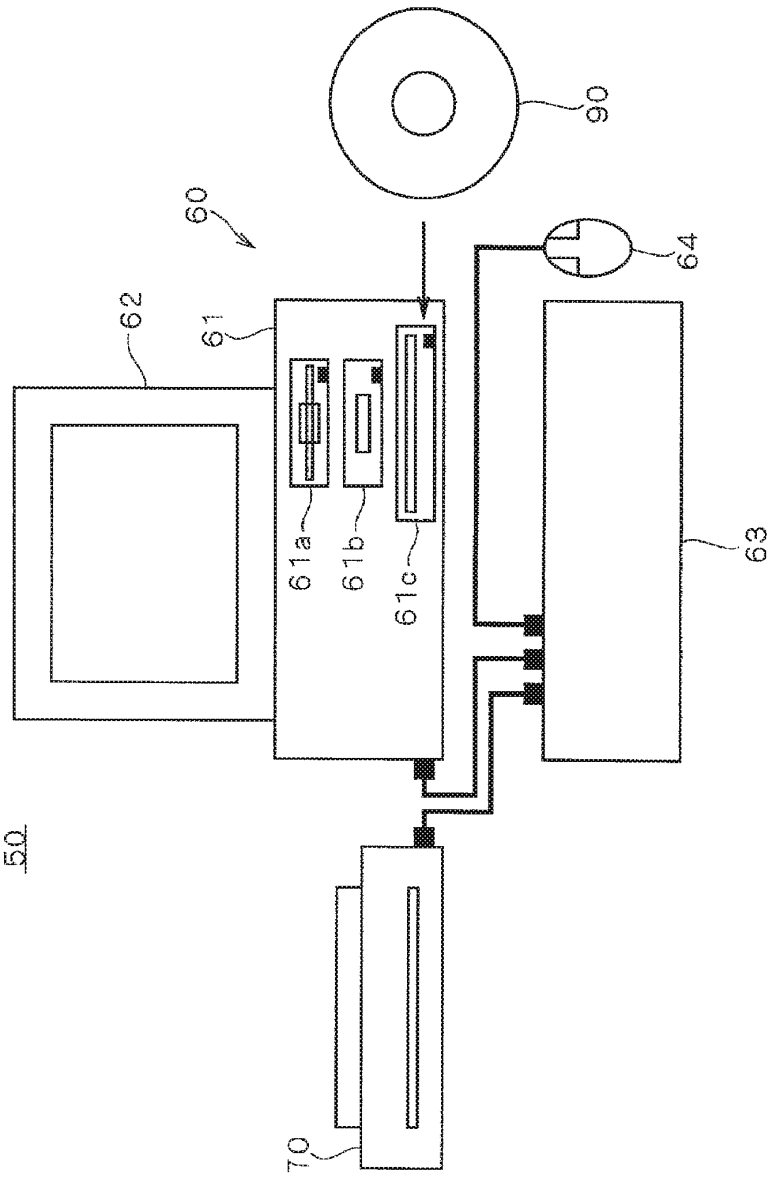


FIG. 17B



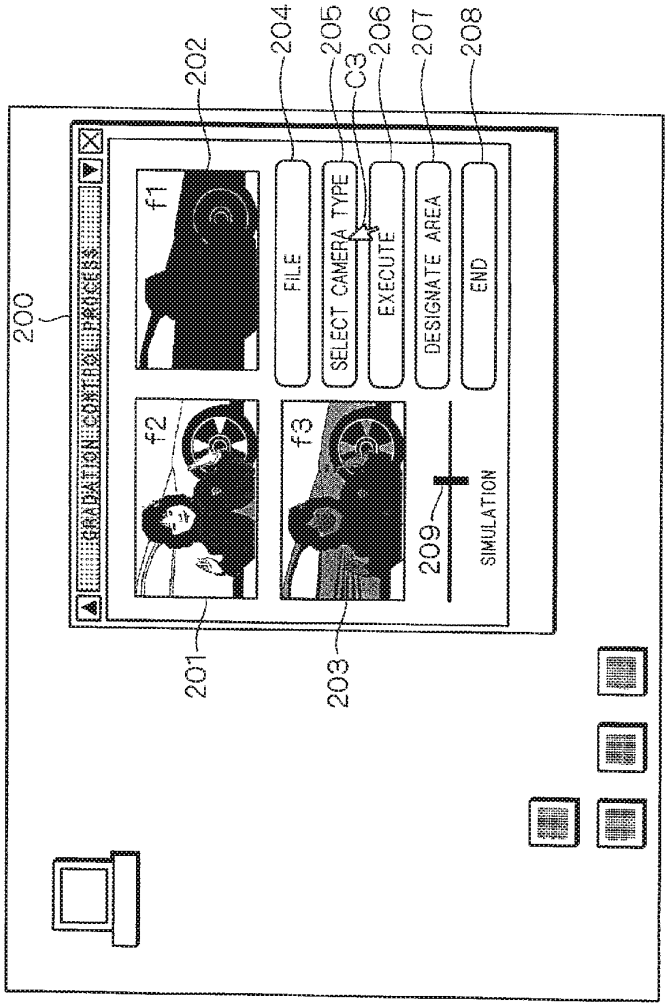
PE

FIG. 18



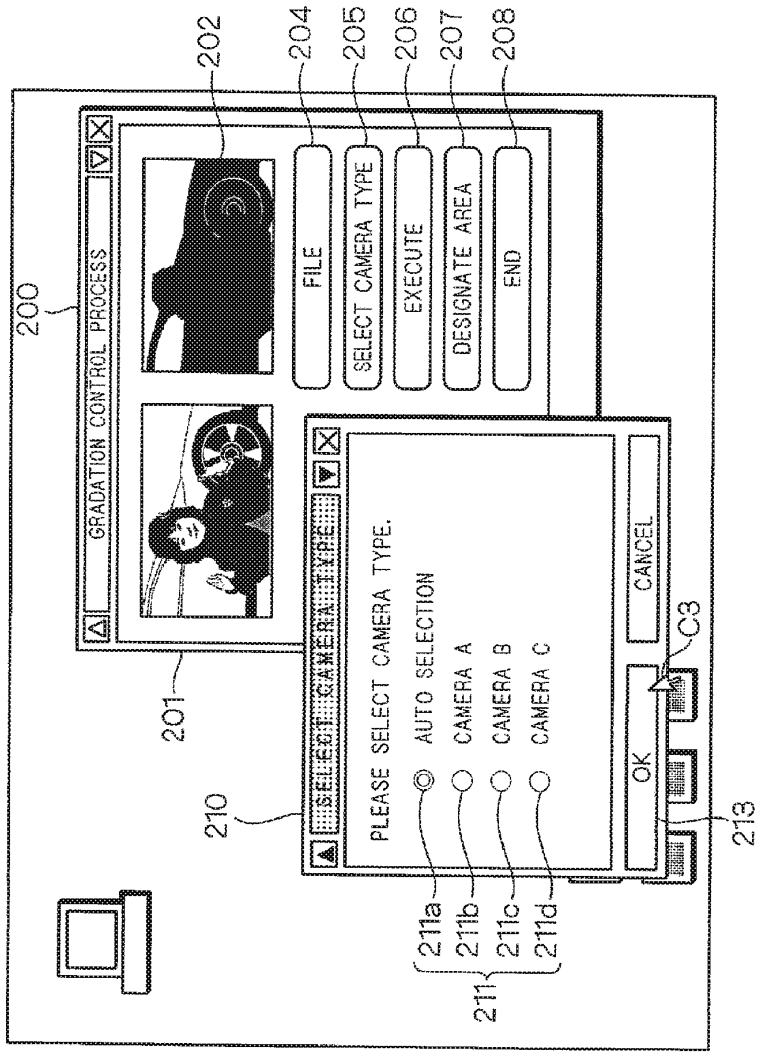
PE

FIG. 19


200
202
204
205
C3
206
207
208
f1
FILE
SELECT CAMERA TYPE
EXECUTE
DESIGNATE AREA
END
f2
f3
209
SIMULATION
201
203

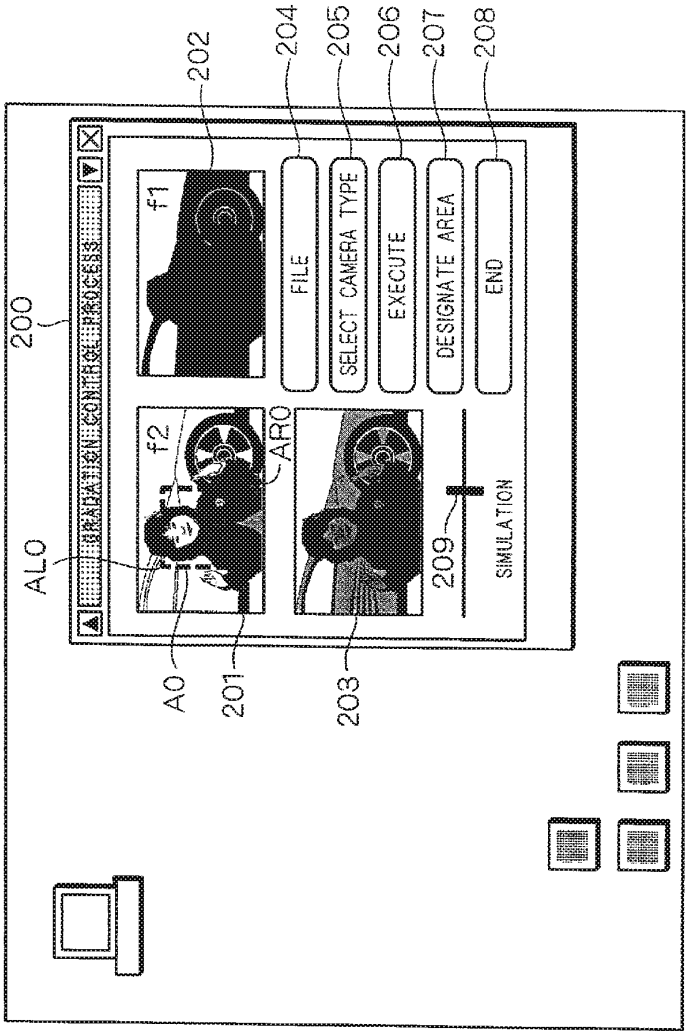
PE

FIG. 20


200
GRADATION CONTROL PROCESS
202
204
205
206
207
208
FILE
SELECT CAMERA TYPE
EXECUTE
DESIGNATE AREA
END
201
210
SELECT CAMERA TYPE
PLEASE SELECT CAMERA TYPE.
AUTO SELECTION
CAMERA A
CAMERA B
CAMERA C
CANCEL
OK
C3
213
211a
211b
211c
211d
211

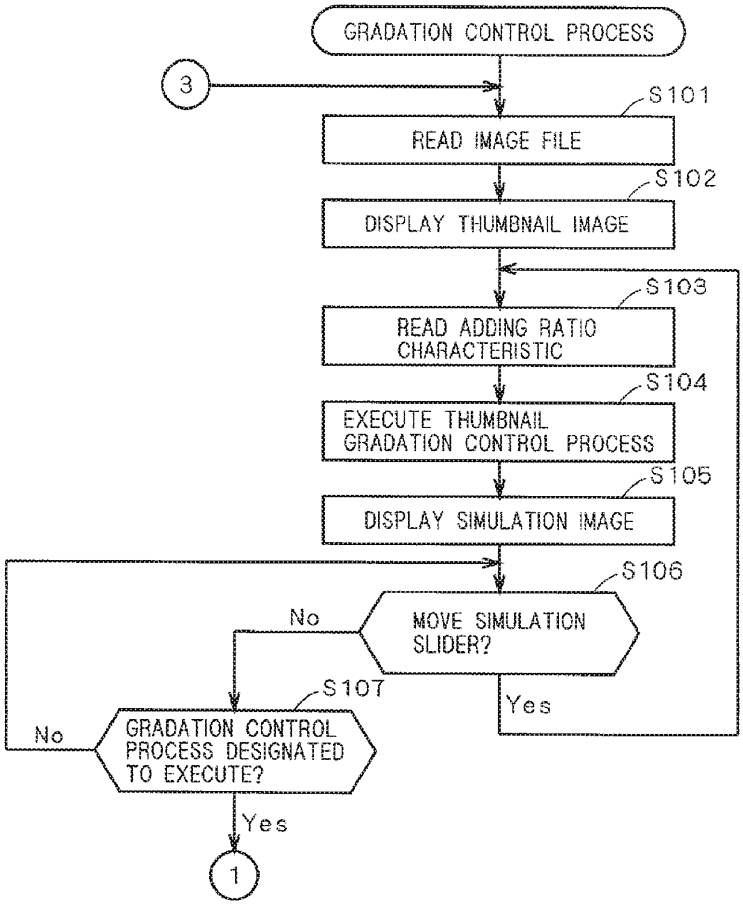
PE

FIG. 21


200
202
204
205
206
207
208
f1
FILE
SELECT CAMERA TYPE
EXECUTE
DESIGNATE AREA
END
f2
AR0
AL0
209
SIMULATION
A0
201
203

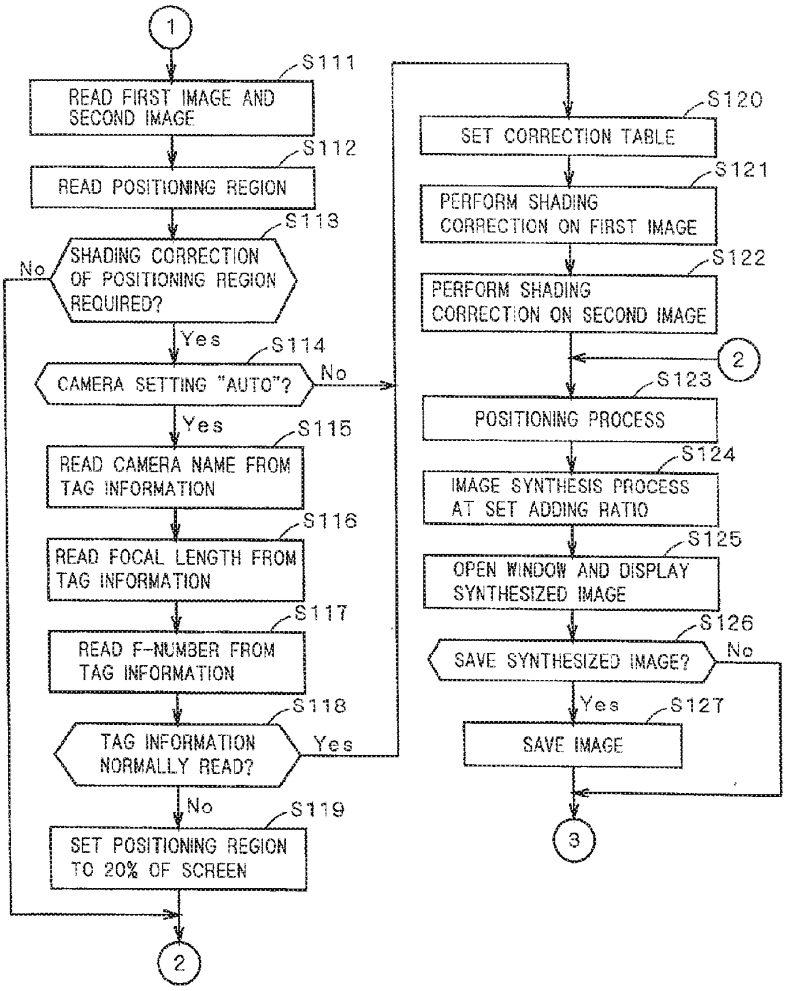
PE

FIG. 22


GRADATION CONTROL PROCESS
3
S101
READ IMAGE FILE
S102
DISPLAY THUMBNAIL IMAGE
S103
READ ADDING RATIO CHARACTERISTIC
S104
EXECUTE THUMBNAIL GRADATION CONTROL PROCESS
S105
DISPLAY SIMULATION IMAGE
S106
MOVE SIMULATION SLIDER?
No
Yes
S107
GRADATION CONTROL PROCESS DESIGNATED TO EXECUTE?
No
Yes
1

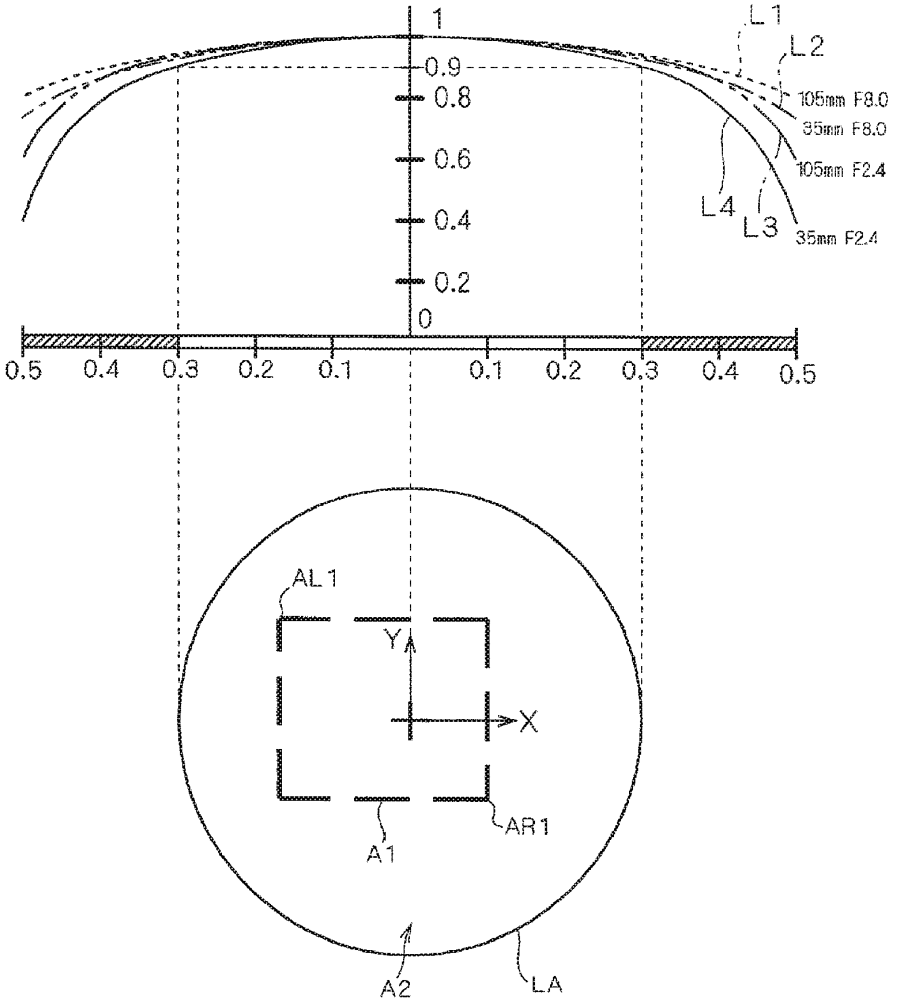
PE

FIG. 23


1
S111
READ FIRST IMAGE AND SECOND IMAGE
S112
READ POSITIONING REGION
S113
SHADING CORRECTION OF POSITIONING REGION REQUIRED?
No
Yes
S114
CAMERA SETTING "AUTO"?
No
Yes
S115
READ CAMERA NAME FROM TAG INFORMATION
S116
READ FOCAL LENGTH FROM TAG INFORMATION
S117
READ F-NUMBER FROM TAG INFORMATION
S118
TAG INFORMATION NORMALLY READ?
Yes
No
S119
SET POSITIONING REGION TO 20% OF SCREEN
2
S120
SET CORRECTION TABLE
S121
PERFORM SHADING CORRECTION ON FIRST IMAGE
S122
PERFORM SHADING CORRECTION ON SECOND IMAGE
2
S123
POSITIONING PROCESS
S124
IMAGE SYNTHESIS PROCESS AT SET ADDING RATIO
S125
OPEN WINDOW AND DISPLAY SYNTHESIZED IMAGE
S126
SAVE SYNTHESIZED IMAGE?
No
Yes
S127
SAVE IMAGE
3

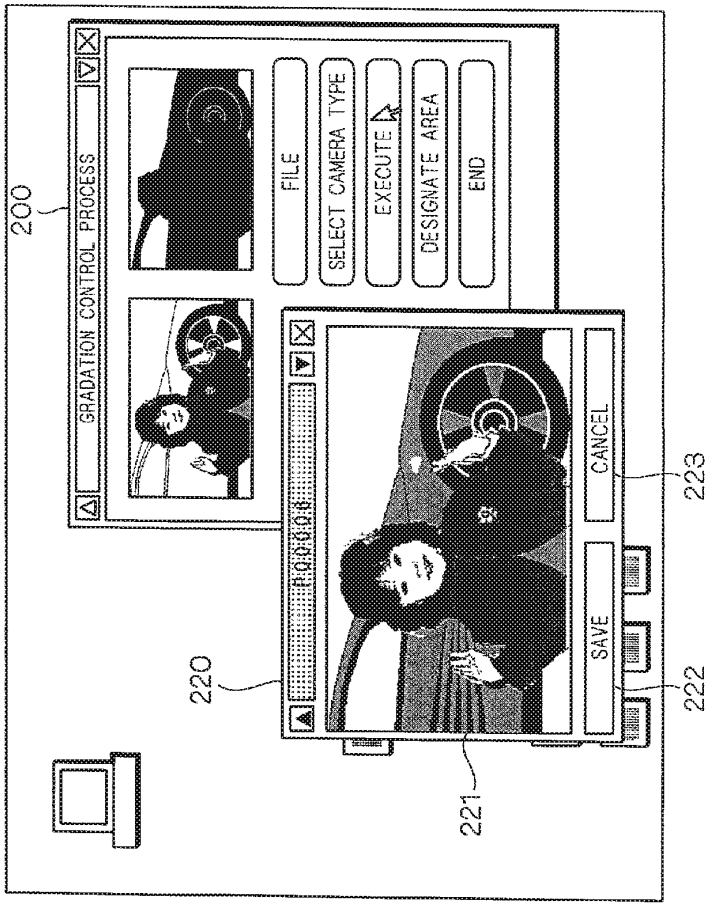
PE

FIG. 24


1
0.9
0.8
0.6
0.4
0.2
0
L1
L2
105mm F8.0
35mm F8.0
105mm F2.4
L4
L3
35mm F2.4
0.5 0.4 0.3 0.2 0.1 0.1 0.2 0.3 0.4 0.5
AL1
Y
X
AR1
A1
A2
LA

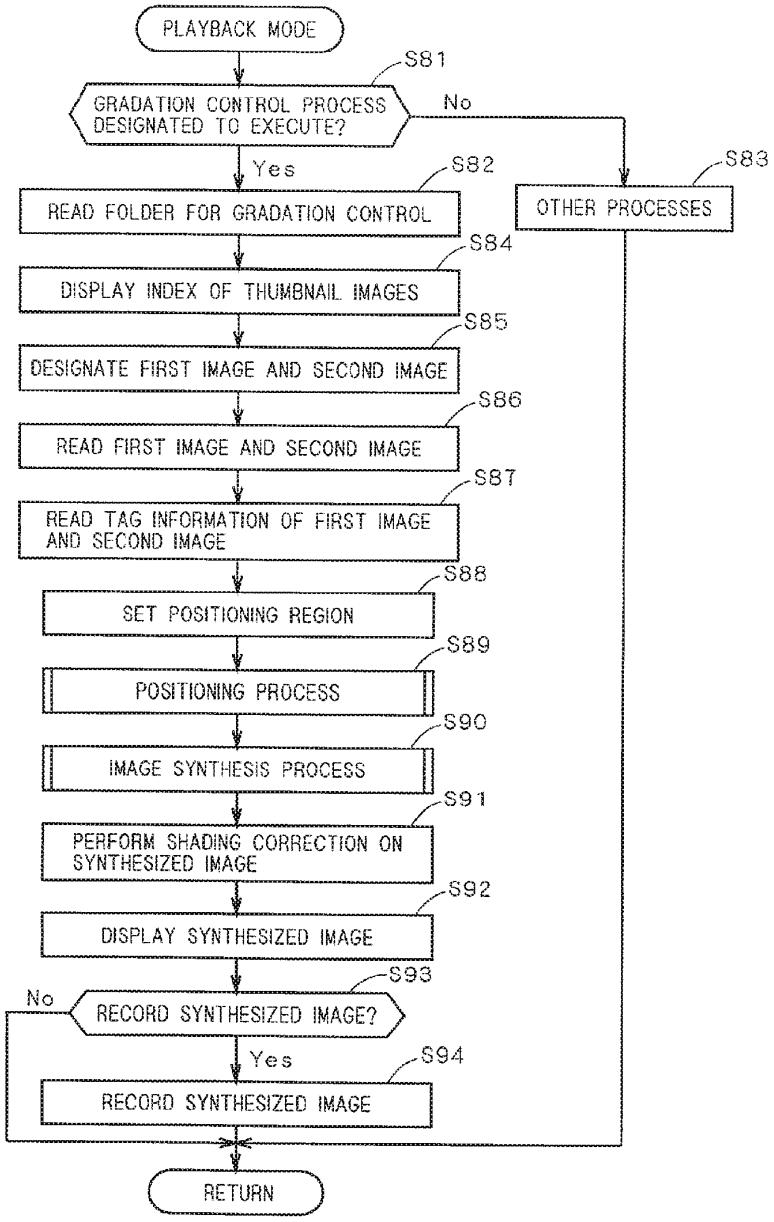
PE

FIG. 25


200
GRADATION CONTROL PROCESS
FILE
SELECT CAMERA TYPE
EXECUTE
DESIGNATE AREA
END
220
CANCEL
223
SAVE
222
221

PE

FIG. 26


PLAYBACK MODE
S81
GRADATION CONTROL PROCESS DESIGNATED TO EXECUTE?
No
Yes
S82
READ FOLDER FOR GRADATION CONTROL
S83
OTHER PROCESSES
S84
DISPLAY INDEX OF THUMBNAIL IMAGES
S85
DESIGNATE FIRST IMAGE AND SECOND IMAGE
S86
READ FIRST IMAGE AND SECOND IMAGE
S87
READ TAG INFORMATION OF FIRST IMAGE AND SECOND IMAGE
S88
SET POSITIONING REGION
S89
POSITIONING PROCESS
S90
IMAGE SYNTHESIS PROCESS
S91
PERFORM SHADING CORRECTION ON SYNTHESIZED IMAGE
S92
DISPLAY SYNTHESIZED IMAGE
S93
No
RECORD SYNTHESIZED IMAGE?
Yes
S94
RECORD SYNTHESIZED IMAGE
RETURN

PE

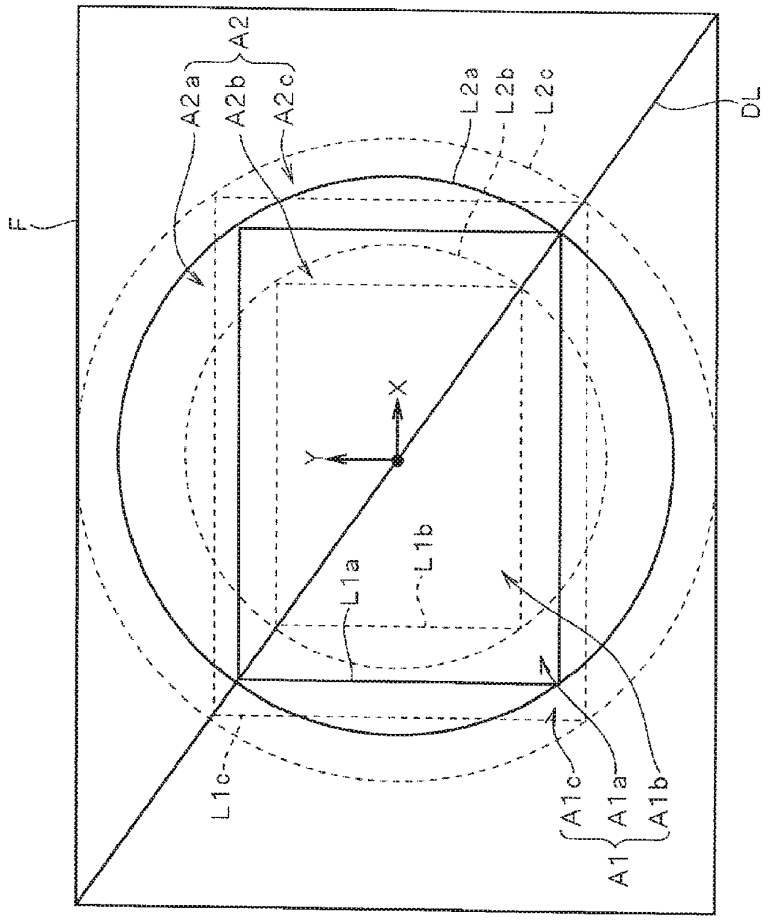


FIG. 27

PE

FIG. 28A

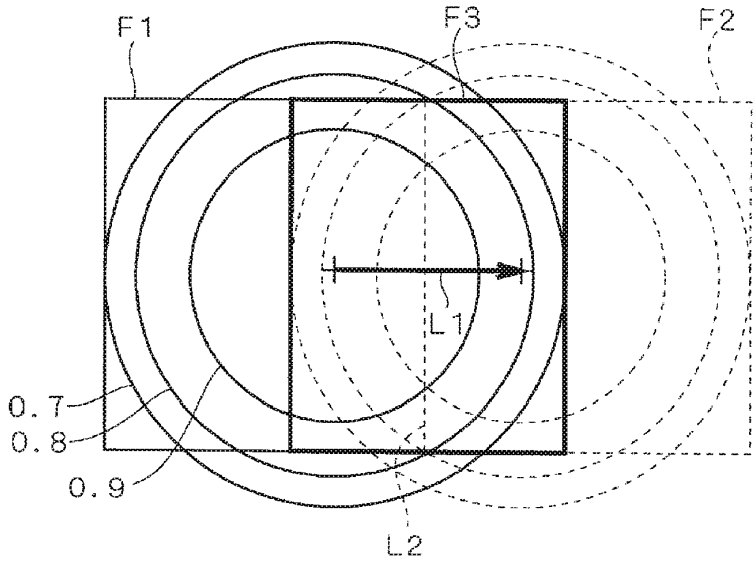
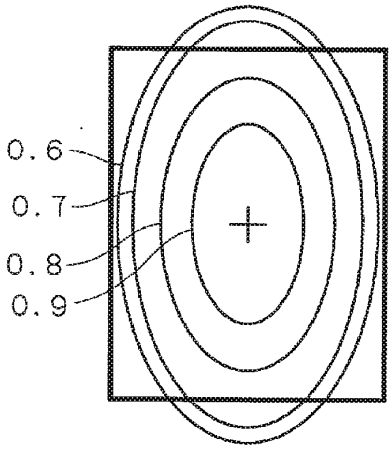


FIG. 28B



PE

IMAGE PROCESSING APPARATUS

[0001] This application is based on application No. 2001-088015 filed in Japan, the contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to an image processing technique for obtaining a synthesized image having improved image quality and graphic effect by synthesizing two images.

[0004] 2. Description of the Background Art

[0005] Conventionally, there have been proposed image processing techniques wherein using two images of different image qualities that have been captured for the same subject, an image having improved image quality and graphic effect compared to the original images is synthesized.

[0006] As one example according to the conventional art, a technique for correcting a blur wherein a plurality of images that have been captured at a shutter speed which is short enough so as not to be influenced by a blur are additively synthesized in accordance with the amount of blur is known.

[0007] As another example according to the conventional art, it is known that image data wherein any subjects at different positions are in focus can be obtained by synthesizing image data that has been obtained by capturing images while changing the focus position.

[0008] Further, U.S. Pat. No. 5,162,914 publication discloses a camera having a substantially widened dynamic range by capturing odd fields and even fields while changing the exposure time and synthesizing unblurred parts of these fields.

[0009] Further, U.S. Pat. No. 5,402,171 publication discloses a technique for improving resolution of image by synthesizing an image from image data captured while moving the image pickup device.

[0010] Practically, in the case of capturing two images for the same subject with a digital camera or the like, the images are captured at different timings and a small movement of the subject or movement of the camera itself will occur in this time lag of exposure. For this reason, a small difference in position arises between these two captured images.

[0011] In the case of synthesizing the above-mentioned two images, it is necessary to carry out positioning on these two images prior to synthesizing the images while taking such a positional difference between these images into consideration. If these images are synthesized without carrying out such positioning accurately, which leads rather deterioration of image.

[0012] Furthermore, it is general that when an image is captured via a lens in a digital camera or the like, so-called "shading" that the level of image data decreases with distance from the center of the image to the periphery. However, conventionally, in the case of synthesizing the above-mentioned two images, positioning of images was carried out without taking an influence of shading into account, so that deterioration in image quality resulted due to unsatisfactory positioning between images in some scenes.

SUMMARY OF THE INVENTION

[0013] The present invention is directed to an image processing apparatus which synthesizes a plurality of images.

[0014] According to the present invention, this image processing apparatus comprises: an image acquiring part for acquiring a first image and a second image; a shading corrector for performing a shading correction on each of the first image and the second image acquired by the image acquiring part; a position adjuster for performing positioning of the first image and the second image that have been subjected to the shading correction by the shading corrector; and an image generator for generating a synthesized image of the first image and the second image that have been subjected to the positioning by the position adjuster.

[0015] It is possible to perform accurate positioning while taking an influence of shading into consideration, and hence it is possible to prevent an image quality from deteriorating during the image synthesis process.

[0016] According to one aspect of the present invention, the image processing apparatus further comprises: an image memory capable of storing a plurality of images; and a controller for controlling the image memory to store a shading-corrected image that has been subjected to a shading correction by the shading corrector whenever each of the first image and the second image is acquired, wherein the position adjuster performs positioning in response to that either one of the first image and the second image that is acquired later is stored in the image memory as the shading-corrected image.

[0017] Since the positioning process is performed in response to that the image captured later from the first image and the second image is stored in the image memory as an image that has been subjected to the shading correction, it is possible to achieve optimization of the process.

[0018] According to another aspect of the present invention, the processing apparatus further comprises: an image memory capable of storing a plurality of images; and a controller for controlling the image memory to store each of the first image and the second image acquired in the image acquiring part; wherein the shading corrector performs a shading correction on each of the first image and the second image stored in the image memory.

[0019] After the first image and the second image are stored in the image memory, the shading correction is for each of the first image and the second image, with the result that it is possible to reduce the interval of the exposures for the first image and the second image.

[0020] According to yet another aspect of the present invention, the image acquiring part is an image sensor for capturing the first image and the second image for the same subject in different timings.

[0021] It is possible to synthesize two images acquired for the same subject in different timings while taking an influence of shading into consideration.

PE

[0022] Also the present invention is directed to a program product containing a program for executing an image processing.

[0023] Therefore, it is an object of the present invention to make it possible to synthesize two images with high accuracy in consideration of an influence of shading

[0024] These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] **FIG. 1** is a view showing an example of an influence by shading in an image.

[0026] **FIG. 2** is a plan view showing an image processing apparatus according to a preferred embodiment of the present invention.

[0027] **FIG. 3** is a section view showing an image processing apparatus according to the preferred embodiment of the present invention.

[0028] **FIG. 4** is a front view showing an image processing apparatus according to the preferred embodiment of the present invention.

[0029] **FIG. 5** is a block diagram showing a functional configuration of an image processing apparatus according to the first preferred embodiment.

[0030] **FIG. 6** is a view showing a coefficient processing hardware circuit for performing a shading correction.

[0031] **FIG. 7** is a view showing one example of a correction table used for a shading correction.

[0032] **FIG. 8** is a view showing a recording method of an image file to a memory card.

[0033] **FIG. 9** is a view showing a processing procedure of a gradation control process in the first preferred embodiment.

[0034] **FIG. 10** is a view showing a processing procedure of a positioning process.

[0035] **FIG. 11** is a view showing movement of an image in a positioning process.

[0036] **FIG. 12A** is a view showing respective gradation characteristics of an overexposed image and an underexposed image.

[0037] **FIG. 12B** is a view showing a synthesis ratio of an overexposed image and an underexposed image in a gradation control process.

[0038] **FIG. 13** is a block diagram showing a functional configuration of an image processing apparatus in the second preferred embodiment.

[0039] **FIG. 14** is a view showing a processing procedure of a gradation control process in the second preferred embodiment.

[0040] **FIG. 15** is a view showing a configuration example of image file stored in a memory card.

[0041] **FIG. 16** is a view showing a processing procedure of a gradation control process in the third preferred embodiment.

[0042] **FIG. 17A** is a view showing a selection screen for an image to be subjected to a gradation control process in the playback mode.

[0043] **FIG. 17B** is a view showing a playback screen in the playback mode.

[0044] **FIG. 18** is an appearance view showing a configuration of an image processing apparatus according to the fourth preferred embodiment.

[0045] **FIG. 19** is a view showing one example of a work window displayed on the display in the case where a gradation control program is executed.

[0046] **FIG. 20** is a view showing an example of a camera selection window displayed on the display.

[0047] **FIG. 21** is a view showing an example of designating a positioning area using thumbnail images displayed on the display.

[0048] **FIGS. 22 and 23** are views each showing a processing procedure of a gradation control program.

[0049] **FIG. 23** is a view showing a processing procedure of a gradation control program.

[0050] **FIG. 24** is a view showing an influence of shading and a non-shading area in captured image data.

[0051] **FIG. 25** is a view showing an example of a process result display window displayed on the display.

[0052] **FIG. 26** is a view showing a processing procedure of a gradation control process in the fifth preferred embodiment.

[0053] **FIG. 27** is a view showing an example of a non-shading area in accordance with a focal length and an f-number at the time of exposure.

[0054] **FIGS. 28A and 28B** are views showing curves each having a constant distribution of correction coefficients used for shading correction in captured image data and a synthesized image.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0055] Before explaining concrete configurations and operations of the preferred embodiments of the present invention, the background of the present invention will be explained by way of a concrete example.

[0056] When a subject is photographed by using an image pickup device such as CCD in an image processing apparatus such as digital camera equipped with an imaging lens, a phenomenon that the level of image data decreases with the distance from the center of the image to the periphery, so-called "shading" occurs.

[0057] **FIG. 1** is a view showing an example of an influence of shading on an image captured by means of a certain digital camera. The image depicted in **FIG. 1** is such that all the pixels constituting the image receive incident light from the subject of the uniform brightness. The horizontal axis represents distance from the optical axis of each

PE

Samsung Exhibit 1002, Page 467 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

image data, in a relative distance with the distance of diagonal line of the image being 1. That is, the center point of the image which is image data of the optical axis is the origin point. The vertical axis represents level of each image data, in a relative value with the level of image data of the optical axis being 1. It is contemplated that this relative value represents a decrease rate of level of image data due to shading at each pixel position.

[0058] The respective curves denoted by the reference numerals L1 to L4 represent decrease rates in level of image data when the focal length and the diaphragm of the imaging lens are changed while using the same digital camera and the same imaging lens. The curve L1 represents the case where the focal length is 105 mm (converted value in a 35 mm film camera) and the f-number is 8.0, the curve L2 represents the case where the focal length is 35 mm and the f-number is 8.0, the curve L3 represents the case where the focal length is 105 mm and the f-number is 2.4, and the line L4 represents the case where the focal length is 35 mm and the f-number is 2.4.

[0059] As shown in this drawing, the longer the distance from the center point of the image which is the optical axis to the periphery, the lower the level of image data. That is, the closer to the periphery the image data exists, the more the image is likely to be influenced by shading (larger decrease rate of level).

[0060] Furthermore, in the case of using the same digital camera and the same imaging lens, the influence of shading varies with the focal length and the amount of exposure light. As shown in the drawing, the shorter the focal length (wide side), the larger the influence of shading (influence range and decrease rate of level), whereas the longer the focal length (tele side), the smaller the influence of shading. Furthermore, in the same manner, the larger the amount of exposure light, the larger the influence of shading, whereas the smaller the amount of exposure light, the smaller the influence of shading. As can be seen in the drawing, the smaller the f-number (the smaller the f-stop number of diaphragm), the larger the influence of shading, whereas the larger the f-number (the larger the f-stop number of diaphragm), the smaller the influence of shading.

[0061] By the way, when a subject is photographed by a digital camera or the like, a phenomenon sometimes occurs that light portions in the subject image are too white, while dark portions in the subject image are too black. This phenomenon results from a narrow dynamic range of a general image pickup device and causes deterioration in image quality. For eliminating such a phenomenon, it has been supposed that an image whose dynamic range is substantially widened is generated by capturing two images of different exposures for the same subject in different timings and synthesizing them to conduct a gradation control process.

[0062] In the case of capturing two images in different timings for obtaining a synthesized image, a small difference in position occurs between these two images thus captured because of the difference in timing. For this reason, in synthesizing two images, it is necessary to effect positioning for these two images prior to synthesizing the images while taking such a positional difference between these images into consideration. However, it is impossible to effect accurate positioning without taking such an influence of shading as described above into consideration. In preferred embodiments as will be described below, the above-mentioned influence of shading is taken into consideration when effecting the positioning on such two images.

[0063] In the following, preferred embodiments of the present invention will be explained in detail while referring to the attached drawings.

[0064] <1. First Preferred Embodiment>

[0065] FIGS. **2** to **4** show schematic configurations of an appearance of a digital camera **1** which is an image processing apparatus according to the first preferred embodiment of the present invention. **FIG. 2** is a plan view of the digital camera **1**, **FIG. 3** is a cross section view viewed from the position II-II of **FIG. 2**, and **FIG. 4** is a rear view of the digital camera **1**.

[0066] As shown in these drawings, the digital camera **1** comprises a camera main body **2** which is a nearly rectangular parallelepiped and an imaging lens **3** which is detachably attached to the camera main body **2**. As shown in **FIG. 2**, the digital camera **1** is adapted to detachably accommodate a memory card **8** for recording a captured image. The digital camera **1** uses a power battery E in which four AA cells E1 to E4 are serially connected as a driving source.

[0067] As shown in **FIG. 3**, the imaging lens **3** which is a zoom lens having a macro function comprises a lens group **30** including a zoom lens **300** and a focus lens **301**. On the other hand, inside the camera main body **2** are provided a zoom motor M1 for changing the zoom ratio of the zoom lens **300** and a focus motor M2 for driving the focus lens **301** to achieve focusing. Also, behind the lens group **30** of the imaging lens **3** is provided a color image pickup device **303** at an appropriate position. The color image pickup device **303** is configured by a single-sheet type color area sensor in which colors filters of R(red), G(green) and B(blue) are bonded in a checker on the surface of each pixel of the area sensor formed of a CCD. The color image pickup device (hereinafter, referred to as "CCD") **30** has, for example, a total of 1,920,000 pixels of 1,600 pixels in the horizontal direction and 1,200 pixels in the vertical direction.

[0068] On the front surface of the camera main body **2** is provided a grip portion G as shown in **FIG. 2**, and at an appropriate position of the upper end of the camera main body **2** is provided an integrated flash of hop-up type. Further, as shown in **FIG. 4**, a shutter button **9** is provided on the top surface of the camera main body **2**. The shutter button **9** has a function of detecting and discriminating a half-pressed state (S1) to be used as a trigger for focus adjustment and a full-pressed state (S2) to be used as a trigger for exposure for recording.

[0069] On the other hand, the rear surface of the camera main body **2** is provided with an electronic viewfinder (hereinafter, referred to as "EVF") **20** and a liquid crystal display (hereinafter, referred to as "LCD") **10**. In contrast with the case of the optical finder, the EVF **20** and the LCD **10** serve as a finder for performing a live view display of an image signal from the CCD **303** in the image standby state.

[0070] Also the LCD **10** can display a menu screen for setting an exposure mode, an imaging condition or the like in the recording mode and reproducing and displaying a captured image recorded on the memory card **8** in the playback mode.

PE

Samsung Exhibit 1002, Page 468 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

[0071] In the left part on the rear surface of the camera main body **2** is provided a power switch **14**. This power switch **14** also serves as a mode setting switch for switching the mode between a recording mode (mode for executing photographing) and a playback mode (mode for reproducing a recorded image on the LCD **10**). To be more specific, the power switch is formed of a three-position slide switch wherein when the contact is slid to the center "OFF" position, the power is turned off, when the contact is slid to the upper "REC" position, the power is turned on and the recording mode is effected, and when the contact is slid to the lower "PLAY" position, the power is turned on and the playback mode is effected.

[0072] In the light part on the rear surface of the camera main body **2** is provided a four-gang switch **15**. The four-gang switch **15** has a circular operational button which enables various operations to be made by pressing buttons U, D, L and R provided in the right, left, upward and downward directions in this operational button. For example, this four-gang switch **15** serves as a switch for changing the item selected on the menu screen displayed on the LCD **10** and for changing the frame to be reproduced which is selected on an index screen. Furthermore, the left and right buttons L, R serve as switches for changing the zoom ratio in the recording mode. When the right switch R is pressed down, the zoom lens **300** continuously moves to the wide side being driven by the zoom motor M1 and when the left switch L is pressed down, the zoom lens **300** continuously moved to the tele side by being driven by the zoom motor M1.

[0073] Also, below the four-gang switch **15** is provided a switch group **16** including a cancel switch **33**, an execute switch **32**, a menu display switch **34**, a LCD display switch **31** and the like. The cancel switch **33** is a switch for canceling the content that has been selected on the menu screen. The execute switch **32** is a switch for confirming or executing the content that has been selected on the menu screen. The menu display switch **34** is a switch for displaying a menu screen on the LCD **10** or changing the contents of the menu screen. The LCD display switch **31** is an ON/OFF changeover switch of the display on the LCD **10**.

[0074] A user can open the menu screen for selection of exposure mode and select an exposure mode by operating the four-gang switch **15**, the switch group **16** and the like. The exposure mode includes a normal exposure mode in which an exposure is made one by one in the usual manner and a gradation control processing mode. The gradation control processing mode refers to a mode intended for obtaining a synthesized image with substantially widened dynamic range by capturing two images having different exposures for the same subject in different timings, and synthesizing these images in an appropriate adding ratio. A single operation of the shutter button **9** triggers two exposures while changing the exposure condition so as to obtain two images.

[0075] Next, an internal configuration of the digital camera **1** will be explained. **FIG. 5** is a schematic block diagram showing an internal configuration of the digital camera **1**.

[0076] The imaging lens **3** has therein a diaphragm **302** for adjusting an amount of light transmission, as well as the zoom lens **300** and the focus lens **301**.

[0077] An image capturer **110** photoelectrically converts a subject light source entered via the imaging lens **3** into an image signal and captures the image signal, and is provided with a timing generator **111** and a timing control circuit **112** as well as the CCD **303**. The CCD **303** receives the light of the subject light source for a predetermined exposure time based on a drive control signal inputted from the timing generator **111** to convert it to an image signal, and outputs the image signal to a signal processor **120** by using a readout control signal inputted from the timing generator. At this time, the image signal is outputted to the signal processor **120** while being divided into each of the color components R, G and B.

[0078] The timing generator **111** generates a drive control signal on the basis of a control signal inputted from the timing control circuit **112**, as well as generates a readout signal on the basis of a reference clock to output it to the CCD **303**. The timing control circuit **112** controls the imaging operation of the image capturer **110**. The timing control circuit **112** generates an imaging control signal on the basis of a control signal inputted from a general controller **150**. Examples of the imaging control signal include a control signal for photographing a subject, a reference clock, a timing control signal (synchronous clock) for processing an image signal outputted from the CCD **303** at the signal processor **120**. The timing control signal is inputted to a signal processing circuit **121**, an A/D conversion circuit **122**, a shading correction circuit **123** and the like in the signal processor **120**.

[0079] The signal processor **120** executes a predetermined analogue signal processing and digital signal processing with respect to an image signal outputted from the CCD **303**. The signal processing of image signal is executed for every light reception signal of each pixel constituting the image data. The signal processor **120** has the signal processing circuit **121**, the A/D conversion circuit **122**, the shading correction circuit **123**, an WB circuit **124**, a γ correction circuit **125** and an image memory **126**.

[0080] The signal processing circuit **121** is designed to execute analogue signal processing, mainly configured by a CDS (correlation double sampling) circuit and an AGC (auto gain control) circuit, and serves to reduce the sampling noise and adjust the signal level for the image signal outputted from the CCD **303**. The gain control in the AGC circuit includes the case where a level shortage of the captured image is compensated when a correct exposure is not obtained by the f-number of the diaphragm **302** and the exposure time of the CCD **303**.

[0081] The A/D conversion circuit **122** is designed to convert an image signal which is an analogue signal outputted from the signal processing circuit **121** to image data which is a digital signal. The A/D conversion circuit **122** converts image signals received by the respective pixels into, for example, digital signals of **10** bits to render image data having gradation values of 0 to 1023.

[0082] The shading correction circuit **123** corrects a shading due to optical system with respect to the image data that has been subjected to A/D conversion. The shading correction circuit has a multiplier **123***a* as shown in **FIG. 6**, and receives a timing control signal inputted from the timing control circuit **112** and performs multiplication of image data converted in the A/D conversion circuit **122** and a correction table inputted from the general controller **150**.

[0083] **FIG. 7** is a view showing one example of the correction table. As shown in **FIG. 7**, the correction table

PE

has 1,920,000 correction coefficients (actually, inverses of correction coefficients) for corresponding to the respective 1,920,000 pixels of 1,600 pixels×1,200 pixels of the CCD **303**. Each correction coefficient corresponds to the rate of decrease in level of each pixel data shown in **FIG. 1**, and the inverse of the correction coefficient is held in the correction table in advance. When each pixel shown in the curve of **FIG. 1** is multiplied by the inverse of the correction coefficient, the curve is converted to a straight line in which the levels of image data are constantly **1**. That is, by subjecting every pixel data to the multiplication by the inverse of the correction coefficient (coefficient process), the shading can be corrected. In the case where overflow occurs in this multiplication process, the level of the image data is set at the maximum value of 1023.

[0084] A plurality of correction tables for different parameters which are the optical conditions such as focal length and f-number at the time of imaging are prepared and stored in a shading ROM **153** provided in the general controller **150**. The general controller **150** performs selection of correction table from the shading ROM **153** in accordance with the optical condition such as focal length and f-number at the time of imaging. Therefore, the shading correction circuit **123** can perform a shading correction in accordance with the optical condition.

[0085] In the above correction table, since the correction coefficients are set for every pixel, the data size is enormous. For this reason, for example, it is also possible to set one correction data for each block unit of 4 pixels×4 pixels and perform correction for each pixel block. Furthermore, it is also possible to set a correction data of each block unit as a reference value of the block, and determine a correction coefficient of each pixel by weights of reference values of the block to which the object pixel belongs and the peripheral blocks with the position (distance) of the pixel. In this case, it is possible to reduce the data size of the correction table to 1/16 in comparison with the case where correction coefficients are prepared for every pixel.

[0086] Referring again to **FIG. 5**, the WB circuit **124** adjusts a white balance of captured image. The WB circuit **124** adjusts a white balance of captured image by converting the level of image data of each color component R, G, B with the use of a level conversion table inputted from the general controller **150**. The γ correction circuit **125** corrects a γ characteristic of image data. The γ correction circuit **125** corrects the level of each image data using the γ correction table which is preliminarily set.

[0087] The image memory **126** is a memory for temporarily storing image data for which image processing has been completed. The image memory **126** has two memory areas, concretely a first memory **126***a* and a second memory **126***b* so as to be capable of storing image data of two frames. The first memory **126***a* and the second memory **126***b* each have a memory capacity capable of storing image data of one frame. In the present preferred embodiment, since the number of pixels is **1,920,000**, each of them has a capacity that can store image data of 1,920,000 pixels.

[0088] A light emission controller **102** controls light emission of the flash **5** on the basis of a light emission control signal inputted from the general controller **150**. The light emission control signal includes an indication for making preparation for light emission, a light emission timing and an amount of light emission.

[0089] A lens controller **130** controls drivings of the zoom lens **300**, the focus lens **301** and the diaphragm **302** in the imaging lens **3**. The lens controller **130** has a diaphragm control circuit **131** for controlling an f-number of the diaphragm **302**, a zoom control circuit **132** for controlling driving of the zoom motor **M1** and a focus control circuit **133** for controlling driving of the focus motor **M2**.

[0090] On the basis of an f-number inputted from the general controller **150**, the diaphragm control circuit **131** drives the diaphragm **302** and sets the amount of aperture at that f-number. The focus control circuit **133** controls the amount of drive of the focus motor **M2** on the basis of an AF control signal inputted from the general controller **150** and sets the focus lens **301** at the in-focus position. The zoom control circuit **132** drives the zoom motor **M1** on the basis of the zoom control signal inputted from the general controller **150** and causes the zoom lens **300** to move in the direction designated by the four-gang switch **15**.

[0091] A display part **140** achieves display on the LCD **10** and the EVF **20**. The display part **140** has a LCD VRAM **141** serving as a buffer memory for image data to be reproduced and displayed on the LCD **10** and an EVF VRAM **142** serving as a buffer memory for image data to be reproduced and displayed on the EVF **20**, as well as the LCD **10** and the EVF **20**.

[0092] In the imaging standby state, each image data of images taken every 1/30 (sec.) by the CCD **303** is temporarily stored in the image memory **126** after being subjected to a predetermined signal processing by the signal processor **120**. Then, the image data is read out by the general controller **150**, transferred to the LCD VRAM **141** and the EVF VRAM **142** after being subjected to data size adjustment, and displayed on the LCD **10** and the EVF **20** in the form of a live view display. This allows the user to visually recognize the subject image. On the other hand, in the playback mode, an image read out from the memory card **8** is transferred to the LCD VRAM **141** after being subjected to a predetermined signal processing by the general controller **150** to be reproduced and displayed on the LCD **10**.

[0093] An RTC **104** is a clock circuit for controlling the date and time of exposure. The date and time of exposure thus obtained is stored in the memory card **8** while being associated with the captured image data.

[0094] An operational part **101** inputs operational information from the above-mentioned operational members relating to exposure and playback provided on the camera main body **2** to the general controller. The operational information inputted from the operational part **101** includes operational information of each operational member such as shutter button **9**, power switch **14**, four-gang switch **15** and switch group **16**.

[0095] The general controller **150** is implemented by a microcomputer and performs centralized control of the exposure function and playback function. The general controller **150** is connected with the memory card **8** via a card interface **103**. Also a personal computer PC is externally connected via a communication interface **105**.

[0096] The general controller **150** has a ROM **151** which stores processing programs for executing a variety of concrete processings in the exposure function and the playback function and control programs for controlling drivings of the

PE

above-mentioned members of the digital camera **1**, and a RAM **152** which is a work area for executing a number of operations in accordance with the processing programs and the control programs. Also, it is so configured that program data recorded on a memory card **8** which is a recording medium can be read out via the card interface **103** to be stored in the ROM **151**. Therefore, these processing programs and control programs can be installed into the digital camera **1** from the memory card **8**. The processing programs and the control programs may be installed from the personal computer PC via the communication interface **105**.

[0097] In **FIG. 5**, an exposure setting part **154**, a display controller **155**, a recording controller **156**, a playback controller **157**, a special imaging controller **158** and an image synthesizer **159** represent functions implemented by the processing programs of the general controller **150** in the forms of functional blocks.

[0098] The exposure setting part **154** for executing an exposure control process and determines a brightness of the subject using image data of G color component of the live view image and calculates an exposure control value based on the determination result.

[0099] The display controller **155** for executing an image display process performs the above-mentioned display operation of the display part **140**, that is, it performs an operation of reading image data temporarily stored in the image memory **126** and transferring the image data to the LCD VRAM **141** or the EVF VRAM **142** after adjusting the image size to adapt to the image size of the display destination as is necessary.

[0100] The recording controller **156** executes a recording process. In the normal exposure mode, the recording controller **156** reads out the image data that has been temporarily stored in the image memory **126** after an instruction for exposure is made, and performs predetermined processes based on the JPEG system such as two-dimensional DCT conversion and Huffman coding to generate image data for use recording as captured image data. Furthermore, a thumbnail image is generated by reading out the image data every **8** pixels in each of the vertical and the horizontal directions from the image memory **126** to the RAM **152**. Moreover, tag information relating to the captured image data which to be recorded in association with these captured image data is generated. Then, the recording controller **156** generates an image file in which tag information is attached to compressed captured image and thumbnail image, and records the image file onto the memory card **8**. In the case where two images are captured in the gradation control processing mode, the same recording process as described above is performed on the synthesized image having subjected to synthesis process by the image synthesizer **159**.

[0101] **FIG. 8** is a view showing a recording method of image file onto the memory card **8**. In the top recording area of the memory card, an index area for storing folder information and information of image files belonging to the respective folder is provided, and in subsequently areas, image files are sequentially stored in the order of being captured. The recording area of each image file in the memory card **8** is composed of three areas and tag information, captured image data and thumbnail image are sequentially stored in these three areas from upstream. As shown in the drawing, the tag information includes a camera name, a lens name, a focal length at the time of exposure, an f-number at the time of exposure, an exposure mode, a focal position, a file name, a subject brightness, a white balance adjustment value and a date and time of exposure. The imaging mode represents information whether the image is captured in the normal exposure mode or in the gradation control processing mode.

[0102] The playback controller **157** performs reproducing process of a captured image recorded on the memory card **8** on the LCD **10**. The playback mode is set by the power switch **14**, and then the playback controller **157** reads out thumbnail images from each image file recorded on the memory card **8** and stores them sequentially in the LCD VRAM **141** according to a predetermined index form. As a result of this, thumbnail images are index displayed on the LCD **10**. When a thumbnail image to be reproduced is designated from the index displayed thumbnail images by the four-gang switch **15** and the switch group **16**, the playback controller **157** reads out the captured image data from the image file and after performing a predetermined elongation process on compressed captured image data, the playback controller **157** transfers it to the LCD VRAM **141** to make the LCD **10** display it.

[0103] The special imaging controller **158** controls the exposure operation of the CCD **303** when the shutter button **9** is pressed all the way down (S2) in the condition that the exposure mode is set at the gradation control mode. When the shutter button **9** is brought into the S2 state, for capturing images for synthesis to which the gradation control process is to be effected, the special imaging controller **158** changes the exposure time of the CCD **303** which corresponds to the shutter speed, thereby achieving the control such that exposure operation is repeated twice at a predetermined interval.

[0104] The image synthesizer **159** performs a synthesis process of data of two images with different exposure amounts that have been captured in the gradation control processing mode. In this synthesis processes, positioning (positioning process) is performed between two images, and a process for generating an actual synthesized image (image synthesis process) by adding these at an appropriate adding ratio is performed, the detail of which will be described later.

[0105] Next, exposure operation in the gradation control processing mode of the digital camera **1** configured as described above will be explained. **FIG. 9** is a flow chart showing a procedure of image capturing operation in the gradation control processing mode.

[0106] In step S11, when the shutter button **9** is pressed half way down, a focal point of the lens group **30** of the imaging lens **3** is adjusted for a main subject, an exposure control value is calculated by using a live view image and a while balance adjustment value is set. The exposure control value which is calculated at this time is a value to provide correct exposure, and concretely, a shutter speed and an f-number which are correct values are obtained (step S12).

[0107] Next, when the shutter button **9** is pressed all the way down in step S13, the shutter speed is set at a shutter speed which is at two steps under the shutter speed which is a correct value (step S14). Then, the CCD **303** is exposed to the light for an exposure time corresponding to this shutter speed, and thereby a first image F1 of the subject is captured (step S15). After exposure, an image signal outputted from

PE

the CCD **303** is subjected to a predetermined analogue signal processing in the signal processing circuit **121**, and converted into pixel data of 10 bits in the A/D conversion circuit **122**.

[0108] Next, in the shading correction circuit **123**, correction of shading is executed (step S16). At this time, a correction table which corresponds to the optical conditions of focal length and f-number at the time of exposure is selected and inputted to the shading correction circuit **123** by the general controller **150**. The shading correction circuit **123** performs shading correction by executing multiplication process of image data outputted from the A/D conversion circuit **122** and the inputted correction table (see **FIG. 6**).

[0109] After that, predetermined processes are executed by the WB circuit **124** and the γ correction circuit **125**, and stored in the first memory **126***a* of the image memory **126** (step S17). As for this first image F1, since the exposure time of the CCD **303** is set shorter than the proper value, the image is in general dark because of less amount of light exposure compared to images captured in the normal exposure mode. Furthermore, since the shading correction is performed in the shading correction circuit **123**, an influence of shading is eliminated.

[0110] Next, from the shatter speed which is a proper value, a shutter speed over two steps is set (step S18), and the CCD **303** is exposed to the light for an exposure time corresponding to this shutter speed, and a second image F2 of the subject is captured (step S19). After the exposure, as is the same with the first image F1, an image signal outputted from the CCD **303** is subjected to a predetermined analogue signal processing in the signal processing circuit **121**, converted into pixel data of **10** bits in the A/D conversion circuit **122**, subjected to a shading correction in the shading correction circuit **123**, subjected to predetermined processes in the WB **123** and the **7** correction circuit **125**, and stored in the second memory **126***b* of the image memory (steps S20, S21). As for this second image F2, since the exposure time of the CCD **303** is set longer than the proper value, the image is in general light because of the amount of light exposure is larger in comparison with images captured in the normal exposure mode. Furthermore, as is the same with the first image F1, since the shading correction is performed in the shading correction circuit **123**, an influence of shading is eliminated.

[0111] Next, in response to that the second image F2 is stored in the second memory **126***b* of the image memory, the image synthesizer **159** of the general controller **150** reads out the captured first image F1 and the second image F2 from the image memory and performs positioning of these images (step S22). This positioning process is such that both of the images to be synthesized are positioned so as to synthesize the same patterns in the image accurately in the image synthesis process. In this positioning process, the second image F2 is moved while referring the first image F1 as a reference image. **FIG. 10** is a flow chart showing a flow of this positioning process.

[0112] In step S31, a movement amount of the second image F2 in the rectangular XY plane coordinate system is calculated. This can be achieved by determining a movement amount by which the correlative coefficient C (ξ,η) represented by the following Expression 1 is minimum, assuming that the second image F2 is moved in parallel in the X direction and the Y direction.

$$C(\xi,\eta)=\Sigma\Sigma\{P1\ (x,y)-P2\ (x-\xi,y-\eta)\}^2 \quad [1]$$

[0113] In the above expression, x, y represent coordinate variables in the rectangular XY plane coordinate system whose origin is the center of the image, P1 (x, y) represents levels of image data at the coordinate points (x, y) of the first image F1, and P2 (x−ξ,y−η) represents levels of image data at the coordinate points (x−ξ, y−η) of the second image F2. That is, the correlative coefficient C (ξ,η) expressed by the Expression 1 is obtained by squaring a difference in level between corresponding image data of two images, and calculating a total sum of the resultant values for all pixel data. And, when (ξ, η) which represents movement amount of the second image F2 is changed, the (ξ, η) at which the correlative coefficient C becomes minimum will be a movement amount of the second image F2 when the both images are best matched.

[0114] In the present preferred embodiment, (ξ, η) at which the correlative coefficient C becomes minimum is calculated as (x3, y3), for example, by changing ξ representing movement amount regarding the X coordinate of the second image F2 from −80 to +80, and η representing movement amount regarding the Y coordinate of the second image F2 from −60 to +60. It is to be noted that in the gradation control mode, since the first image F1 and the second image F2 are captured while changing the exposure time of the CCD **303**, there is a difference in brightness level of entire image between the first image F1 and the second image F2. Therefore, it is preferred to determine the correlative coefficient C after normalization by dividing both image data by the respective average brightness's.

[0115] Furthermore, in this positioning process, only G color component which exerts a large influence on the resolution from the view point of the human visual characteristic may used. In such a case, as for the R, B color components which exert a little influence on the resolution from the view point of the human visual characteristic, positioning processes can be simplified by utilizing the movement amount calculated for the G color component.

[0116] Next, in step S32, as shown in **FIG. 11**, the second image F2 is moved in parallel by the calculated movement amount (x3, y3). Then, after completion of the parallel movement, the part not overlapping with the first image F1 is deleted from the image data of the second image F2 resulting from parallel movement. Next, in step S33, also in the first image F1, the part of the image data not overlapping with the second image F2 is deleted. In this way, image data of the part not required for synthesizing images (represented by hatching in **FIG. 11**) is deleted, and image data necessary for synthesis having been subjected to accurate positioning can be obtained.

[0117] Since the first image F1 and the second image F2 have been subjected to shading correction by the shading correction circuit **123** at the time of capturing of images, positioning of images can be achieved without being influenced by a shading.

[0118] Next, synthesis process of images having been subjected to positioning process is performed by the image synthesizer **159** of the general controller **150** (**FIG. 9**, step S23). Now, A/D conversion output level with respect to the brightness level of the subject in the first image F1 and the second image F2 will be explained. As shown in **FIG. 12A**,

PE

Samsung Exhibit 1002, Page 472 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

since the exposure amount is suppressed for the underexposed first image F1, the gradation characteristic is as shown by the characteristic LU, such that the A/D conversion output level is suppressed to low with respect to the brightness level of the subject. On the other hand, as for the overexposed second image F2, the exposure amount is excess, and hence the gradation characteristic will be such that the A/D conversion output level is emphasized to be high with respect to the brightness level of the subject as shown by the characteristic LO.

[0119] In the image synthesis process, by adding the image data of the first image F1 and the image data of the second image F2 for every pixel at an appropriate adding ration, image data having desired gradation characteristic within the range interposed between the gradation characteristic LU and the gradation characteristic LO in **FIG. 12A** is generated. **FIG. 12B** is a view showing a curve R representing adding ratios at various levels on the basis of the level of the overexposed second image F2. As shown in the drawing, the adding ratios are not constant regardless of the level of the image data, and as the level of the overexposed second image F2 decreases, the adding ratio of the overexposed second image F2 increases. The adding ratio of the overexposed second image F2 is made large as described above for making it easier to view dark portions of the subject.

[0120] To be more specific, if the level P2 (i, j) of the pixel data at the coordinate point (i, j) of the second image F2 is D as shown in the drawing, for example, the level P2 (i, j) of the pixel data and the level P1 (i, j) of the pixel data at the coordinate point (i, j) of the first image F1 are added to each other by R2:R1 to generate the level P3 (i, j) of the pixel data of the synthesized image under gradation control. In this way, by adding all the pixel data at the adding ratio in accordance with the level of the pixel data of the overexposed second image F2, all pixel data of the synthesized image under gradation control is generated. As a result, a gradation-controlled synthesized image having an intermediate gradation characteristic between the gradation characteristic of the first image F1 and the gradation characteristic of the second image F2.

[0121] Next, in the recording controller **156** of the general controller **150**, a predetermined compression process is effected on the generated synthesized image to generate captured image data. In addition to this, data for thumbnail image and tag information is generated. Then, an image file is generated from the captured image data of synthesized image thus generated and the data for thumbnail image and tag information, and recorded onto the memory card **8** (**FIG. 9**, step S24).

[0122] In the above, explanation was made for the first preferred embodiment, and in the present preferred embodiment, at the time of capturing image data of two images to be used for synthesis, each of these image data is subjected to shading correction by the shading correction circuit **123** which is a counter processing hardware circuit. Therefore, it is possible to achieve the subsequent positioning process without being influenced by a shading. In addition, since the shading correction is implemented by a special hardware circuit, it is possible to perform the shading correction with relatively high speed.

[0123] In the present preferred embodiment, each of two images is subjected to the shading correction at the time of capturing image data. However, it is also possible to make control so that shading correction is effected on only the second image F2 exposed with a large amount of light without effecting shading correction for both of the captured two images.

[0124] To be more specific, at the time of capturing the data of the first image F1 which is two-step underexposed with a smaller amount of light, the image data having subjected to A/D conversion is inputted to the WB circuit **124** and subjected to a predetermined process rather than being inputted to the shading correction circuit **123**. That is, the shading correction process of step S16 in **FIG. 9** may be omitted.

[0125] In such a case, as described above, by configuring so that the two-step underexposed first image F1 which is exposed with a relatively small amount of light is priorly captured, shading correction process between the first image F1 and the second F2 is not effected, so that it is possible to reduce the exposure interval. Therefore, it is possible to reduce the positional difference due to the difference in timing of exposure time, and hence to achieve more accurate positioning.

[0126] <2. Second Preferred Embodiment>

[0127] Next, the second preferred embodiment of the present invention will be explained. In the first preferred embodiment, the shading correction is executed by a count processing hardware circuit which is a special circuit at the time of capturing image data, however, the present invention differs from the first preferred embodiment in that the image data is directly stored in the image memory and the shading correction is executed by software. The image processing apparatus according to the present preferred embodiment is as same as the digital camera **1** shown in the schematic views of appearance in FIGS. **2** to **4**.

[0128] **FIG. 13** is a schematic block diagram showing an internal configuration of the digital camera **1** which is the image processing apparatus according to the present invention. In this drawing, those having the same functions as in the first preferred embodiment are denoted by the same reference numerals and detail description thereof will be omitted.

[0129] The digital camera **1** of the present preferred embodiment has a shading corrector **160** implemented by a processing program of the general controller **150** and for performing a shading correction by software, in place of the shading correction circuit **123**.

[0130] The shading corrector **160** implements the process as same as the process executed by the shading correction circuit **123** in the first preferred embodiment. That is, it performs shading correction by multiplying obtained image data and the correction table stored in the shading ROM **153**. Shading correction is effected on the image data that having been subjected to A/D convention in the first preferred embodiment, however, the present preferred embodiment differs from the first preferred embodiment in that shading correction is effected on the image data stored in the image memory **126**.

[0131] Also in the same manner, the white balance adjustment process and γ correction process are implemented by software. Therefore, a WB/γ corrector **161** is provided as a

PE

function implemented by processing programs in the general controller **150** in place of the WB circuit **124** and the γ correction circuit **125**. The processes in this WB/γ corrector **161** are as same as the processes in the WB circuit **124** and the γ correction circuit **125**. In the normal exposure mode, this WB/γ corrector **161** performs a predetermined process on the image data having been subjected to the shading correction in the shading corrector **160**. On the other hand, in the gradation control processing mode, a predetermined process is effected on the synthesized image resulting from the synthesis process by the image synthesizer **159**.

[0132] Furthermore, in the first preferred embodiment, the image memory **126** stores image data outputted from the CCD **303** for which a predetermined signal process has completed. To the contrary, in the present preferred embodiment, image data of the CCD-RAW form which has been outputted from the CCD **303** and just subjected to the A/D conversion is stored. The general controller **150** reads out the image data of the CCD-RAW form and performs the above-mentioned processes such as shading correction.

[0133] Next, an image capturing operation in the gradation control processing mode of the digital camera **1** configured as described above will be explained. **FIG. 14** is a flow chart showing a procedure of image capturing operation in the gradation control processing mode.

[0134] First, in step **S41**, when the shutter button is pressed half way down, as preparation for image capturing, a focal point of the lens group **30** of the imaging lens **3** is adjusted for a main subject, an exposure control value is calculated by using a live view image and a white balance adjustment value is set. The exposure control value which is calculated at this time is a value to provide correct exposure, and concretely, a shutter speed and an f-number which are correct values are obtained (step **S42**).

[0135] Next, when the shutter button **9** is pressed all the way down in step **S43**, the shutter speed is set at a shutter speed which is at two steps under the shutter speed which is a correct value (step **S44**). Then, the CCD **303** is exposed to the light for an exposure time corresponding to this shutter speed, and thereby a first image F1 of the subject is captured (step **45**).

[0136] After the exposure, an image signal outputted from the CCD **303** is subjected to a predetermined analogue signal processing in the signal processing circuit **121**, and converted into pixel data of **10** bits in the A/D conversion circuit **122**. Then, the A/D converted first image **F1** is stored in the first memory **126***a* in the image memory **126** in the CCD-RAW form (step **S46**). As for this first image F1, since the exposure time of the CCD **303** is set shorter than the proper value, the image is in general dark because of less amount of light exposure compared to images captured in the normal exposure mode.

[0137] Next, from the shutter speed which is a proper value, a shutter speed of two steps over is set (step **S47**), and the CCD **303** is exposed to the light for an exposure time corresponding to this shutter speed, and a second image F2 of the subject is captured (step **S48**). After exposure, as is the same with the first image **F1**, an image signal outputted from the CCD **303** is subjected to a predetermined analogue signal processing in the signal processing circuit **121**, converted into pixel data of **10** bits in the A/D conversion circuit **122**, and stored in the second memory **126***b* of the image memory in the CCD-RAW form (step **S49**). As for this second image F2, since the exposure time of the CCD **303** is set longer than the proper value, the image is in general light because of the amount of light exposure is larger in comparison with images captured in the normal exposure mode.

[0138] Next, the shading corrector **160** of the general controller **150** reads out the first image F1 from the first memory **126***a* of the image memory **126** and performs shading correction (step **S50**). This process can be achieved by executing the same multiplication process of the image data and the correction table in the first preferred embodiment by software. Then, the shading corrector **160** stores the first image F1 that has been subjected to shading correction in the first memory **126***a* again. In the same manner, the shading corrector **160** reads out the second image F2 from the second memory **126***b* of the image memory **126**, performs shading correction, and stores again in the second memory **126***b* (step **S51**).

[0139] Next, the image synthesizer **159** of the general controller **150** reads out the shading corrected first image F1 and the second image F2 from the image memory and performs positioning and synthesis processes of these images (step **S52**, **S53**). These processes are as same as those in the steps **S22** and **S23** in **FIG. 9**. Also in the present preferred embodiment, the shading correction is effected before performing the positioning process, it is possible to perform the positioning process without being influenced by a shading.

[0140] Next, the WB/γ corrector **161** of the general controller **150** performs adjustment of white balance and γ correction on the generated synthesized image (step **S54**). The following process of step **S55** is as same as in step **S24** of **FIG. 9**.

[0141] In the above, explanation was made for the second preferred embodiment, and in the present preferred embodiment, at the time of capturing image data of two images to be used for synthesis, each of these image data is subjected to shading correction by way of software. Therefore, it is possible to achieve the subsequent positioning process without being influenced by a shading.

[0142] In addition, since any image processing such as shading correction is not executed between exposures of the first image F1 and the second image F2, it is possible to reduce the exposure interval. Therefore, it is possible to achieve more accurate positioning by reducing a positional difference between images due to a difference in exposure timing.

[0143] Also, it is possible to control so that the shading correction is not effected on the first image F1 that has been two-step underexposed with a relatively small amount of light. That is, step **S50** of **FIG. 14** is omitted. As a consequence of this, it is possible to reduce the total time before generating a gradation-controlled synthesized image.

[0144] <3. Third Preferred Embodiment>

[0145] Next, the third preferred embodiment of the present invention will be explained. In the second preferred embodiment, an image is synthesized while performing a shading correction and a synthesized image having been subjected to

PE

the gradation control process is stored in the memory card **8** in the recording mode, and the present preferred embodiment differs form the second preferred embodiment in that two images captured in the recording mode are stored in the memory card **8** as they are, and image synthesis process can be executed in the playback mode.

[0146] The image processing apparatus according to the present preferred embodiment is a digital camera **1** having a similar appearance to the schematic configurationally views of FIGS. **2** to **4**, and having a similar internal configuration to the schematic block diagram shown in **FIG. 13**.

[0147] The exposure mode of the digital camera **1** of the present preferred embodiment has a gradation control exposure mode, as well as a normal exposure mode for normally capturing an image one by one. In contrast to the aforementioned gradation control processing mode in the above preferred embodiment, the gradation control exposure mode is a mode limited to capturing two images of different exposures for the same subject in different timings, and recording the respective images onto the memory card **8**.

[0148] In the gradation control exposure mode, since the recording controller **156** of the general controller **150** uses the obtained image data for the subsequent image synthesis or the like, the data is directly stored as the captured image data without performing compression which may deteriorate the image quality. That is, the image data of the CCD-RAW form stored in the image memory **126** and just A/D converted is directly subjected to the recording process as the captured image data. Since two captured image data of different exposures are generated by a single shutter operation in the gradation control exposure mode, an image file wherein tag information is attached to the captured image data of the CD-RAW form and a thumbnail image is generated for each of the two images, and the image files are stored in the memory card **8**. To the exposure mode of the tag information of the generated image file, information making it possible to recognizing the captured image for gradation control such as "gradation control exposure mode ½" is given. This "gradation control exposure mode ½" represents that it is the first image file captured in the gradation control exposure mode.

[0149] **FIG. 15** shows an example of configuration of an image file stored in the memory card **8**. In **FIG. 15**, "P000001.JPG", "P000002.JPG" and the like represent the names of image files. In the present preferred embodiment, the name of image file is expressed by "PL.M" and "L" in the "PL.M" represent a **6**-order number indicating the order that the image file is generated, and "M" represents an extension indicating the form of the captured image data. In "M", "JPG" represent captured image data compressed in the JPEG form and recorded, and "RAW" represents captured image data recorded in the CCD-RAW form. The captured image data captured in the normal exposure mode is represented by the extension "JPG", and the captured image data captured in the gradation control exposure mode is represented by the extension "RAW".

[0150] In the gradation control exposure mode, data of two images are continuously captured, and image files are generated for each of these captured image data, so that the both image files are stored in the same folder in the memory card **8** according to the present preferred embodiment. In the drawing, "*1r*", "*2r*" and the like represent folder names of image files captured in the gradation control exposure mode. In the present preferred embodiment, a folder name is represented by "Nt", and "N" shows captured order in the gradation control exposure mode.

[0151] Next, a gradation control process in the playback mode of the digital camera **1** thus configured will be explained. **FIG. 16** is a view showing a flow of the gradation control process in this playback mode.

[0152] When the playback mode is selected by the power switch **14**, and the menu display switch **34** is pressed down, a playback menu screen as shown in **FIG. 17A** is displayed on the LCD **10**. On the playback menu screen, it is possible to select special playback methods other than the normal playback display of captured image. These special playback methods include a gradation control process. The user operates the four-gang switch **15** to move a cursor C1 displayed on the LCD **10** so as to point at the gradation control process, and presses down the execute switch **32** to give a direction for the gradation control process to the digital camera **1** (step **S61**).

[0153] On this playback menu screen, when a special playback method such as slide show other than the gradation control process is designated, a predetermined process according to the designated special playback method will be executed (step **S63**).

[0154] Next, the playback controller **157** of the general controller **150** searches only the folder of the image file captured in the gradation control exposure mode from captured images stored in the memory card **8**, and reads out a thumbnail image (step **S62**). To be more specific, folders represented by the folder name "Nt" are sequentially searched from the memory card **8**, and only thumbnail images of the first image F1 and the second image F2 included in the folder are read out.

[0155] Next, the playback controller **157** stores the thumbnail images in the LCD VRAM **141** according to such an index form that four thumbnail images are two-dimensionally arranged in **2** x **2** per one page of the screen of the LCD **10**. As a result of this, two sets of combination of two thumbnail images captured in the gradation control exposure mode are displayed on the LCD **10** as shown in **FIG. 17B** (step **S64**).

[0156] When the image captured in the gradation control exposure mode is displayed, the user operates the four-gang switch **15** and the switch group **16** to move a cursor C2 displayed on the LCD **10** and designate the first image F1 and the second image F2 to which the gradation control process is to be executed (step **S65**). In the case of designating an image that has been captured in the gradation control exposure mode, this cursor C2 for selecting an image can designate either combination of two thumbnail images. That is, the user can designate any first image F1 and second image F2 by a single designating operation.

[0157] When the first image F1 and the second image F2 to which the gradation control process is to be executed are designated, the playback controller **157** reads out designated two captured image data of the CCD-RAW form and stores them in the image memory **126** so as to allow the subsequent process to be executed (step **S66**). Furthermore, the playback controller **157** reads out the respective tag information of the designated two image files, and stores them in the RAM **152** (step **S67**).

PE

Samsung Exhibit 1002, Page 475 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

[0158] Next, the shading corrector **160** of the general controller **150** reads out the first image F1 from the image memory **126** and performs shading correction thereon (step S68). This process is achieved by multiplication of the image data and the correction data by using software as is the same with the second preferred embodiment. The correction table used in this shading correction is selected from the shading ROM **153** using the tag information read out from the file of the first image F1. Since the tag information includes the focal length and the f-number at the time of exposure, it is possible to select the correction table that is suited for the optical condition at the time of exposure. The shading corrector **160** stores the first image F1 that has been subjected to the shading correction in the image memory **126** again, and reads out the second image F2 from the image memory **126** and performs shading correction in the same manner as described above (step S69).

[0159] Next, the image synthesizer **159** of the general controller **150** reads out the first image F1 and the second image F2 that have been subjected to the shading correction from the image memory **126**, and performs positioning and synthesis of these images to generate a gradation-controlled synthesized image. These processes are as same as steps **22** and **23** in **FIG. 9** (steps S70, S71). The generated synthesized image is displayed on the LCD **10**, and the user confirms the result of the synthesis process by referring to the LCD **10** (step S72). Also in the present preferred embodiment, since the shading correction is performed before executing the positioning process, it is possible to achieve positioning of images without being influenced by a shading.

[0160] Next, when a predetermined time has elapsed after the synthesized image was displayed on the LCD **10**, LCD **10** displays a screen which enables the user to select whether or not the generated synthesized image is to be recorded. When the user gives an instruction to record the image on this screen, the recording controller **156** of the general controller **150** performs recording process of the generated synthesized image. That is, while a captured image data is generated by performing a predetermined compressing process, the data is recorded on the memory card **8** as an image file with the data of thumbnail image and tag information being added thereto (step S73, S74).

[0161] In the above, the third preferred embodiment was explained, and in the present preferred embodiment, an image is read out from the memory card **8** and a shading correction is performed by software before executing the synthesis process. Therefore, the subsequent positioning can be executed without being influenced by a shading.

[0162] Furthermore, processes such as shading correction, positioning and image synthesis generally require a long time, and if these processes are executed in the recording mode, a processing time from image capturing to recording to the memory card **8** would be elongated. In the present preferred embodiment, these processes can be performed at user's convenient time.

[0163] <4. Fourth Preferred Embodiment>

[0164] Next, the fourth preferred embodiment of the present invention will be explained. In the above third preferred embodiment, the gradation control process such as synthesis process with respect to the recorded captured image data is performed in the digital camera, however, according to the present preferred embodiment, the gradation control process is performed by an image processing apparatus configured by a personal computer or the like. That is, an image processing apparatus such as digital camera having image pickup means just makes continuous exposures of two images to be used for synthesis, and an image processing apparatus configured by a personal computer or the like performs gradation control process such as positioning of these two images and image synthesis process.

[0165] The two images used for the gradation control process are images captured in the gradation control exposure mode of the digital camera according to the third preferred embodiment. That is, the captured image data underexposed than the correct exposure (the first image F1) and the captured image data overexposed than the correct exposure (the second image F2) that have been subjected to only the A/D conversion and recorded in the CCD-RAW form are used. In addition, it is preferred to use image files in each of which tag information including optical conditions at the time of exposure and a thumbnail image are added to the captured image data of the CCD-RAW form.

[0166] **FIG. 18** is an appearance view showing a configuration of the image processing apparatus according to the present preferred embodiment. As shown in **FIG. 18**, the image processing apparatus **50** has a personal computer **60** and a printer **70** which is an output device thereof.

[0167] The personal computer **60** has a computer main body **61**, a display **62** for making various displays, a keyboard **63** and a mouse **64** for receiving an entry from a user. Furthermore, the computer main body **61** has a reading devices **61***a*,**61***c* for reading out various data from a recording medium **90** such as magneto-optic disc, and a memory card reader **61***b* for performing read of a memory card.

[0168] The personal computer **60** stores a plurality of correction tables used for the shading correction in a stationary disk which is a predetermined memory device in the computer main body **61**. These correction tables each are associated in advance with the type of digital camera that is assumed to capture images for use in the gradation control process (digital camera having a function of capturing two images while varying the exposure amount for the same subject, hereinafter, referred to as "assumed camera"). Furthermore, a plurality of correction tables are stored for each of parameters or optical conditions such as focal length and f-number at the time of capturing an image in an assumed camera. That is, by designating the camera which the two captured image data to be subject to the gradation control process and the optical conditions at the time of capturing those captured image data (hereinafter, referred to as "correction table selecting condition"), it is possible to select an optimum correction table for use in the shading correction.

[0169] Furthermore, the personal computer **60** stores a gradation control program for synthesizing data of two captured images of different amounts of light exposure in a stationary disk inside the computer main body **61** and generating a synthesized image having a desired gradation. The personal computer **60** functions as an image processing apparatus that performs the gradation control process by reading out the gradation control program from the stationary disk and executing the program. This gradation control

PE

program is in advance installed in the computer main body **61** via a reader **61***a* or **61***b* from a recording medium such as a magneto-optic disk on which that program is recorded. Also, this gradation control program may be installed by downloading the same over a communication line such as the Internet from a predetermined server storage device.

[0170] **FIG. 19** is a view showing one example of a work window displayed on the display **62** when the personal computer **60** executes the gradation control program. In a work window **200** are displayed three display regions **201** to **203** for displaying thumbnail images of image data related to the gradation control process, and command buttons **204** to **208** for designating the process contents, process conditions and the like.

[0171] The display region **201** and the display region **202** are arranged on the upper side of the screen, and a thumbnail image f2 of the overexposed second image F2 is displayed in the display region **201**, and a thumbnail image f1 of the underexposed first image F1 is displayed on the display region **202**. Furthermore, the display region **203** is arranged on the lower side of the display region **201**, and a thumbnail image f3 resulted from synthesis of the thumbnail image f1 and the thumbnail image f2 and gradation control simulation.

[0172] Furthermore, the command buttons **204** to **208** are vertically arranged on the lower side of the display region **202**. It is possible to designate predetermined process assigned to the respective command buttons by clicking these command button with a mouse cursor C3.

[0173] The command button displayed "FILE" (hereinafter, "file button") is intended for designating an image file. This file button **204** is clicked, and then a file designating window opens, allowing designation of image files of the first image F1 and the second image F2 to be subjected to the gradation control process from a memory card or the like attached to the memory card reader **61***b*. In the case where an image file captured using the digital camera of the third preferred embodiment is used, since the image files of the first image F1 and the second image F2 are included in the same folder "Nt", both of the image files can be designated by designating the folder.

[0174] The command button displayed "EXECUTE" (hereinafter, "execute button") **206** is intended for actually executing the gradation control process by using data of two captured images of different amounts of light exposure. Details of the gradation control process will be described later.

[0175] The command button displayed "SELECT CAMERA TYPE" (hereinafter, "camera selection button") **205** is intended for designating a camera with which the data of two captured images to be subjected to the gradation control process, and an optical condition at the time of capturing that data of captured images. That is, by operating this camera selection button **250**, it is possible to designate the condition for selecting a correction table.

[0176] The camera selection button **205** is selected, and then a camera selection window **210** as shown in **FIG. 20** is displayed on the display **62**. The camera selection window **210** includes an optional button group **211** having an auto selection button **211** a and assumed camera buttons **211***b* to **211***d* to which names of assumed cameras are assigned. The assumed camera buttons **211***b* to **211***d* are displayed in the same number as the number of types of assumed cameras registered in advance, though three buttons are displayed in the present drawing. The user can select desired one of the auto selection button **211** a or assumed camera buttons **211***b* to **211***d* by clicking it by means of the mouse cursor C2.

[0177] In the case where the selection condition of correction table is manually inputted, a corresponding camera name is designated from the assumed camera buttons **211***b* to **211***d*. Either one of the assumed camera buttons **211***b* to **211***d* is designated and an "OK" button **213** is clicked, and then an optical condition inputting window for inputting a focal length and an f-number. In the optical condition inputting window, the user enters a focal length and an f-number at the time of capturing an image via the keyboard **63**. Through such an operation, a correction table selection condition is manually designated.

[0178] On the other hand, in the case of using an image file to which tag information is attached, the auto selection button **211***a* is selected. Tag information previously describes exposure condition information including a camera name, a focal length and an f-number as described above, and by automatically reading these, it is possible to set these as a correction table selecting condition. Therefore, when the auto selection button **21** la is selected, it is not necessary for the user to manually input the correction table selecting condition. It is to be noted that when designations of camera and optical condition at the time of capturing an image is not made by operating the camera selection button **205**, this auto selection button **211***a* is selected by default.

[0179] Returning to **FIG. 19**, the command button displayed "DESIGNATE AREA" (hereinafter "area designation button") **207** is intended for designating a positioning area A1 for use in positioning of two captured image data. In the present preferred embodiment, when the above-mentioned correlative coefficient C in the positioning process is calculated, pixel data in the designated positioning area A1 is summed rather than summing all pixel data, to determine the correlative coefficient C.

[0180] Designation of this positioning area is achieved by designating the area corresponding to the positioning area in the real captured image data as a positioning temporary area A0 by using the thumbnail image f2 displayed on the display region **201** as shown in **FIG. 21**. Based on the positioning temporary area A0 designated by this thumbnail image f2, the positioning area A1 of the real captured image data is set at the time of gradation control process. The rectangular positioning temporary area A0 is defined by the positions of point AL0 which is the left top end point and the point AR0 which is the right bottom end point in a rectangular XY plane coordinate in which the center of the image is an origin point. Concretely, the point that the user first clicks in the thumbnail image f2 is designated as the coordinate point of the left top end point AL0, and the point that the user clicks next is designated as the coordinate point of the right bottom end point AR0.

[0181] Returning to **FIG. 19**, the command button displayed "END" (hereinafter, "end button") **208** is provided for ending execution of the gradation control program. The user clicks this END button to end all the processes.

[0182] Further, a slider **209** is displayed on the lower part of the display region **203** of the work window **200**. This

PE

Samsung Exhibit 1002, Page 477 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

slider **209** is intended for setting a synthesis ratio between the thumbnail image f1 and the thumbnail image f2 in the simulation for gradation adjusting process using the thumbnail images. The term "synthesis ratio" used herein is a synthesis ratio of the general thumbnail image f1 and the thumbnail image f2 rather than the adding ratio of each level of overexposed image data shown in **FIG. 12B**. In **FIG. 12B**, it resembles the area ratio between the upper area partitioned by the curve R representing the adding ratio characteristic (the area where the underexposed first image F1 is added) and the lower area (the area where the overexposed second image is added).

[0183] Therefore, by moving the slider **209** in the right and left direction using the mouse cursor C3, the curve R representing the adding ratio characteristic in **FIG. 12B** is shifted in the up and down direction, and thereby the synthesis ratio is desirably set. Concretely, as the slider **209** is moved to the right from the center point, the synthesis ratio of the overexposed second image F2 increases, whereas as the slider **209** is moved left, the synthesis ratio of the underexposed first image F1 increases.

[0184] Next, a gradation control process in this image processing apparatus **50** configured as described above will be explained. **FIGS. 22 and 23** are flow charts showing procedures of the gradation control process.

[0185] First, the user designates two image files for use in the gradation control process. Image files are designated by clicking the file button **204**, and the thumbnail images f1, f2 are read from the respective designated image file and displayed on the display region of the work window **200** (steps **S101**, **S102**).

[0186] Next, an adding ratio characteristic is read from the set position of the slider **209** (step **S103**), and a gradation control simulation by thumbnail image is performed using that adding ratio characteristic (step **S104**).

[0187] In the gradation control simulation, first a positioning process is performed using all pixel data of the two thumbnail images f1, f2. This positioning process is as same as that of step **S22** in **FIG. 9**. Though the positioning process is performed using all the pixel data, the process can be done with relatively high speed because thumbnail images consisting of a small number of pixel data. Next, based on the set adding ratio characteristic, the thumbnail image f1 and the thumbnail image f2 are synthesized, and the result of the synthesis is displayed in the display region **203** (step **S105**).

[0188] Upon completion of the gradation control simulation by thumbnail images, whether or not the slider **209** is moved is determined (step **S106**). If the slider is moved, the process returns to step **S103**, and a gradation control simulation by thumbnail images is performed (steps **S103** to **S105**).

[0189] On the other hand, if the slider **209** is not moved, whether or not the execute button **206** is operated is determined (step **S107**). If movement of the slider **209** and operation of the execute button **206** are not made, the process returns to step **S106** to enter a standby state with the simulation result of gradation adjustment by thumbnail images being displayed. Designation of the correction table selection condition by the camera selection button **205** and designation of the positioning temporary area **A0** by the area designation button **207** can be made in this standby state.

[0190] If the execute button **206** is operated in step **S107**, the process proceeds to step **S111** in **FIG. 23**, and each of the captured image data (underexposed first image F1 and overexposed second image F2) is read out from the two designated image files.

[0191] Next, the positioning area A1 for use in the positioning of the captured image data of the first image F1 and the second image F2 is set (step **S112**). As for this positioning area, if the user does not previously set the positioning temporary area **A0** in the thumbnail image f2 as shown in **FIG. 12**, the entire captured image data is set as the positioning area A1. If the positioning temporary area **A0** is previously designated, the coordinate point in the thumbnail image f2 is converted to the coordinate point in the captured image data and set. For example, if the thumbnail image is generated while reducing the size of the captured image data to 1/n, the coordinate point of the left top end point AL1 of the positioning area A1 is (n·l, n·m) provided that the coordinate point of the left top end point AL**0** of the positioning temporary area **A0** is (l, m). In the same manner, the coordinate point of the right bottom end point AR1 of the positioning area A1 is set.

[0192] Next, whether or not the set positioning area A1 requires a shading correction is determined (step **S113**). Now, determination of whether or not a shading correction is necessary will be explained with reference to **FIG. 24**. The upper half of **FIG. 24** shows an example of influence by shading as same as **FIG. 1**. That is, the horizontal axis shows a distance from the center point of captured image data of each pixel data in terms of relative distance provided that the length of the diagonal like of the captured image data is 1. Also, the vertical axis shows a level of each pixel data in terms of relative value. In this context, a predetermine threshold which is considered as not being influenced by shading is set, for example, not less than 0.9 in terms of relative value of the level of the image data. In the same drawing, regardless of the optical conditions such as focal length and f-number, the relative value of the level of the image data is not less than 0.9 in the area within a distance range of 0.3 from the center of the captured image data. That is, it can be considered that an influence by shading will not exert in the area within a distance range of **30%** of the length of the diagonal line regardless of the optical condition.

[0193] The lower half of **FIG. 24** is a view showing an area which is not influenced by shading in the captured image data (hereinafter, "non-shading area") A2 in the rectangular XY plane coordinate whose origin is the center of the captured image data. The boundary curve LA between the non-shading area A2 and the area influenced by shading is nearly circular because of the same distance from the center of the captured image data. In the drawing, the center side area of the boundary curve LA is the non-shading area A2, and the peripheral side area of the boundary curve LA is the area influenced by a shading. If all the pixel data constituting the positioning area A1 is included in this non-shading area A2, it is determined that the positioning area A1 does not require a shading correction. Concretely, if the relative distance from the origin of the coordinate point of the left top end point AL1 of the positioning area A1 and the relative distance from the origin of the coordinate point of the right bottom end point AR1 is not more than 0.3, provided that the length of the diagonal line of the captured image data is 1, it is determined that a shading correction is

PE

Samsung Exhibit 1002, Page 478 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

not required. On the contrary, if the left top end point AL1 or the right bottom end point AR1 is not included in the non-shading area A2, it is determined that a shading correction is required.

[0194] Through such a process, if it is determined that a shading correction is not required for the positioning area A1 (No in step S113), the process proceeds to step S123 and a positioning process is performed without performing a shading correction.

[0195] If it is determined that a shading correction for the positioning area A1 is required (Yes in step S113), subsequently, whether or not the mode of camera selection is auto selection is determined (step S114). At this time, if the mode of camera selection is not auto selection, that is, if the user manually designates the correction table selecting condition on the screen shown in FIG. 20, it is possible to select the correction table in accordance with this correction table selecting condition. Therefore, the process proceeds to step S120 where a correction table is selected.

[0196] On the other hand, if the camera selection mode is auto selection, that is, if the auto selection button 211 a is selected on the screen shown in FIG. 20 as described above, information of exposure condition such as camera name, focal length and f-number is read while referring to the tag information of the image files to be used (step S115, S116, S117). By reading the exposure condition information from the tag information, the correction table selecting condition is automatically determined.

[0197] Next, whether or not the exposure condition information is successfully read from the tag information is determined (step S118), and if it is successfully read, the process proceeds to step S120 where a correction table is selected.

[0198] On the other hand, if the exposure condition information is not read successfully, it is impossible to set the correction table selecting condition, and hence it is impossible to perform a shading correction and perform a correct positioning process. Therefore, the positioning area A1 for use in the positioning process is reduced so that it is within the range that is not influenced by a shading (step S119). This range not influenced by a shading is, for example, a distance range of 30% of the length of the diagonal line of the image from the center of the image as shown in the example of FIG. 24.

[0199] In the present preferred embodiment, for realizing a correct positioning process, the size of the positioning area A1 is set at 20% of the size of the captured image data. That is, for the captured image data constituted by the image data of 1600×1200 pixel data, the positioning area A1 is set so that it is constituted by 320×240 pixel data. The center point of the captured image data and the center point of the positioning area A1 coincide with each other. In the case where the positioning area A1 is reduced so that it is within the area not influenced by a shading, it is not necessary to perform a shading correction, so that the process proceeds to step S123 where the positioning process is performed.

[0200] In steps S114 to S118, if the correction table selecting condition is set, the correction table is selected in accordance with this correction table selecting condition (step S120). Next, by multiplying the captured image data and the correction table, a shading correction is effected on each of the first image F1 and the second image F2 (steps S121, S122).

[0201] In the present preferred embodiment, this shading correction process is performed on only the positioning area A1. That is, the shading correction is performed by multiplying the pixel data only included in the positioning area A1 of the captured image data with inverses of the corresponding correction coefficients. This makes it possible to perform the shading correction on the positioning area A1 and perform the subsequent positioning process accurately, as well as reducing the process time of the shading correction.

[0202] Next, in step S123, a positioning process is performed using only the positioning area A1. In this positioning process, pixel data of the positioning area A1 is summed for calculating the movement amount (x3, y3) where the correlative coefficient C (ξ, η) of the second image F2 as described above is minimum. Then, in the same manner as shown in FIG. 11, the entire second image F2 is moved in parallel by the calculated movement amount (x3, y3). Then the pixel data of the part not overlapping with the first image F1 after being moved in parallel and the pixel data of the part not overlapping with the second image F2 in the first image F1 are deleted. As described above, by determining the correlative coefficient C using only the positioning area A1, it becomes possible to achieve accurate positioning with respect to the image position requested by the user, and reduce the process time of the positioning process.

[0203] Subsequently, an image synthesis process of the first image F1 and the second image F2 is performed in accordance with the adding ratio characteristic set by the slider 209 (step S124). Then, a process result display window 220 is displayed on the display 62 as shown in FIG. 25, and a synthesized image is displayed on the display region 221 (step S125). This process result display window 220 includes a save button 222 and a cancel button 223, and by clicking the save button 222 with the mouse cursor C3, the generated synthesized image can be saved in a predetermined memory means (steps S126, S127). When the cancel button 223 is clicked, the image is not saved.

[0204] In the above, the fourth preferred embodiment was explained, and according to the present invention, the positioning area A1 is designated, and a shading correction is performed only when the positioning area A1 requires a shading correction. This configuration makes it possible to simplify the processes of shading and positioning and to reduce the process time.

[0205] The above preferred embodiment uses the camera type, focal length and f-number were used as correction table selection conditions, however, also the type of imaging lens used at the time of exposure may be set as well.

[0206] Furthermore, in the present preferred embodiment, the process was performed in the image processing apparatus in which a personal computer executes the gradation control program, however, the above process may be performed by making a digital camera execute the like gradation control program.

[0207] <5. Fifth Preferred Embodiment>

[0208] Next, the fifth preferred embodiment of the present invention will be explained. In the above preferred embodi-

PE

Samsung Exhibit 1002, Page 479 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

ment, the positioning process and the image synthesis process were performed after performing the shading correction, however, the shading corrector **160** according to the fifth preferred embodiment performs positioning and image synthesis of the first image F1 and the second image F2, and thereafter performs a shading correction.

[0209] Among these, calculation of the correlative coefficient C at the time of positioning process uses the positioning area A1 as a limited area, and this area A1 is automatically set by the image synthesizer **159** in the general controller **150**.

[0210] Assuming that relative spatial movement amounts of the images F1, F2 where the contents of images mutually match (conform) with each other on the basis of the frame coinciding condition of the first image F1 and the second image F2 are referred to as "conforming movement amount", the distribution of the shading correlative coefficients varies with the conforming movement amounts. This is because, though the influence of shading in each of the original two images F 1, F2 is matched in the synthesized image, the magnitude of the influence varies with the conforming movement amount.

[0211] Other basic configuration of the image processing apparatus according to the present preferred embodiment is as same as the configuration of the digital camera which is the image processing apparatus of the third preferred embodiment. It is also possible to perform the image processings such as positioning process and image synthesis process using the captured image data of the CCD-RAW form stored in the memory card **8** in the playback mode.

[0212] Next, a gradation control process in the playback mode of the digital camera **1** of the present preferred embodiment will be explained. **FIG. 26** is a flow chart showing a flow of the gradation control process in the playback mode.

[0213] The processes in steps **S81** to **S87** are as same as steps **S61** to **S67** of **FIG. 16**. At the time of completion of step **S87**, the captured image data of the CCD-RAW form of each of the first image **F1** and the second image **F2** for use in the gradation control process has been read, and stored in the image memory **126**. Further, respective tag information of these two image files have been read and stored in the RAM **152**.

[0214] Next, a positioning process is performed in the image synthesizer **159** of the general controller **150**. In the present preferred embodiment, each of the first image F1 and the second image F2 is not subjected to a shading correction. Therefore, if the positioning process is performed on the entire captured image data, a shading will influence on it, so that the positioning process cannot be conducted accurately. Therefore, before performing the positioning process, the positioning area A1 for use in the positioning process is set from the area not influenced by a shading (non-shading area A2) (step **S88**).

[0215] For setting this positioning area A1, first, a non-shading area A2 of the captured image data to be subjected to the positioning is acquired, and the positioning area A1 is set that the all pixel data is included in the acquired non-shading area A2. As described above, the influence range of shading varies with the focal length and f-number of the imaging lens **3**. That is, the non-shading area A2 varies with the focal length and f-number at the time of exposure of the captured image data. Therefore, for acquiring the non-shading area A2, a correction table is referred in which the focal length and the f-number at the time of exposure are parameters. Concretely, a correction table is selected based on the focal length and the f-number at the time of exposure of the captured image data to be subjected to the positioning, and the area where the correction coefficient set in the correction table is, for example, not less than 0.9 is acquired as the non-shading area A2. The information of the focal length and the f-number to be used for selecting the correction table is acquired from the tag information stored in the ROM **151**.

[0216] **FIG. 27** is a view showing an example of the non-shading area A2 acquired in accordance with the focal length and the f-number at the time of exposure in the rectangular XY plane coordinate system in the captured image data F. As shown in **FIG. 27**, the boundary curves L2*a* to L2*c* of the non-shading area A2 is nearly circular centered at the center point of the captured image data. That is, the center side area of these boundary curves L2*a* to L2*c* is the non-shading area A2 and the peripheral side area thereof is the area influenced by a shading.

[0217] The area A2*a* surrounded by the solid line L2*a* in the drawing represents the non-shading area A2 acquired in the case of the captured image data captured in the initial condition of the digital camera **1**. The initial condition of the digital camera means a condition that the focal length and the f-number of the imaging lens **3** are the initial values (values when the power is turned ON).

[0218] Furthermore, the areas A2*b*, A2*c* surrounded by the dotted lines L2*b*, L2*c* represent the non-shading area A2 acquired in the case of the captured image data captured with different focal length and f-number from the initial values. As described above, when the focal length and the f-number are varied from the initial values, the non-shading area A2 in which the area is varied for the area A2*a* is acquired. That is, the more the focal length tilts from the initial value to the wide side, the narrower the non-shading area A2 as is the area A2*b*, while on the other hand, the more the focal length tilts from the initial value to the tele side, the wider the non-shading area A2 as is the area A2*c*. Likewise, the smaller the f-number than the initial value, the narrower the non-shading area A as is the area A2*b*, while on the other hand, the larger the f-number, the wider the non-shading area A2 as is the area A2*c*.

[0219] After acquiring the non-shading area A2 corresponding to the focal length and the f-number as described above, the image synthesizer **159** sets the rectangular positioning area A1. This setting of positioning area A1 is achieved by setting two intersecting points between the boundary curves L2*a* to L2*c* of the non-shading area A2 and the diagonal line DL of the captured image data as the left top end point and the right bottom end point of the positioning area A1, respectively. Therefore, all pixel data of the set positioning area A1 is included in the non-shading area A2.

[0220] The area A1*a* surrounded by the solid line L1*a* shown in **FIG. 27** represents the positioning area A1 set for the case of the captured image data captured in the initial condition of the digital camera **1**. Furthermore, the areas A1*b*, A1*c* surrounded by the dotted lines L1*b*, L1*c* repre-

PE

Samsung Exhibit 1002, Page 480 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

sents the positioning area A1 set for the captured image data captured after the focal length or the f-number has been changed from the initial value.

[0221] Since the positioning area A1 is set in accordance with the size of the non-shading area A2, when the focal length or the f-number is changed from the initial value, the positioning area A1 whose width is changed with respect to the area A1*a* in accordance with the change of the focal length or the f-number. That is, the more the focal length tilts to the wide side from the initial side, the narrower the positioning area A1 is set as is the area A1*b*, while on the other hand, the more the focal length tilts to the tele side from the initial value, the wider the positioning area A1 is set as is the area A1*c*. Likewise, the smaller the f-number than the initial value, the narrower the positioning area A1 is set as is the area A1*b*, while on the other hand, the larger the f-number than the initial value, the wider the positioning area A1 is set as is the area A1*c*.

[0222] In this connection, the non-shading area A2 in the case where of "the focal length is wide end" and "the f-number is open" is the narrowest among the non-shading areas A2 of any optical conditions of focal length and optical condition. That is, by setting so that the positioning area A1 is included in the non-shading area A2 in the case of "the focal length is wide end" and "the f-number is open", it will be necessarily included in the non-shading area A2 in any optical conditions. In other words, that positioning area A1 can be used in any optical conditions. Therefore, the area included in the non-shading area A2 in the case of "the focal length is wide end" and "the f-number is open" may be set as a fixed positioning area A1 without changing the positioning area A1 in accordance with the focal length and the f-number as described above.

[0223] By setting the positioning area A1 by way of such a process, the image synthesizer **159** can perform the positioning process of the first image F1 and the second image F2 using this positioning area A1 (step S89). This positioning process is the same process as step S123 of **FIG. 23**. And, a synthesis process of the first image F1 and the second image F2 (step S90) is performed. This synthesis process is as same as step S23 of **FIG. 9**.

[0224] Subsequently, as the synthesized image is generated, the shading corrector **160** performs a shading correction on the generated synthesized image (step S91). In this shading correction, the shading correction is performed using a correction coefficient corresponding to the movement amount by which the first image F 1 and the second image F2 are relatively moved from the frame coincidence condition in the positioning process.

[0225] **FIG. 28A** shows curves each having a constant distribution of correction coefficients used for the shading correction in the case where the second image F2 is moved in the positioning process from the condition that frames of the first image F1 and the second image F2 coincide with each other before performing the positioning process. In the drawing, the moved second image F2 is denoted by the dotted line, the synthesized image F3 obtained by a synthesis process after the positioning process is denoted by the bold line.

[0226] In addition, the movement line L1 shown in **FIG. 28A** represents relative displacement between the respective centers of the first image F1 and the second image F2 in the image matching condition. The length of this movement line L1 represents a relative moving amount of the second image F2 on the basis of the frame coincidence condition of the first image F1 and the second image F2, and the position corresponding to ½ of the moving amount from the original center on the movement line L1 coincides with the center point of the synthesized image F3.

[0227] As shown in **FIG. 28A**, the curves in which distribution of correction coefficient is constant are nearly circular centered at the respective center points of the first image F1 and the second image F2. By the way, assuming the normal L2 to the movement line L1 at the center point of the synthesized image F3, the correction coefficients for the part of the synthesized image F3 are distributed symmetrically with respect to this normal L2. That is, the curves in which distribution of correction coefficients with respect to the synthesized image F3 is constant are nearly oval-like curves whose short diameter lies in the moving direction of the second image F2 as shown in **FIG. 28B**. By performing the shading correction using such correction coefficients, it is possible to perform the shading correction on the synthesized image.

[0228] By the way, a spatial distribution of correction coefficients used for the shading correction of the first image F1 or the second image F2 is represented by the function S (sqrt (x^2+y^2)) depending on the distance from the center point of the captured image data sqrt (x^2+y2) wherein "sqrt" represents square root. And in the case where the first image F1 and the second image F2 are addingly synthesized in the ratio of k:(1−k) (0<k<1), the correction coefficient used for the shading correction of the synthesized image F3 is preferably determined on the basis of the weighed mean value using the function S.

$$k\cdot S(r)+(1-k)\cdot S(r') \quad (A)$$

[0229] provided that

[0230] $r=\mathrm{sqrt}\ (x^2+y^2)$;

[0231] $r'=\mathrm{sqrt}\ \{(x-\delta x)^2+(y-\delta y)^2\}$;

[0232] x, y represent coordinate variables in the rectangular XY plane coordinate system whose origin point is the center point of image of either one of the first image F1 and the second image F2; and δx, δy represent X, Y component values of conforming movement amount.

[0233] Subsequent steps S92 to S94 are as same as steps S72 to S74 of **FIG. 16**.

[0234] In the above description, the fifth preferred embodiment was explained, and in the present preferred embodiment, since the positioning area A1 is set in accordance with the influence of shading, it is possible to perform a positioning process without carrying out the shading correction.

[0235] It is to be noted that though the synthesized image is subjected to the shading correction in the present preferred embodiment, the shading correction may not be performed since the positioning process can be accurately carried out by setting the positioning area A1 in consideration of the influence of shading.

PE

[0236] <6. Other Preferred Embodiments>

[0237] In the above preferred embodiment, the synthesized image that has been subjected to gradation control is obtained by capturing two images of different exposures for the same subject in different timings and synthesizing these two images in an appropriate adding ratio, however, the present invention is not limited to this. For example, such a process is also possible that a first image focused at the main subject and a second image focused at the background of the main subject are synthesized to obtain a desirably blurred synthesized image. Furthermore, such a process is also possible that a first image and a second image in which exposure positions for the subject are slightly different from each other, and a synthesized image having a higher resolution than the original images is acquired. That is, the present invention may be applicable to any processes insofar as they capture two images in different timing and synthesize these images.

[0238] While the invention has been shown and described in detail, the foregoing description is in all aspects illustrative and not restrictive. It is therefore understood that numerous modifications and variations can be devised without departing from the scope of the invention.

What is claimed is:

1. An image processing apparatus comprising:

an image acquiring part for acquiring a first image and a second image;

a shading corrector for performing a shading correction on each of said first image and said second image acquired by said image acquiring part;

a position adjuster for performing positioning of said first image and said second image that have been subjected to the shading correction by said shading corrector; and

an image generator for generating a synthesized image of said first image and said second image that have been subjected to the positioning by said position adjuster.

2. The image processing apparatus according to claim 1,

wherein said shading corrector comprises:

a shading memory for holding a correction table on which coefficients for shading correction are registered; and

a coefficient processing hardware circuit for performing a coefficient process using said correction table with respect to the images acquired by said image acquiring part.

3. The image processing apparatus according to claim 2, further comprising:

an image memory capable of storing a plurality of images; and

a controller for controlling said image memory to store a shading-corrected image that has been subjected to a shading correction by said shading corrector whenever each of said first image and said second image is acquired,

wherein said position adjuster performs positioning in response to that either one of said first image and said second image that is acquired later is stored in said image memory as the shading-corrected image.

4. The image processing apparatus according to claim 1, further comprising:

an image memory capable of storing a plurality of images; and

a controller for controlling said image memory to store each of said first image and said second image acquired in said image acquiring part,

wherein said shading corrector performs a shading correction on each of said first image and said second image stored in said image memory.

5. The image processing apparatus according to claim 4,

wherein said shading corrector comprises:

a shading memory for holding a correction table in which coefficients for shading correction are registered; and

a processor for performing an operational process on an image stored in said image memory using said correction table.

6. The image processing apparatus according to claim 1,

wherein said image acquiring part is an image sensor for capturing said first image and said second image for the same subject in different timings

7. The processing apparatus according to claim 1, further comprising:

an image memory for storing a plurality of images; and

an image designator for allowing a user to designate said first image and said second image among the plurality of images stored in said image memory,

wherein said image acquiring part acquires said first image and said second image that have been designated by said image designator from said image memory.

8. An image processing apparatus comprising:

an image sensor for acquiring a first image and a second image for the same subject in different timings;

an exposure controller for controlling said image sensor so that said first image and said second image differ in amount of exposure from each other;

an image generator for generating a synthesized image using said first image and said second image; and

a shading corrector for performing a shading correction on an image acquired in said image sensor,

wherein said shading corrector performs a shading correction on either one of said first image and said second image that has been exposed with a larger amount of light.

9. The image processing apparatus according to claim 8, further comprising:

a controller for controlling said image sensor to acquire either one of said first image and said second image that has been exposed with a smaller amount of light earlier than the other.

10. A program product containing a program for enabling an image processing, in which execution of said program by a computer allows said computer to execute the steps of:

acquiring a first image and a second image;

performing a shading correction on each of acquired said first image and said second image;

PE

Samsung Exhibit 1002, Page 482 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

performing a positioning of said first image and said second image that have been subjected to the shading correction; and

generating a synthesized image of said first image and said second image that have been subjected to the positioning.

11. The program product according to claim 10, in which execution of said program by said computer allows said computer to execute the further step of:

allowing a user to designate an area to be used for positioning of said first image and said second image.

12. The program product according to claim 11,

wherein said step of performing a shading correction is executed only for said designated area to be used for positioning.

13. The program product according to claim 11, in which execution of said program by said computer allows said computer to execute the further step of:

determining whether or not it is necessary to perform a shading correction on said designated area to be used for positioning,

wherein when it is determined that a shading correction is not necessary, said step of performing a shading correction is not executed..

14. A program product according to claim 10, in which execution of said program by said computer allows said computer to execute the further step of:

allowing a user to designate a correction table to be used for a shading correction in accordance with an apparatus by which said first image and said second image are acquired.

15. The program product according to claim 10, in which execution of said program by said computer allows said computer to execute the further steps of:

acquiring information relating to exposure condition associated with each of said first image and said second image; and

selecting a correction table to be used for shading correction in accordance with the acquired said information relating to exposure condition.

16. The program product according to claim 15, in which execution of said program by said computer allows said computer to execute the further step of:

narrowing the area to be used for positioning said first image and said second image when said information relating to exposure condition cannot be acquired.

17. An image processing apparatus comprising:

an image acquiring part for acquiring a first image and a second image;

a position adjuster for specifying an area where an influence of shading is ignorable for each of said first image and said second image acquired by said image acquiring part, and performing a positioning of said first image and said second image contained in said area where an influence of shading is ignorable thus specified; and

an image generator for generating a synthesized image of said first image and said second image that have been subjected to positioning by said position adjuster.

18. The image processing apparatus according to claim 17,

wherein said first image and said second image each consist of a center side area and a peripheral side area, and

said area where an influence of shading is ignorable is the center side areas of said first image and said second image.

19. The image processing apparatus according to claim 17, further comprising:

an imaging lens of which focal length is variable,

wherein said position adjuster changes the area to be used for positioning in accordance with the focal length of said imaging lens.

20. The image processing apparatus according to claim 19,

wherein said position adjuster widens said area to be used for positioning as said focal length increases.

21. The image processing apparatus according to claim 17, further comprising:

an imaging lens of which focal length is variable,

wherein said position adjuster specifies the area in the case where the focal length of said imaging lens is a wide angle end as an area to be used for positioning.

22. The image processing apparatus according to claim 17, further comprising.

an imaging lens of which f-number is variable,

wherein said position adjuster changes the area to be used for positioning in accordance with an f-number of said imaging lens.

23. The image processing apparatus according to claim 22,

wherein said position adjuster widens the area to be used for positioning as said f-number increases.

24. The image processing apparatus according to claim 17, further comprising:

an imaging lens of which f-number is variable,

wherein said position adjuster specifies the area in the case where the f-number of said imaging lens is open value as an area to be used for positioning.

25. A program product containing a program for executing an image processing, in which execution of said program by a computer allows said computer to execute the steps of:

acquiring a first image and a second image;

specifying an area where an influence of shading is ignorable for each of acquired said first image and said second image;

performing positioning of said first image and said second image included in said specified area where an influence of shading is ignorable; and

generating a synthesized image of said first image and said second image that have been subjected to positioning.

PE

Samsung Exhibit 1002, Page 483 of 1260
Samsung Electronics Co., Ltd. et al. v. Optimum Imaging Technologies LLC
IPR2025-00463

26. An image processing apparatus comprising:

an image acquiring part for acquiring a first image and a second image;

a position adjuster for performing positioning of said first image and said second image acquired in said image acquiring part;

an image generator for generating a synthesized image of said first image and said second image that have been subjected to positioning by said position adjuster; and

a shading corrector for performing a shading correction of said synthesized image using a shading correction coefficient in accordance with a relative amount of movement of said first image and said second image at the time of positioning by said position adjuster.

27. The image processing apparatus according to claim 26,

wherein curves each having a constant distribution of said shading correction coefficients of each of said first image and said second image are nearly circular curves; and

curves each having a constant distribution of said shading correction coefficients in accordance with the amount of movement are nearly oval curves each with a shorter diameter extending along the direction of movement.

28. The image processing apparatus according to claim 26,

wherein said image generator additively synthesizes said first image and said second image in a ratio of:

k: (1−k), provided that 0<k<1, and

said shading correction coefficient in accordance with the amount of movement is determined based on a weighed mean value using a predetermined function S as follows:

$$k \cdot S(r)+(1-k)\cdot s(r'),$$

provided that

$r=\mathrm{sqrt}(x^2+y^2)$;

$r'=\mathrm{sqrt}\{(x-\delta x)^2+(y-\delta y)^2\}$;

"sqrt" represents square root;

x, y represent coordinate variables in the rectangular XY plane coordinate system whose origin point is the center of image of either one of said first image and said second image; and

δx, δy represent said amounts of movement in the X coordinate direction and the Y coordinate direction, respectively.

29. A program product containing a program for executing an image processing, in which execution of said program by a computer allows said computer to execute the steps of:

acquiring a first image and a second image;

performing positioning on acquired said first image and said second image;

generating a synthesized image of said first image and said second image that have been subjected to positioning; and

performing a shading correction on said synthesized image using a shading correction coefficient in accordance with a relative amount of movement of said first image and said second image at the time of positioning.

* * * * *

PE

US008451339B2

(12) **United States Patent**
Solomon

(10) **Patent No.: US 8,451,339 B2**
(45) **Date of Patent: *May 28, 2013**

(54) **DIGITAL IMAGING SYSTEM FOR CORRECTING IMAGE ABERRATIONS**

(76) Inventor: **Neal Solomon**, Oakland, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 655 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/586,221**

(22) Filed: **Sep. 18, 2009**

(65) **Prior Publication Data**

US 2010/0033604 A1 Feb. 11, 2010

(51) **Int. Cl.**
H04N 5/228 (2006.01)

(52) **U.S. Cl.**
USPC **348/222.1**; 348/231.99; 348/224.1; 348/273; 348/208.11; 348/333.08; 348/335; 348/340; 348/241

(58) **Field of Classification Search**
USPC 348/222.1, 231.99, 224.1, 273, 342, 348/208.11, 333.08, 335, 340, 241
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2007/0080280 A1* 4/2007 Havens 250/201.1
2007/0236574 A1* 10/2007 Alon et al. 348/207.99

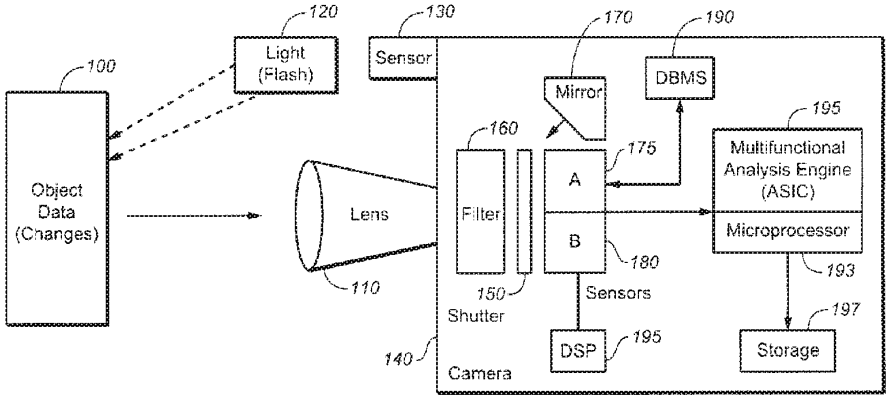
* cited by examiner

Primary Examiner — Usman Khan

(57) **ABSTRACT**

A system is disclosed for the automated correction of optical and digital aberrations in a digital imaging system. The system includes (a) digital filters, (b) hardware modifications and (c) digital system corrections. The system solves numerous problems in still and video photography that are presented in the digital imaging environment.

18 Claims, 19 Drawing Sheets



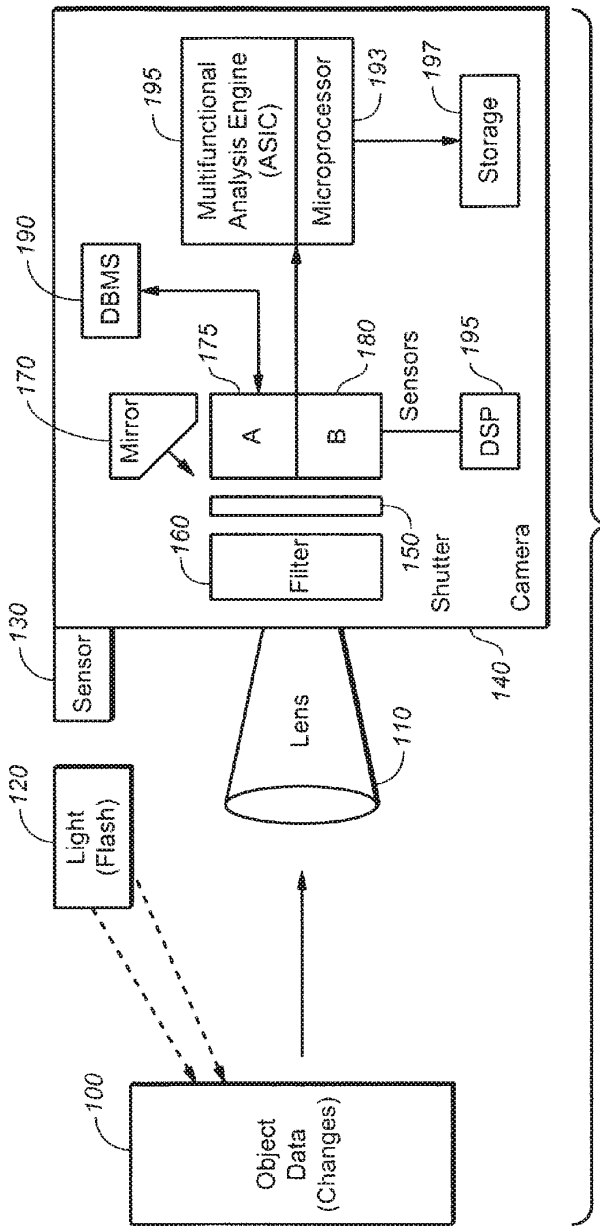

Object Data (Changes)
100
Light (Flash)
120
Lens
110
Sensor
130
Filter
160
Shutter
150
Mirror
170
A
175
B
180
Sensors
DSP
195
DBMS
190
Multifunctional Analysis Engine (ASIC)
195
Microprocessor
193
Storage
197
Camera
140

FIG. 1

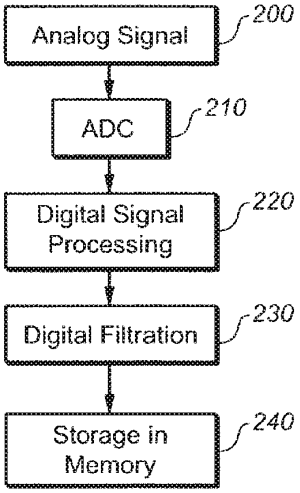


FIG. 2

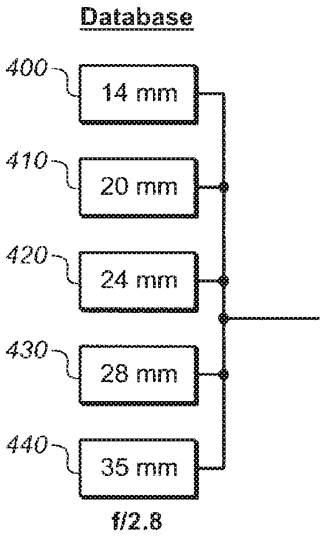


FIG. 4

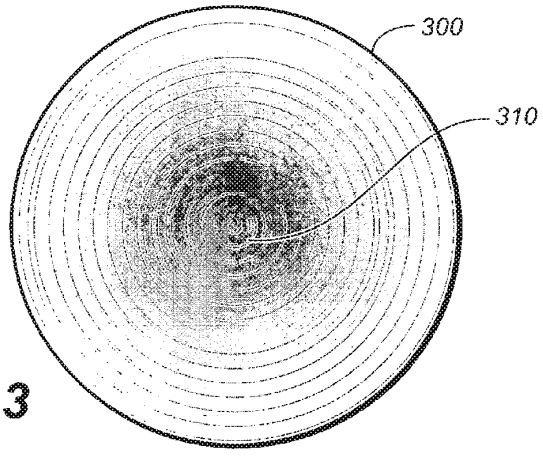


FIG. 3

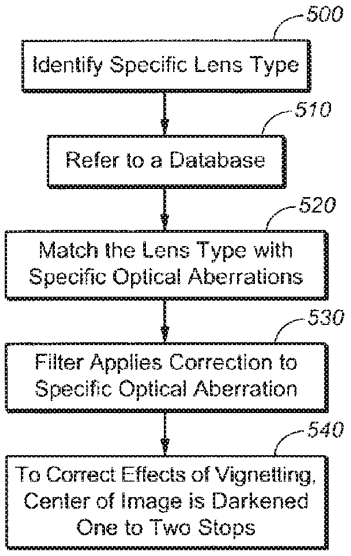


FIG. 5

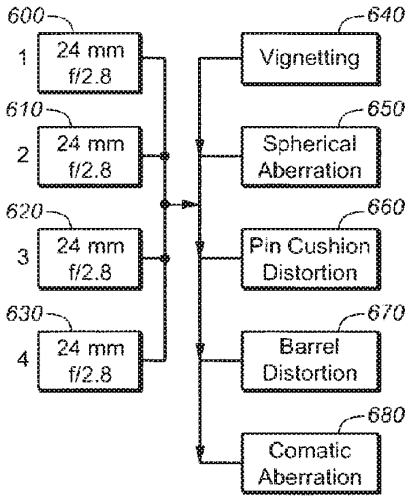


FIG. 6

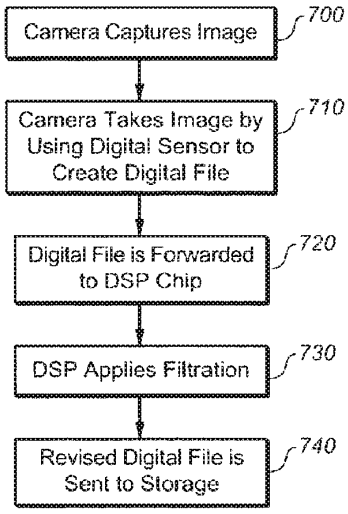


FIG. 7

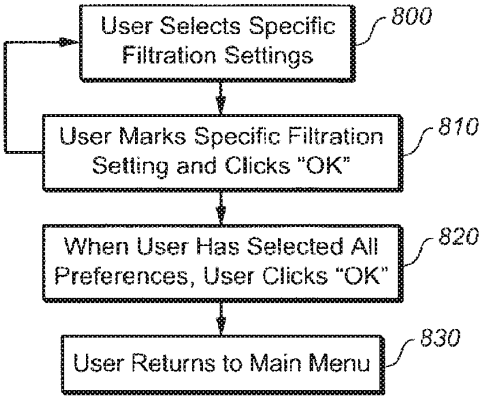

User Selects Specific Filtration Settings
800
User Marks Specific Filtration Setting and Clicks "OK"
810
When User Has Selected All Preferences, User Clicks "OK"
820
User Returns to Main Menu
830

FIG. 8

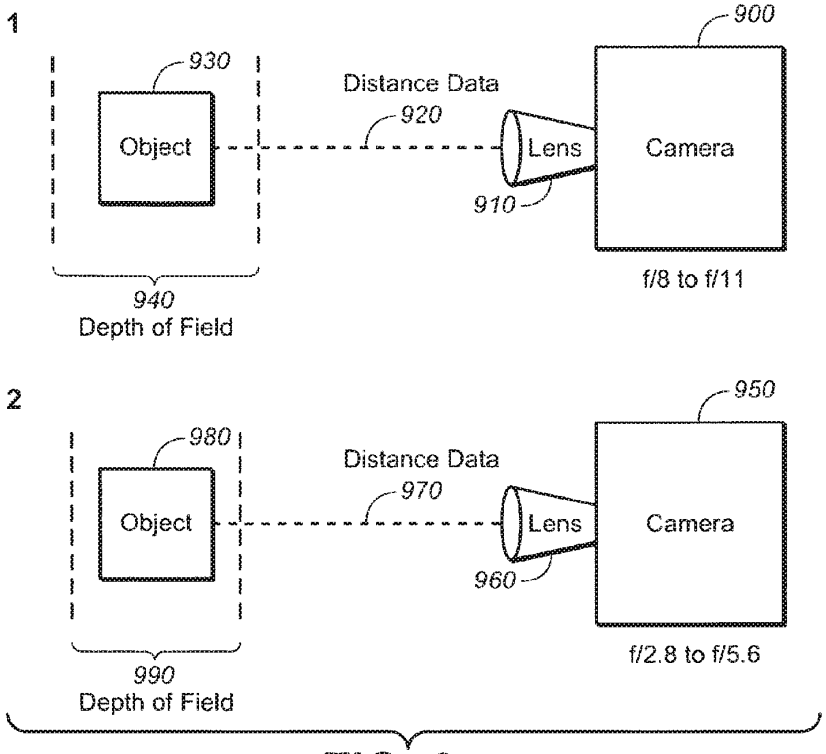

1
900
930
Object
Distance Data
920
Lens
910
Camera
f/8 to f/11
940
Depth of Field
2
950
980
Object
Distance Data
970
Lens
960
Camera
f/2.8 to f/5.6
990
Depth of Field

FIG. 9

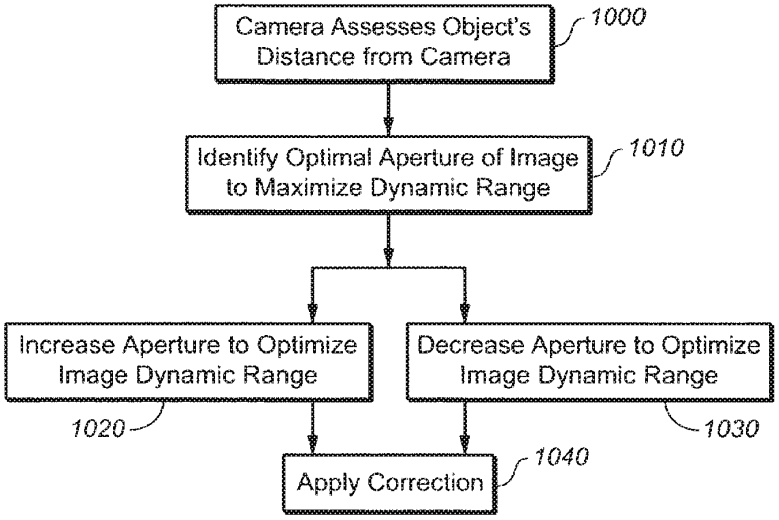

Camera Assesses Object's Distance from Camera
1000
Identify Optimal Aperture of Image to Maximize Dynamic Range
1010
Increase Aperture to Optimize Image Dynamic Range
1020
Decrease Aperture to Optimize Image Dynamic Range
1030
Apply Correction
1040

FIG. 10

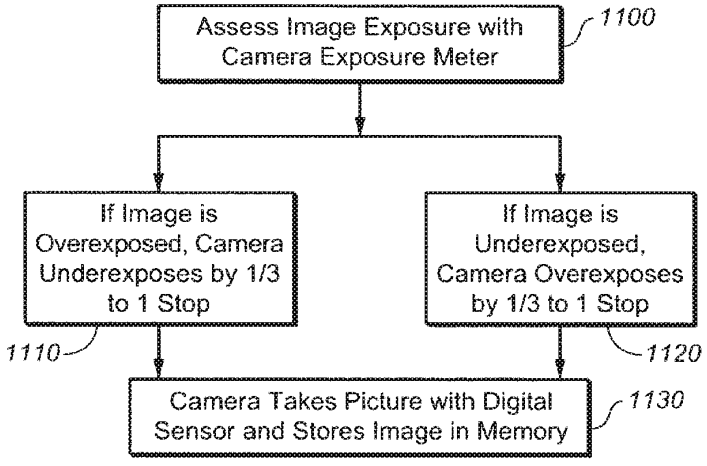

Assess Image Exposure with Camera Exposure Meter
1100
If Image is Overexposed, Camera Underexposes by 1/3 to 1 Stop
1110
If Image is Underexposed, Camera Overexposes by 1/3 to 1 Stop
1120
Camera Takes Picture with Digital Sensor and Stores Image in Memory
1130

FIG. 11

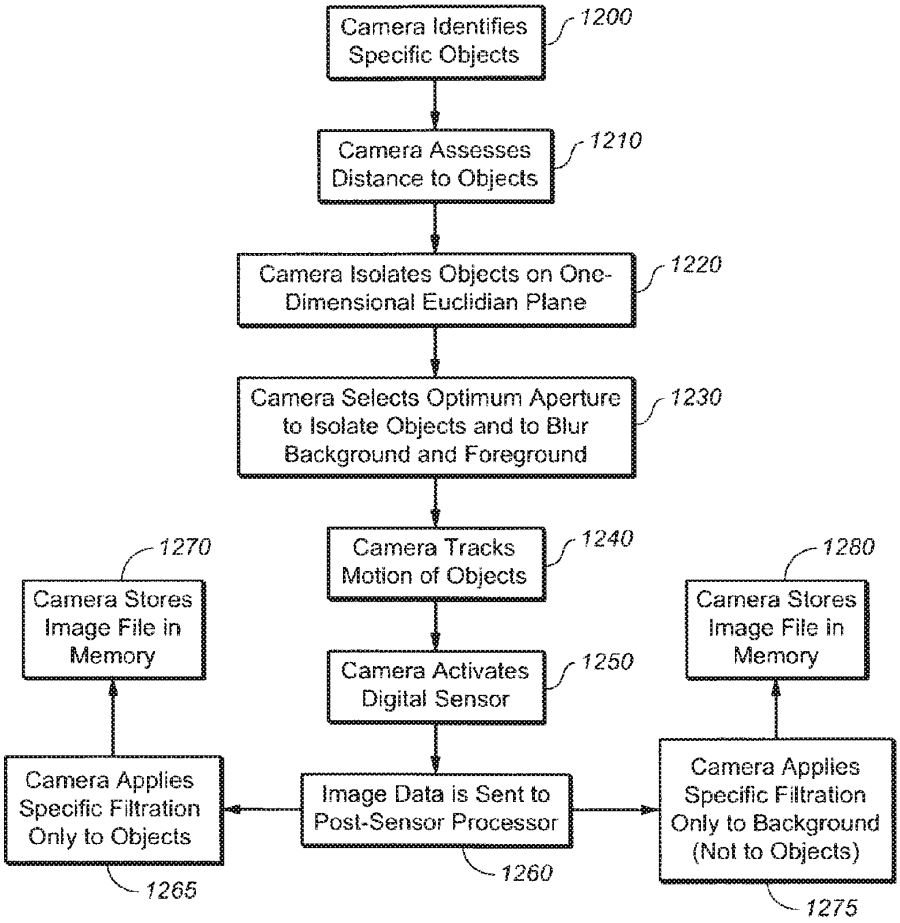

Camera Identifies Specific Objects
1200
Camera Assesses Distance to Objects
1210
Camera Isolates Objects on One-Dimensional Euclidian Plane
1220
Camera Selects Optimum Aperture to Isolate Objects and to Blur Background and Foreground
1230
Camera Tracks Motion of Objects
1240
Camera Activates Digital Sensor
1250
Image Data is Sent to Post-Sensor Processor
1260
Camera Applies Specific Filtration Only to Objects
1265
Camera Stores Image File in Memory
1270
Camera Applies Specific Filtration Only to Background (Not to Objects)
1275
Camera Stores Image File in Memory
1280

FIG. 12

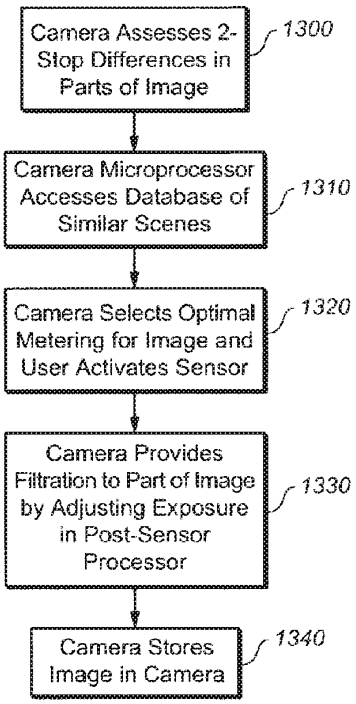

Camera Assesses 2-Stop Differences in Parts of Image
1300
Camera Microprocessor Accesses Database of Similar Scenes
1310
Camera Selects Optimal Metering for Image and User Activates Sensor
1320
Camera Provides Filtration to Part of Image by Adjusting Exposure in Post-Sensor Processor
1330
Camera Stores Image in Camera
1340

FIG. 13

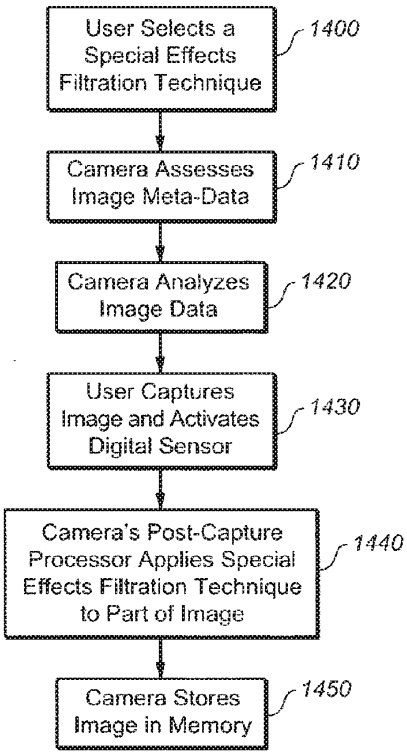

User Selects a Special Effects Filtration Technique
1400
Camera Assesses Image Meta-Data
1410
Camera Analyzes Image Data
1420
User Captures Image and Activates Digital Sensor
1430
Camera's Post-Capture Processor Applies Special Effects Filtration Technique to Part of Image
1440
Camera Stores Image in Memory
1450

FIG. 14

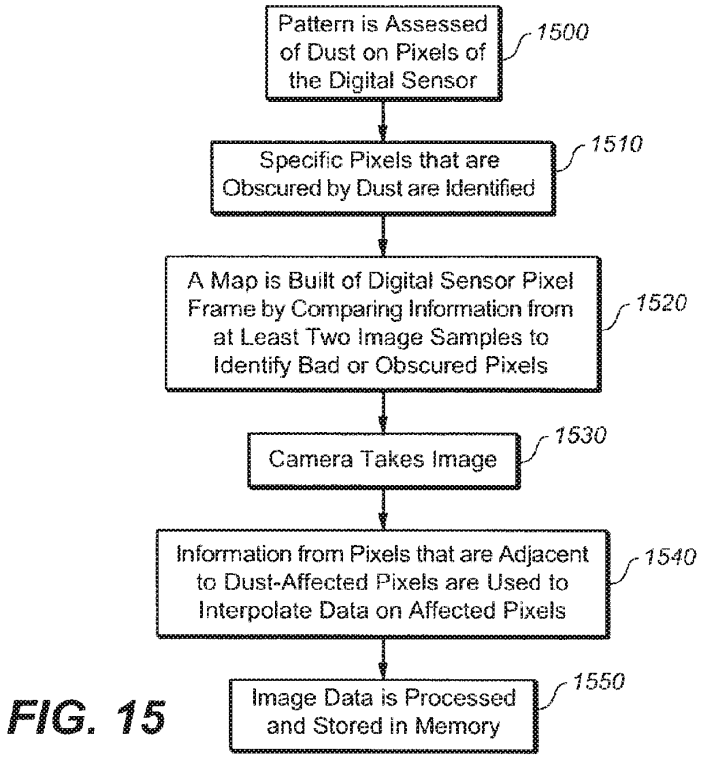

Pattern is Assessed of Dust on Pixels of the Digital Sensor
1500
Specific Pixels that are Obscured by Dust are Identified
1510
A Map is Built of Digital Sensor Pixel Frame by Comparing Information from at Least Two Image Samples to Identify Bad or Obscured Pixels
1520
Camera Takes Image
1530
Information from Pixels that are Adjacent to Dust-Affected Pixels are Used to Interpolate Data on Affected Pixels
1540
Image Data is Processed and Stored in Memory
1550

FIG. 15

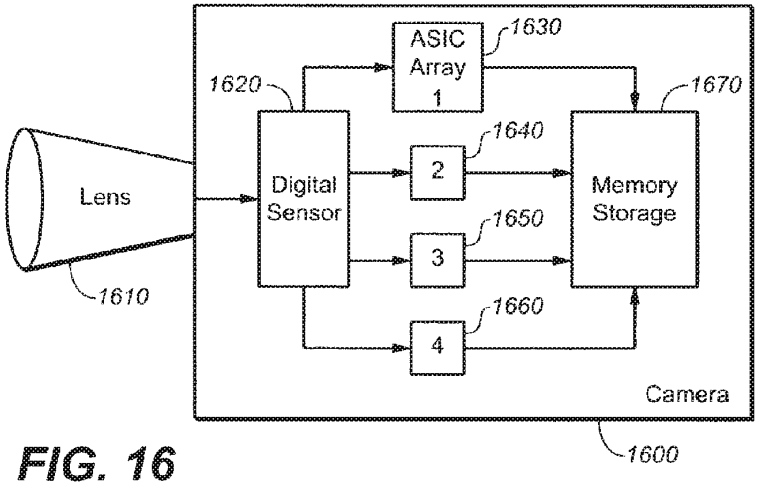

ASIC Array 1
1630
1620
1670
Lens
Digital Sensor
2
1640
3
1650
4
1660
Memory Storage
1610
Camera
1600

FIG. 16

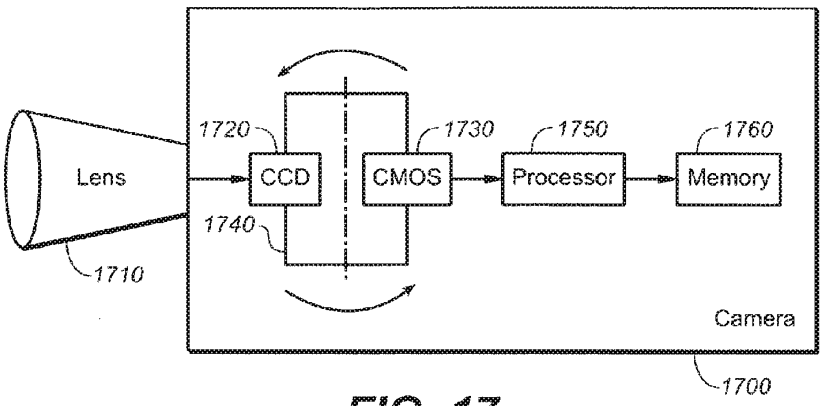

Lens
1710
1720
CCD
1740
1730
CMOS
1750
Processor
1760
Memory
Camera
1700

FIG. 17

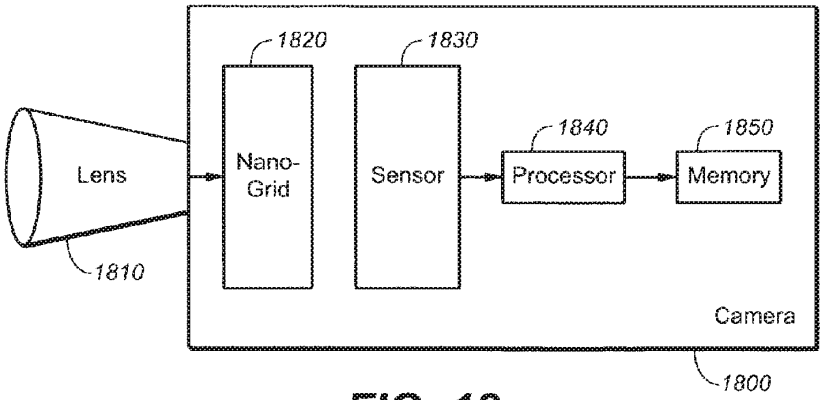

Lens
1810
1820
Nano-
Grid
1830
Sensor
1840
Processor
1850
Memory
Camera
1800

FIG. 18

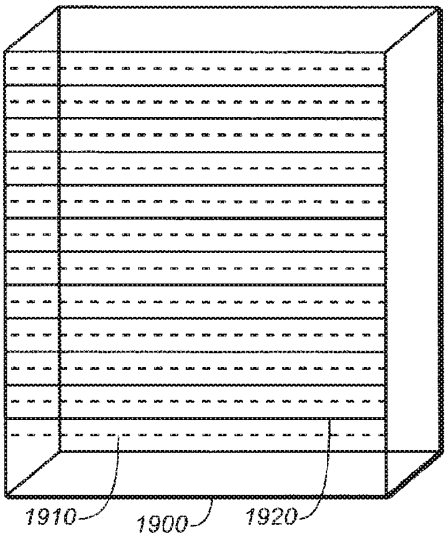

1910
1900
1920

FIG. 19

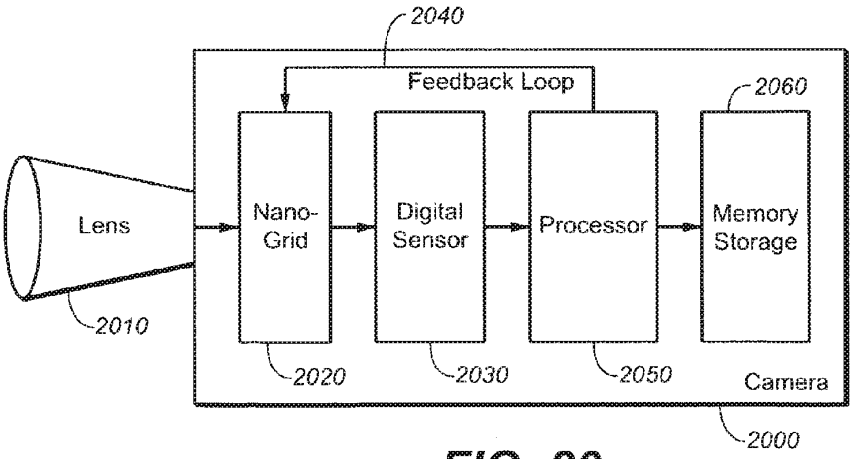

2040
Feedback Loop
2060
Lens
Nano-Grid
Digital Sensor
Processor
Memory Storage
2010
2020
2030
2050
Camera
2000

FIG. 20

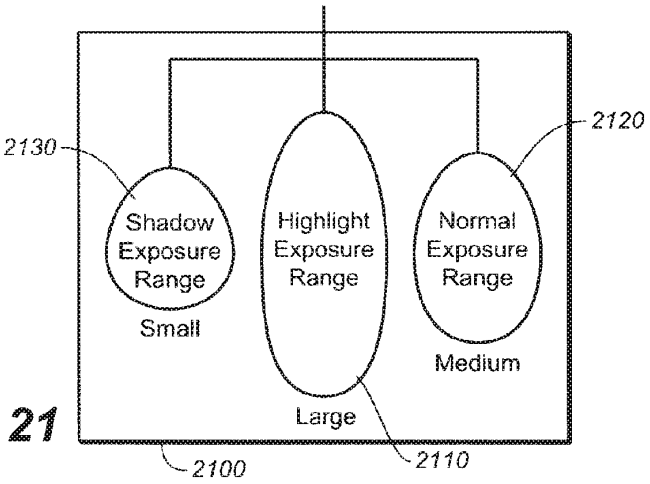

2130
2120
Shadow Exposure Range
Small
Highlight Exposure Range
Large
Normal Exposure Range
Medium
2100
2110

FIG. 21

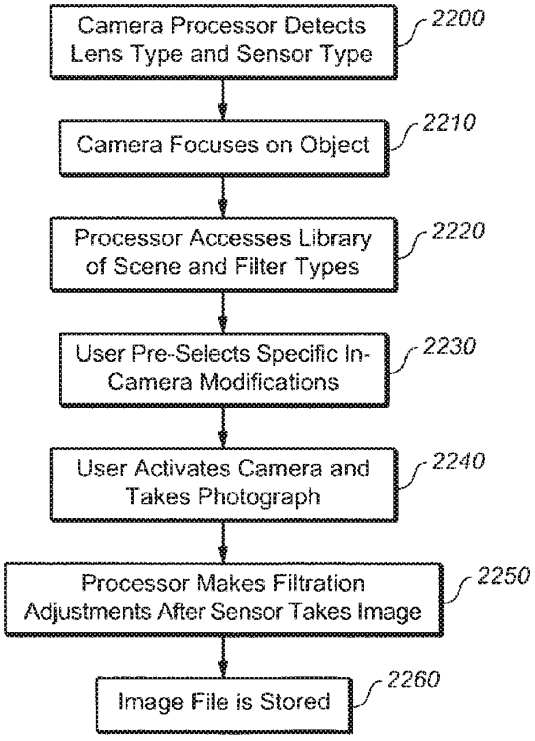

Camera Processor Detects Lens Type and Sensor Type
2200
Camera Focuses on Object
2210
Processor Accesses Library of Scene and Filter Types
2220
User Pre-Selects Specific In-Camera Modifications
2230
User Activates Camera and Takes Photograph
2240
Processor Makes Filtration Adjustments After Sensor Takes Image
2250
Image File is Stored
2260

FIG. 22

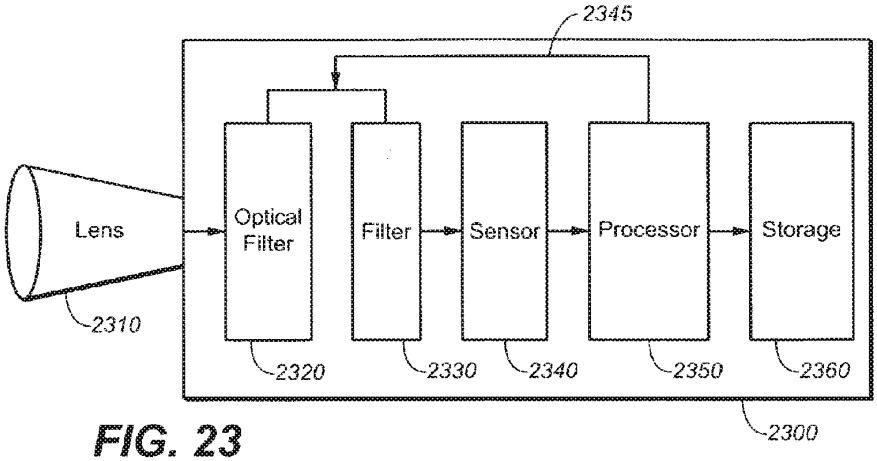

2345
Lens
Optical Filter
Filter
Sensor
Processor
Storage
2310
2320
2330
2340
2350
2360
2300

FIG. 23

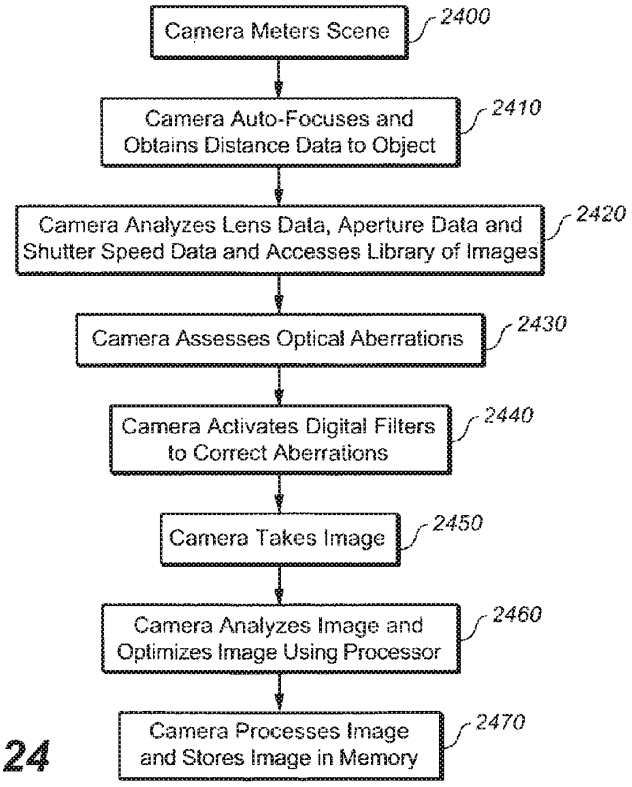

Camera Meters Scene
2400
Camera Auto-Focuses and Obtains Distance Data to Object
2410
Camera Analyzes Lens Data, Aperture Data and Shutter Speed Data and Accesses Library of Images
2420
Camera Assesses Optical Aberrations
2430
Camera Activates Digital Filters to Correct Aberrations
2440
Camera Takes Image
2450
Camera Analyzes Image and Optimizes Image Using Processor
2460
Camera Processes Image and Stores Image in Memory
2470

FIG. 24

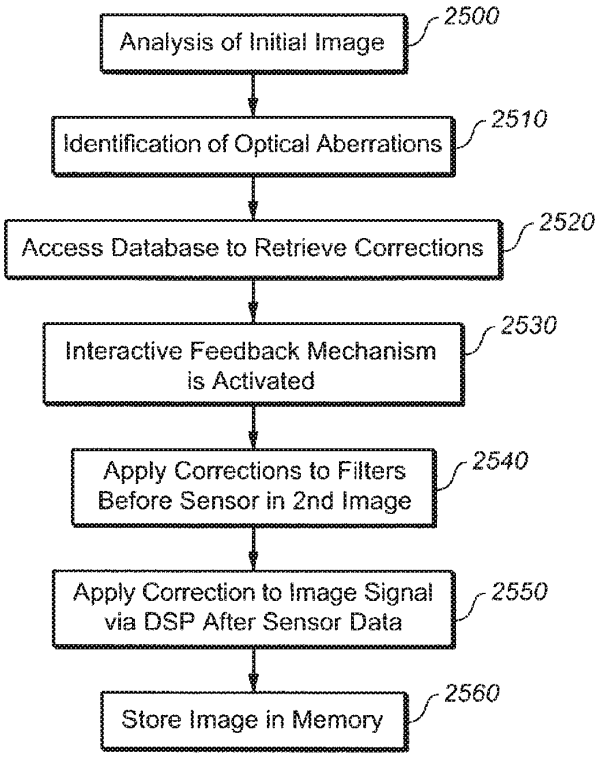

Analysis of Initial Image
2500
Identification of Optical Aberrations
2510
Access Database to Retrieve Corrections
2520
Interactive Feedback Mechanism is Activated
2530
Apply Corrections to Filters Before Sensor in 2nd Image
2540
Apply Correction to Image Signal via DSP After Sensor Data
2550
Store Image in Memory
2560

FIG. 25

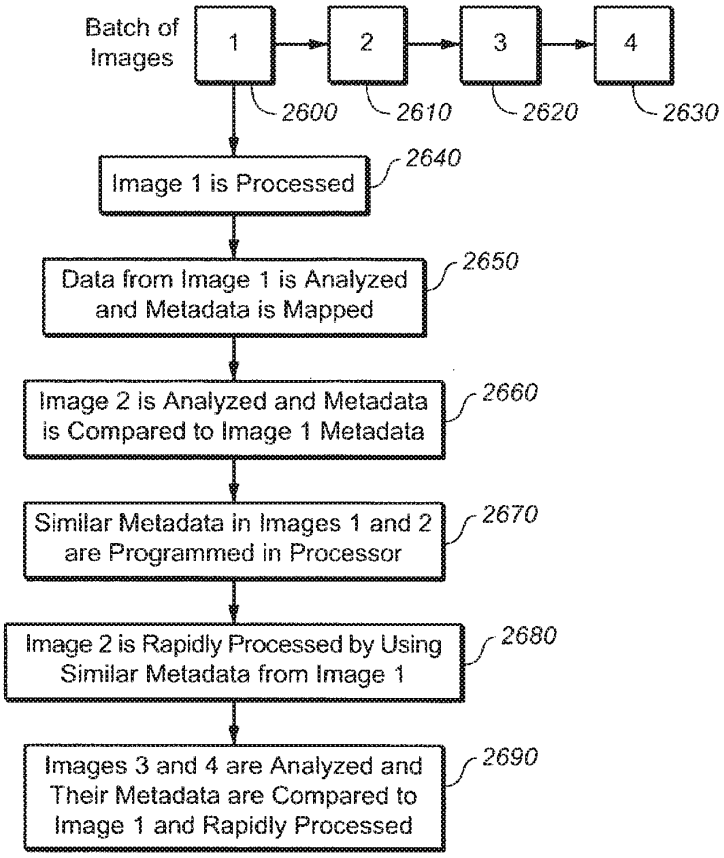

Batch of Images
1
2
3
4
2600
2610
2620
2630
Image 1 is Processed
2640
Data from Image 1 is Analyzed and Metadata is Mapped
2650
Image 2 is Analyzed and Metadata is Compared to Image 1 Metadata
2660
Similar Metadata in Images 1 and 2 are Programmed in Processor
2670
Image 2 is Rapidly Processed by Using Similar Metadata from Image 1
2680
Images 3 and 4 are Analyzed and Their Metadata are Compared to Image 1 and Rapidly Processed
2690

FIG. 26

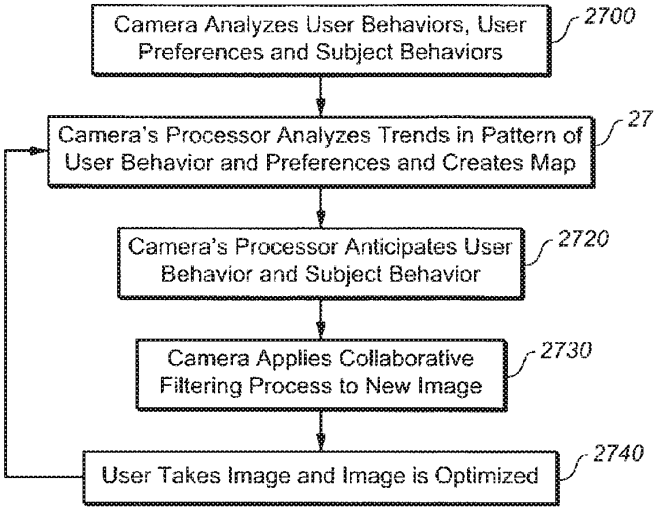

Camera Analyzes User Behaviors, User Preferences and Subject Behaviors
2700
Camera's Processor Analyzes Trends in Pattern of User Behavior and Preferences and Creates Map
2710
Camera's Processor Anticipates User Behavior and Subject Behavior
2720
Camera Applies Collaborative Filtering Process to New Image
2730
User Takes Image and Image is Optimized
2740

FIG. 27

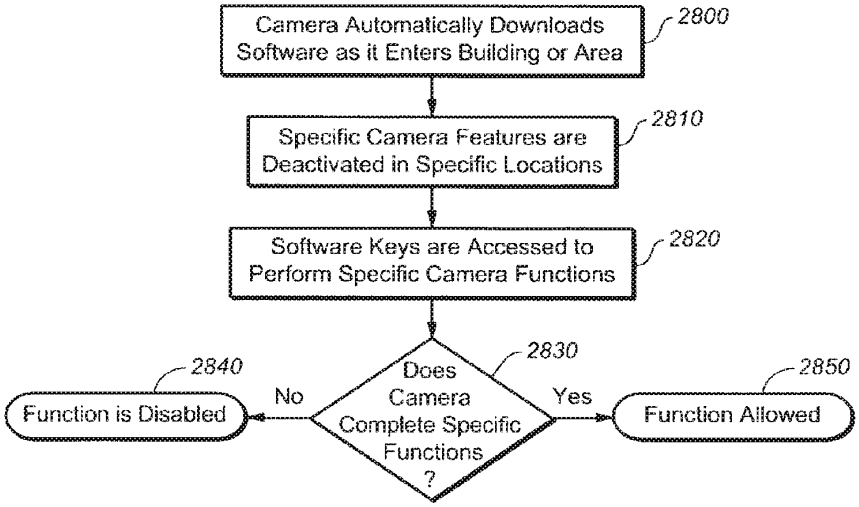

Camera Automatically Downloads Software as it Enters Building or Area
2800
Specific Camera Features are Deactivated in Specific Locations
2810
Software Keys are Accessed to Perform Specific Camera Functions
2820
Does Camera Complete Specific Functions ?
2830
No
Yes
Function is Disabled
2840
Function Allowed
2850

FIG. 28

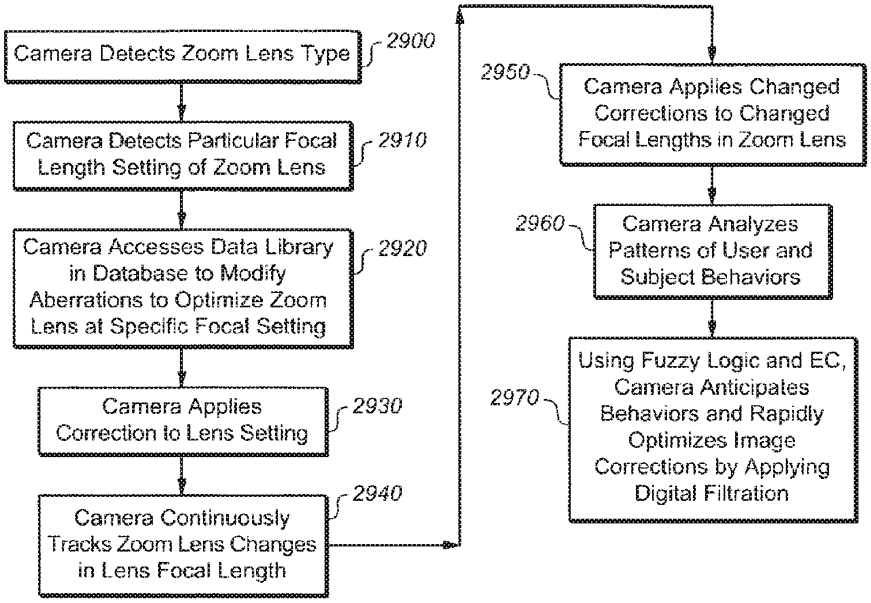

Camera Detects Zoom Lens Type
2900
Camera Detects Particular Focal Length Setting of Zoom Lens
2910
Camera Accesses Data Library in Database to Modify Aberrations to Optimize Zoom Lens at Specific Focal Setting
2920
Camera Applies Correction to Lens Setting
2930
Camera Continuously Tracks Zoom Lens Changes in Lens Focal Length
2940
2950
Camera Applies Changed Corrections to Changed Focal Lengths in Zoom Lens
2960
Camera Analyzes Patterns of User and Subject Behaviors
2970
Using Fuzzy Logic and EC, Camera Anticipates Behaviors and Rapidly Optimizes Image Corrections by Applying Digital Filtration

FIG. 29

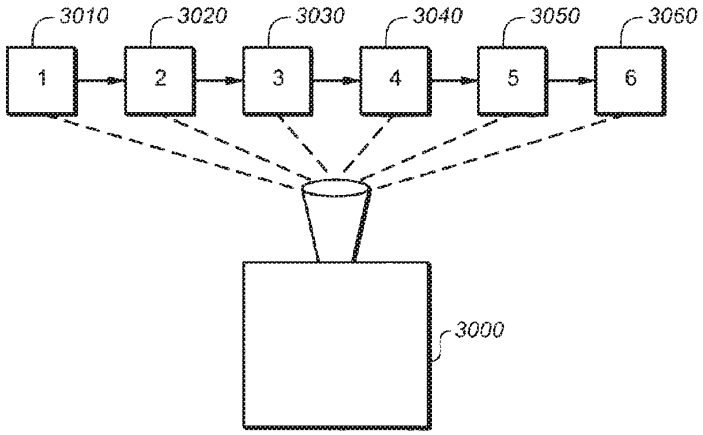

3010
3020
3030
3040
3050
3060
1
2
3
4
5
6
3000

FIG. 30

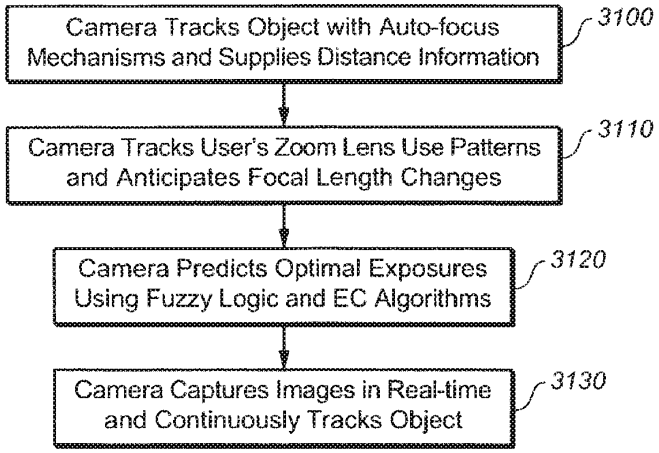

Camera Tracks Object with Auto-focus Mechanisms and Supplies Distance Information
3100
Camera Tracks User's Zoom Lens Use Patterns and Anticipates Focal Length Changes
3110
Camera Predicts Optimal Exposures Using Fuzzy Logic and EC Algorithms
3120
Camera Captures Images in Real-time and Continuously Tracks Object
3130

FIG. 31

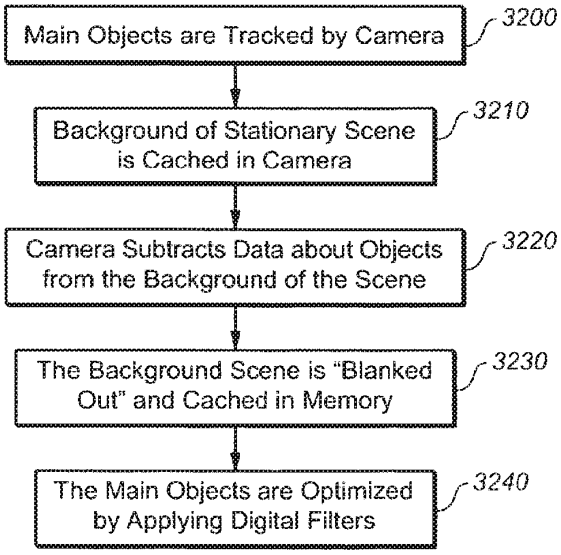

Main Objects are Tracked by Camera
3200
Background of Stationary Scene is Cached in Camera
3210
Camera Subtracts Data about Objects from the Background of the Scene
3220
The Background Scene is "Blanked Out" and Cached in Memory
3230
The Main Objects are Optimized by Applying Digital Filters
3240

FIG. 32

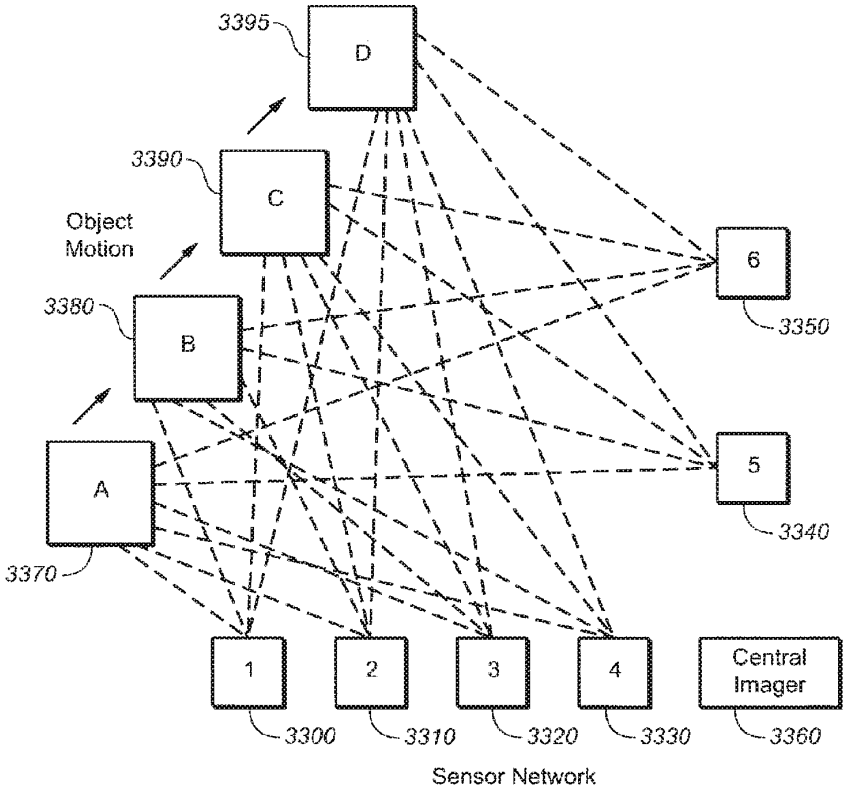

3395
D
3390
C
Object
Motion
3380
B
A
3370
6
3350
5
3340
1
2
3
4
Central
Imager
3300
3310
3320
3330
3360
Sensor Network

FIG. 33

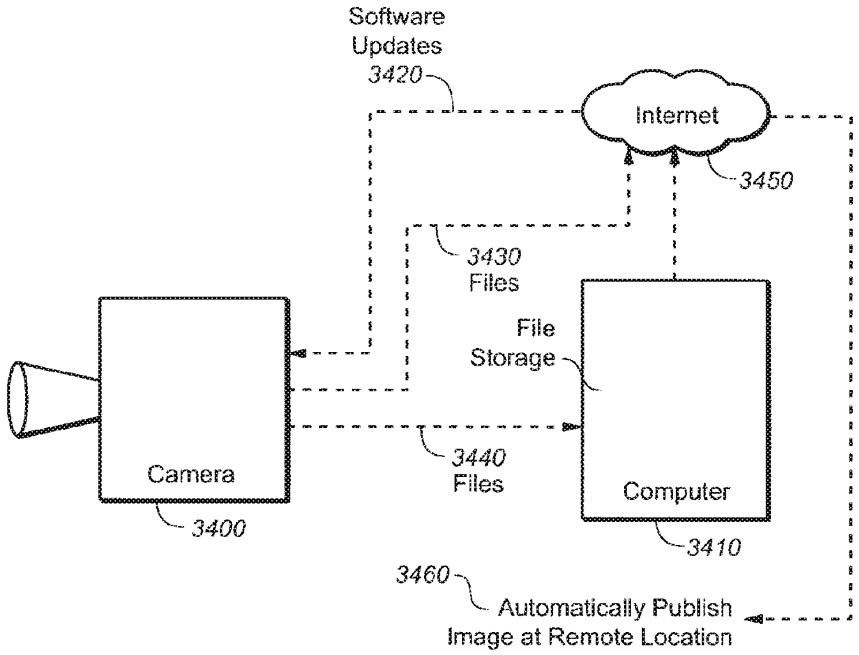

Software
Updates
3420
Internet
3450
3430
Files
File
Storage
3440
Files
Camera
3400
Computer
3410
3460
Automatically Publish
Image at Remote Location

FIG. 34

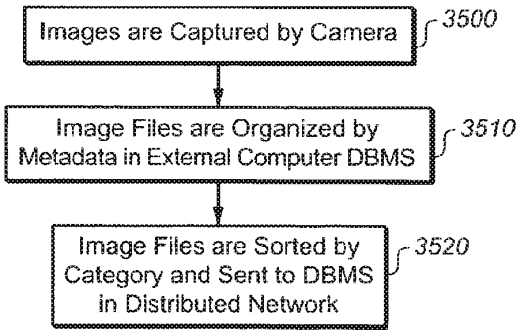

Images are Captured by Camera
3500
Image Files are Organized by
Metadata in External Computer DBMS
3510
Image Files are Sorted by
Category and Sent to DBMS
in Distributed Network
3520

FIG. 35

DIGITAL IMAGING SYSTEM FOR CORRECTING IMAGE ABERRATIONS

CROSS-REFERENCES TO RELATED APPLICATIONS

The present application claims the benefit of priority under 35 U.S.C. section 119 from U.S. patent application Ser. No. 11/825,521 filed on Jul. 11, 2007 and Provisional Patent Application Ser. No. 60/807,065 filed on Jul. 11, 2006, the disclosures of which are hereby incorporated by reference in their entirety for all purposes.

FIELD OF THE INVENTION

The present invention pertains to imaging systems. The invention presents electronic methods to optimize optical processing, the digital capture of light and post-capture image organization of digital data sets. The system may be used in any device that captures, records, replicates, scans, reproduces, accesses, organizes, modifies, edits or stores images digitally. The invention applies to any imaging system that includes interaction between optics, digital image sensors, post-capture integrated circuits and digital storage components. The system includes self-organizing apparatus for optical image collection, electronic organization and optimization of digital data using integrated circuits and software applications. The system applies to consumer and professional still and video photography, including cinematography, to the processing of images with digital sensors, and to copying and scanning technologies. The system also applies to complex grids of multiple video cameras and satellites for surveillance and reconnaissance.

BACKGROUND OF THE INVENTION

The history of photography in the twentieth century is a story of finding solutions for optimizing optical problems. The main challenges have involved improving lens configurations to optimize image quality for film capture. As an example of this, lens aberrations have been reliably corrected by creating aspherical lens elements in wide-angle lenses and by creating apochromatic lens elements in telephoto lenses. The use of lens element coatings has also improved optical quality. Similarly, the evolution of zoom lenses has included improvement in optical quality via the combining of complex optical element configurations; as the optical quality of zoom lenses improved dramatically, their simplicity and utility led them to dominate lens sales. Complex computer-aided design (CAD) software has been used to test a broad range of possible lens configurations so as to optimize the optical performance in terms of clarity and contrast of each lens type, as much as optically possible within economic constraints.

In the last twenty-five years, an additional revolution has occurred with the advent of auto-focus (AF) technology in still photographic and video cameras. Invented by Minolta in the early 1980s, AF technology was a photographic application of technology developed for the U.S. military. The AF system used an infrared light sensor to reflect light onto an object that allowed a camera's lens to focus on the object by employing a motor in the camera. Canon eventually developed improved methods of auto focus by using electronic means (viz., micro ultrasonic motors) to increase speed and accuracy. This AF technology was integrated with automatic exposure (AE) technology which developed complex algorithms in a "program" mode to combine shutter and aperture data to match each lens with particular subject matter, as well as an aperture-priority exposure mode and a shutter-priority exposure mode. Of course, the photographer could use manual focus and manual exposure at any time, but these improvements increased the creative process and the competitive advantages of camera makers and photographers that employed them. Ultimately, the combination of these developments allowed ordinary photographers to achieve high quality standards.

AE was improved by Nikon, particularly with the use of a "3D color matrix" system, which included a library of pre-programmed image types. The combination of the improved AF and AE subsystems allowed a dramatic simplification of photographic imaging because the photographer no longer labored over the time-consuming focus and the exposure variables. Automated film advance, in the form of built in motor drives, increased the working speeds of camera operation as well. Nearly all consumer and professional cameras became automated to some degree by the mid-1990s, including formats beyond the 35 mm film standard.

In the last decade, a new technology of image stabilization (IS) has emerged to help correct the problem of vibrations caused camera shake that lead to image blur. This technology is implemented in lenses by the use of gyros to reorient the light plane to compensate for camera shake; when combined with the earlier automated camera technologies such as AF and AE, IS further improves the photographic experience, particularly for larger lenses.

In addition to these advances in camera automation, technologies improved in the category of artificial flash as well. With microprocessors and sensors employed to measure minute variances, the development of photographic flash systems allowed the photographer to control the lighting in an environment to some degree. Nikon's use of distance information in its flash system advanced the state of the art in flash photography. The combination of AF and AE with automated flash mechanisms provided increased efficiency and simplicity in image capture processes.

The last several years have witnessed a revolution in digital photography. Because of its simplicity, potential quality improvement, immediate feedback and cost savings, digital photography has captured an increasing market share relative to film-based cameras. Kodak holds a number of patents involving the charge coupled device (CCD) for converting and recording light into electronic format. A competing technology for digital capture is complementary metal-oxide semiconductor (CMOS) which, though developed by Fairchild Semiconductor over forty years ago, is predominantly used in photographic cameras by Canon. Although there are trade-offs in the application of CCD and CMOS digital sensors for image capture, they both find wide acceptance in the market.

In order to correct for digital artifacts in image capture mechanisms, anti-aliasing filters are placed in front of digital sensors. Despite this improvement, digital imaging still has some challenges to overcome in competing with the image quality of film.

At the present time, the most recent advances in digital imaging for professional still photography have come from Hasselblad, which offers a Phase One camera back with a 39 MP digital sensor from Kodak. This system uses software that automatically corrects for digital capture limitations to produce a quality image. Their "digital APO correction" (DAC) technology performs an analysis of meta-data to color-correct the digital capture resulting in moiré-free images.

At the limits of current technology, a Canadian company, Dalsa, has produced a 111MP (10,560 by 10,560 pixels) CCD digital sensor that measures four inches square. This technol-

ogy must be mated with large format-type lenses with large image area, and may be used for satellite surveillance applications and for other astronomical applications.

With both the larger sensor surface area of a medium format camera system and the high-quality fixed focal-length lenses of Zeiss, Schneider and Rodenstock, the quality of even the top optics will be a limiting barrier to advanced digital sensors' ability to perceive maximum resolution. Without new improvements in optical and digital technologies, further progression of photographic camera systems will be limited.

Photographic Problems

Though every major advance in photography has solved an important problem, there are still remaining photographic problems to be solved in order to meet the goals of optimizing optical imaging quality while increasing simplicity and efficiency and lowering cost. Despite the advent and evolution of digital imaging, a number of problems have emerged in the digital realm in addition to earlier problems involving optics. Nevertheless, an opportunity exists to solve some of these problems via digital approaches. These problems are generally categorized as optical or digital.

Optical Problems

In the case of optics, lens aberrations are characterized according to lens type, with wide-angle lens problems differentiated from telephoto lens problems. Some of the problems affecting wide-angle lenses arose from the creation of the single lens reflex (SLR) camera. Before the SLR, the rear element of a lens could be placed in a rangefinder to protrude to a point immediately in front of the film plane in order to correct for aberrations. While the advantages of the mirror mechanism include ability to see exactly what one is photographing, because the mirror of the SLR flips up during exposure, the rear element of the lens must be placed in front of the mirror's plane of movement. This mechanical fact limits lens designs in most 35 mm and medium-format camera systems and particularly affects wide-angle lens configurations.

It is very difficult to control the five aberrations of Seidel—spherical aberration, distortion (barrel distortion and pin cushion distortion), comatic aberration, astigmatism and curvature of field. In wide-angle SLR lenses as they are currently designed, these aberrations are particularly prominent.

For wide-angle lenses, optical vignetting affects peripheral illumination. Though optical vignetting will affect even retrofocus wide-angle lenses in rangefinders, it is particularly prominent in SLR cameras. According to the Cosine law, light fall-off in peripheral areas of an image increases as the angle-of-view increases. While optical vignetting can be reduced by stopping down the lens, the aberrations in rectilinear wide-angle lenses generally exhibit more distortion the wider the lens.

In the case of wide-angle lenses, the depth of field range is much broader, with close focusing causing aberrations without stopping down the aperture. To solve this problem, close-distance focusing is improved by the creation of floating groups of lens elements. The rear lens group elements float to correct close-distance aberrations. With wide-angle lenses that have wide apertures, floating lens elements improve lens aberrations in focusing on distance points also.

Modulation transfer function (MTF) curves represent a quantitative methodology used to assess the resolution and contrast of lens performance at specific apertures. Each lens type has a specific lens element composition, formula and behavior as measured by MTF. In general, MTF measures lens sharpness to 30 lines/mm and contrast to 10 lines/mm.

Because different colors of the visible light spectrum behave uniquely, the goal of lens design is to have all colors accurately hit a film plane or digital sensor plane. The particular challenge for telephoto lenses is that the red and green light colors strike the film plane at different times than blue light colors; thus a compensation must be made in the lens configuration to adjust for chromatic aberrations. Camera lens manufacturers have used extra low dispersion glass and fluorite glass elements in telephoto lenses primarily to adjust the red color light spectra to the film plane. In addition, telephoto lenses use carefully designed lens coatings to limit light diffraction-based aberrations.

Due to their construction, super-telephoto lenses are very large and heavy. While modifying the materials used in the lens barrels could reduce size and weight problems, a technological improvement in telephoto lens design was developed by Canon with the addition of diffractive optical (DO) elements, which behave as a sort of highly-refined fresnel lens magnifier. Though the MTF analyses of wide-angle lenses show dramatic latitude in performance of even high quality SLR lenses, with particular loss in resolution and contrast toward the edges of the image, high quality telephoto lenses show control of aberrations. However, the price of these lenses is prohibitively high.

In the case of zoom lenses, as many as four distinct groups of lens elements correct various optical aberrations. These lens element groups include (a) a focusing group, (b) a magnification variation group, (c) a correction group and (d) an image formation group. Modulating the focal length range of a zoom lens enables the lens to perform within the scope of operation, yet the zoom lens architecture has limits. In particular, the zoom lens configuration sacrifices resolution and wide potential aperture. Generally, the degree of resolution and contrast at the smaller angle of view is traded away in favor of competence at a wider angle of view, or vice-versa. This explains why MTF analyses of zoom lenses generally show a dramatic lowering in resolution and contrast relative to excellent fixed focal length lenses.

Digital Problems

Digital photography has built on the edifice of film camera systems. For instance, the size of the sensor is generally limited to the size of the optical circumference of a lens system. In the case of 35 mm lenses that are designed for a specific angle of view, the largest that a digital sensor in a 35 mm lens system could be, is 24 mm by 36 mm, with a corresponding maximum image circle of 43 mm. In the case of medium format lenses, the largest digital sensors would duplicate the corresponding film plane size, whether 6×4.5 cm, 6×6 cm, 6×7 cm, 6×8 cm, 6×9 cm, 6×12 cm or 6×17 cm (which results in an effective image circle as large as 7 inches).

Digital sensors that are smaller than the limits of a corresponding lens system have been introduced. For example, Nikon digital sensors are smaller than 24 mm×36 mm, or advanced photo system (APS) size. Efficient stacking of pixels allows a smaller sensor to eventually match the performance of a corresponding film system, while using the smaller circumference of the same lenses. Since the outside edges of the lens typically degrade resolution and contrast, this model using the smaller digital sensor can have an advantage of using primarily the centralized "sweet spot" of the image area. However, this smaller sensor size sacrifices the peripheral effects of a wide-angle lens, so a 14 mm becomes a 21 mm in a 1.5× conversion-sized sensor in a 35 mm lens system. On the other hand, with telephoto lenses, the angle of view is limited to the center 65% of the image. This gives the appearance of upconverting a telephoto lens by 1.5× and thus

provides an impression of increased magnification; a 400 mm f/2.8 lens appears as a 600 mm f/2.8 lens on a camera with a cropped digital sensor. Ultra-wide-angle lenses have been introduced with smaller image areas than 35 mm to compensate for smaller sensor size.

Though invented over thirty years ago by Dr. Bayer, the charge coupled device (CCD) that is used in many digital cameras generally emulates the behavior of film. Specifically, since most photographic film has three layers of green, red and blue, with green representing fifty percent of the emulsion and red and blue twenty-five percent each, the CCD architecture also configured pixels to capture fifty percent of the green photonic visible light spectrum and twenty-five percent each for pixels recording red and blue light. Human eyes see more green than red and blue, so both film and digital sensors seek to emulate the way that we see. Each light color is captured by a different pixel in the CCD, just as there are three emulsion layers of film. In recent years, Foveon has developed a digital sensor for image capture that further seeks to emulate film by structuring the pixels into three layers, again with fifty percent capturing green light and twenty-five percent each capturing red and blue light.

Unfortunately, unwanted artifacts are also captured by the digital image capture process. These include banding and moiré effects that present false patterns and colors. Moiré patterns are created because the dot pattern of a sensor will intermittently overlap with the pattern of a subject to create a third pattern; these effects are optically-generated digital distortions that represent the effect of light hitting a pixel without correction. In order to compensate for these effects, digital sensors have employed low pass filters consisting of liquid crystal structures; however, these filters tend to have the effect of softening image resolution. Additionally, RGB or CMYG color filters are placed in front of digital sensors to ensure the accurate capture of colors.

CMOS digital sensors present an alternative to CCDs. By employing alternating positive and negative transistor networks, the CMOS sensors use less power. While they do not have the low noise ratio of the CCD, they do have greater light exposure latitude, in both range of ISO and dynamic range of detail in highlight and shadow. More importantly, CMOS sensors contain the circuitry, including analog to digital converter (ADC) and digital to analog converter (DAC), for post-processing digital images on the chip itself and enabling increased micro-miniaturization of the digital imaging process. An increase in the bit rate of the CMOS chip up to 32-bit makes possible a much richer color palate and level of detail than with earlier generation CCDs.

CMOS sensors can be full-frame, matching the lens specifications for the camera systems for which they are designed. A relatively bigger sensor has a wider depth of field capability, so the background can appear as a blur to set apart the main subject. Given these capabilities, one problem that emerges is that a digital sensor's enhanced capabilities to capture details may exceed the maximum optical resolution capabilities of many lenses. Nevertheless, CMOS sensors still require an anti-aliasing filter to be used in front of the sensor, which marginally degrades resolution.

Over the years, cameras have gotten smaller. While in the 19th century cameras were 11×14 or 8×10, literally capturing images on large emulsion plates, cameras of today are smaller and more automated. Yet the larger the film size, the bigger the enlargement potential and the increase in relative detail in the overall image. Similarly in digital photography, the larger the sensor, the more detail available and the bigger the output print can be enlarged. Because of this correspondence of digital sensor to film, the evolution of digital photography has been restricted to respective film camera systems, with 35 mm and medium format systems dominating the field because well-developed lens systems have already been organized for these camera formats. The potential exists, however, to develop 35 mm camera system digital sensors that rival film-based medium format or large format camera system quality or to surpass the limits of 35 mm camera systems with medium format camera system digital sensors. The relative size, cost and automation advantages of 35 mm camera systems generally show that these systems not only are competitive, but that these markets are increasingly accelerated relative to larger format systems. For example, the development of large aperture lenses, super-telephotos, rapid auto-focus, refined automated exposure and image stabilization systems in 35 mm systems has solved various problems that have emerged in the last century and has improved image quality and camera system efficiency.

However, in the digital imaging realm additional problems have emerged, including the need to improve color (hue and saturation) quality, exposure highlight range, contrast range and other tonal adjustments. In addition, digital image capture brings its own set of aberrations, including moiré and banding effects and noise and ISO range limits. Additional aberrations are linked to the unique design of each type of digital sensor, with trade-offs presented between types of CCDs or CMOS chips. Moreover, there are still optical problems in the digital realm, namely, a range of optical aberrations created particularly by wide-angle and zoom lenses as well as the limits of very large, costly and heavy super-telephoto lenses.

In order to transcend the optical and digital limits of present camera systems, software systems have been developed that deal with the problems in post-production. While the most notable of these post-production digital editing software programs is Adobe Photoshop, each camera manufacturer has its own proprietary program. In the main, these post-production software programs are limited to color correction and sharpening/softening of images. Additionally, some of these software programs are able to emulate specific artificial filter techniques to produce creative modifications of an original image. Nevertheless, manipulating unfiltered RAW image files in post-production processes is time-consuming and expensive and requires considerable skill.

One unintended effect of using digital sensors to capture images in digital photography is that dust accumulates on the sensor surface and thereby obstructs a clear optical image. The vacuum behavior of increasingly ubiquitous zoom lenses moves dust in lenses that are not internally sealed and the existence of dust is a prevalent feature of digital photography. Dust on the sensor is a non-trivial problem that requires tedious post-production correction for each image. The existence of dust on a digital sensor is an inconvenient impediment to achievement of optical imaging quality.

What is needed to correct these various optical and digital aberrations and unfiltered image files is in-camera modification capability for each specific image problem. The present invention describes a digital imaging system to optimize optical results.

APPLICATIONS OF THE PRESENT INVENTION

The present invention has several practical applications. The digital imaging system applies to consumer and professional still and video camera technologies, to cellular telephones and to personal digital assistants (PDAs). Since video technologies are evolving into digital formats, including HDTV and its successors, the present invention would be

applicable to these technologies. The present invention also applies to networks of remote camera sensors for surveillance. The system also applies to native digital cinematography and telecine conversion from analogue to digital media. The system may be applied to image scanning and image copying technologies. Finally, the present system may be applied to any optical digital capture, processing and storage sub-system technologies, including groups of sensors or satellites.

ADVANTAGES OF THE PRESENT INVENTION

There are several important advantages of the present invention. The present system dramatically improves image quality. This digital imaging system eliminates, or minimizes, post-production processes. In addition, the system presents substantial cost savings as well as time savings relative to existing digital imaging systems because of the automation of integrated in-camera optical and digital corrections of aberrations.

With the present system, in-camera digital filters will largely replace optical filters. With less distortion, cost and weight/size than current optical filters and with far more control and quality results, the present system demonstrates that in-camera digital filtration out-performs better than external filters. The in-camera filter system is also an improvement over post-production digital filter systems which require substantial time, cost and skill to implement.

By using the present invention, users will be able to use lens apertures that are wider open, because lens aberrations will be corrected. In turn, this increased latitude will allow more efficient (2+ stops) use of available light and will allow slower lenses to achieve quality images that have traditionally been in the domain of expensive fast lenses. The process of photography will be made generally more efficient.

The present system allows camera manufacturers to design different, predominantly smaller, lenses. Moreover, with providing a system for digital corrections, camera lenses may use less expensive optics and still obtain good results. This process will, in turn, accelerate the adoption of low-cost digital photographic systems and, in the aggregate, increase the overall size of the digital photographic market. Similarly, there will be an increase in the effectiveness of zoom lenses, which are already becoming popular. With the present system, 35 mm optics may obtain the quality typically recognized by 4×5 film camera systems. The present system will thus facilitate photographic digital imaging to supplant the film era.

Its application to digital scanning and copying will allow the present system to become ubiquitous as a system to improve imaging.

Because the system presents an integration of several critical subsystems that are centered on digital imaging processes, the system has applications to video photography, satellite systems and surveillance systems. The dynamics of the operation of the subsystems of the present digital imaging system reveal the refinement, efficiency and optimization of the digital photographic paradigm.

Importantly, since the present system uses apparatus and methods that are implemented with software processes, in-camera software can be constantly upgraded and remotely downloaded, while image files can be automatically uploaded, organized and published.

If the goal of the evolution of photographic technology is to increase the number and quality of excellent images, the present system will revolutionize photography.

Solutions to Digital Imaging Problems that the Present System Presents

The present system provides in-camera digital corrections to both optical and digital aberrations. In the case of optical aberrations, distinct lens-specific imperfections are caused by wide-angle, telephoto and zoom lens types. In the case of digital aberrations, specific digital artifacts, such as aliasing and dust, must be corrected.

The present invention also designs specific improvements to digital sensor design. These hardware architecture modifications allow digital imaging to maximize both optical resolution and image exposure range.

Post-capture in-camera filtration is only part of the solution. There is also a need to modify the digital sensor, whether CCD or CMOS, with specific filtration in some cases, including a low pass anti-aliasing filter and a polarizing filter. This post-optic pre-sensor filtration works with post-sensor in-camera filtration processes.

In the context of specific complex processes, such as in zoom lens modifications of focal length and in full-motion video processing, additional corrections are performed using the digital imaging system which continuously optimizes performance.

Finally, the present system reveals approaches to improve network coordination and wireless external storage and publication capabilities for digital imaging systems.

BRIEF SUMMARY OF THE INVENTION

The present invention is divided into several main subsystems: (1) digital filters to correct optical and digital aberrations; (2) digital sensor improvements and nano-grids; (3) digital system improvements that link multiple digital corrections; (4) dynamic digital imaging system improvements that apply to zoom lenses and video imaging; and (5) digital image network improvements. There are several distinct improvements for each category of sub-system listed.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic drawing of a digital imaging system.

FIG. **2** is a flow chart of an analog to digital signal process.

FIG. **3** is an image of the vignetting corrective filter in an optical lens.

FIG. **4** is a list of wide angle 35 mm lens types.

FIG. **5** is a flow chart of the digital corrective process.

FIG. **6** is a schematic diagram of different types of optical aberrations in different configurations of the same lens.

FIG. **7** is a flow chart of the process of digital image capture, processing and storage.

FIG. **8** is a flow chart illustrating the process of selecting filtration settings.

FIG. **9** is a pair of diagrams showing the varied depth of field optimization at different apertures.

FIG. **10** is a flow chart showing exposure optimization using digital correction in camera.

FIG. **11** is a flow chart illustrating the use of in-camera special effects filtration.

FIG. **12** is a flow chart showing the selective in-camera filtration of specific objects.

FIG. **13** is a flow chart describing the exposure adjustment of an image using in-camera filtration.

FIG. **14** is a flow chart showing the process of in-camera special effects filtration.

FIG. **15** is a flow chart showing the process of in-camera digital correction for sensor dust.

FIG. **16** is a diagram showing a digital camera with an ASIC array.

FIG. **17** is a diagram illustrating a digital camera with interchangeable CCD and CMOS sensors.

FIG. **18** is a diagram of a digital camera with a nano-grid before the sensor.

FIG. **19** is a diagram of a nano-grid.

FIG. **20** is a diagram showing the feedback loop connecting the processor and the nano-grid.

FIG. **21** is a diagram illustrating the tri-pixel architecture in a digital sensor.

FIG. **22** is a flow chart showing the pre-programmed modules for in-camera functionality.

FIG. **23** is a diagram showing the pre-sensor modification process in a digital camera.

FIG. **24** is a flow chart showing the integration of optical and digital corrections with feedback.

FIG. **25** is a flow chart showing the interactive feedback mechanism of integrated corrections.

FIG. **26** is a flow chart describing the adaptive user pattern learning process to process images.

FIG. **27** is a flow chart describing the feedback process in filtering images.

FIG. **28** is a flow chart showing software privacy function in a digital imaging system.

FIG. **29** is a flow chart showing the dynamics of zoom lens corrections in digital imaging.

FIG. **30** is a diagram illustrating object tracking in dynamic changes in video corrections.

FIG. **31** is a flow chart showing object tracking of a digital imaging system.

FIG. **32** is a flow chart showing the caching process of an object in motion in a stationary scene.

FIG. **33** is a diagram showing network coordination of fixed sensor grid tracking multiple objects.

FIG. **34** is a diagram showing the wireless communication features of the digital imaging system.

FIG. **35** is a flow chart showing an image organization system.

DETAILED DESCRIPTION OF THE INVENTION

(I) Digital Filters to Correct Optical and Digital Aberrations

(1) Lens-Specific Digital Correction of Fixed Focal-Length Lens for Specific Optical Aberrations in Camera.

Each lens has some sort of aberrations because of the trade-offs involved in producing lenses of usable size and practical commercial cost. The challenge of building lenses for SLR camera systems lies in accounting for particular restrictions and compromises, particularly for wide-angle and zoom lenses. In the case of wide-angle fixed focal length lenses, several main kinds of aberrations occur, including spherical aberration, distortion (pin cushion distortion and barrel distortion), astigmatism, curvature of field (manifesting as the reduced corner exposure of vignetting) and comatic aberration (a distortion evident with long exposures). The extremes of each of these aberrations have to be corrected in post-production.

In the case of vignetting, a type of aberration in which the corners of an image are exposed a stop less than the image's center area, software can digitally emulate a center-neutral density filter to compensate for the light fall-off on the edges. This operation identifies the degree of light fall-off for each specific lens and adjusts the brighter areas in the center of the lens by appropriate exposure compensation. A consequence of this digital equivalent of the traditional optical solution to vignetting is that the image will require exposure metering of the subject at a level consistent with the outside edges of the image rather than the typical inner section. In the present system, the camera will use pre-set calculations compensating (generally one stop) for the specific gradations of the curvature of the field for each lens, with an increasing compensation correlated to an increased angle of view. Similarly, barrel distortion and pin-cushion distortion, which also manifest in image corners, are corrected using processes of employing pre-set calculations, to compensate for optical distortion, particularly in wide-angle and zoom lenses.

In addition to integrating into the camera the traditional process of image correction for exposure gradations of vignetting, the present invention offers two further embodiments. First, instead of darkening the center to match the darker corners, the in-camera digital compensation system will lighten the corners to match the exposure of the center of the image. In the second embodiment, the in-camera digital compensation system will both lighten the corners somewhat and darken the center of the image somewhat, to produce a more pleasing and realistic effect. The in-camera digital corrections of the vignetting problem dramatically improve the traditional optical solution of a center-weighted neutral density filter, which typically degrades image quality as it evenly illuminates the full image.

Since each lens has specific aberrations, depending on manufacturer and even differences in the specimens themselves, the camera software system will have preprogrammed general corrections for each specific lens type. For instance, while a 20 mm f2.8 lens varies among manufacturers, the general optical aberrations will be similar. An effective software solution is one which brings the optical image quality to a level consistent with a benchmark as measured by low MTF curves for each lens in its class in terms of both resolution and contrast throughout the image. To exemplify this benchmark, retrofocus rangefinder lens performance results of wide-angle lenses, which lack a shutter mechanism to design around, can be used for comparison. To accommodate the mirror in the SLR design type, the rear nodal point in SLR lenses are shifted forward, creating distortion. In contrast, the present system suggests applying a digital solution to compensate for this problem.

In a general sense, this process of correction is similar to correcting an ocular astigmatism with reading glasses. However, rather than using an optical solution to an ocular problem, the present system reveals a digital solution to an optical problem.

In the process, the camera identifies a specific lens and refers to a database that matches the lens type with the specific aberrations. The aberrations are consistent throughout all images for each formula of a specific prime lens type and are thus corrected by adjusting for each specific aberration category. Generally, the larger the angle of view of a lens, the greater the distortion and the greater the need for in-camera digital corrections.

In addition to the kinds of distortions created in wide-angle lenses, other types of distortion occur primarily in large aperture telephoto lenses, most notably chromatic aberrations that require apochromatic corrections. Rather than employing large, heavy and expensive extra dispersion glass, such as fluorite elements, the present system allows each lens type to be digitally corrected for these types of aberrations. The in-camera digital process works by identifying a specific lens and comparing the lens pattern to an internal database. Mathematical calculations compensate for the shift in red and green light that apochromatic corrections require for very low

MTF curves registering high standards of resolution and contrast by emulating the optical benefits of extra low dispersion glass elements.

Since lenses of the same focal length but with different maximum apertures represent completely different lens designs, modifications of their aberrations will vary relative to each specific lens type. For example, a 24 mm f/2.8 lens will have a different optical formula than a 24 mm f1.4 lens in a 35 mm camera system. Similarly, a 28 mm f/2.8 will differ from both a 28 mm f/2 lens and a 28 mm f1.4 lens and will thus each require different adjustments for vignetting, spherical aberration, pin cushion distortion, barrel distortion and coma. In other words, each lens with a unique optical formula will have specific aberrations, the corrections for which will be accessible in a database.

Another type of optical aberration that affects lenses involves flare, which is a sort of specific reflection of light sources. While improvements in lens coatings have been used to correct for flare, high refractive glass also eliminates flare. The present system uses digital processes to emulate these flare reduction functions on lenses even at maximum apertures.

In addition to the lens-specific types of corrections that are supplied by in-camera software, a function that optimizes contrast provided by limited reflected light is required. In general, lens hoods reduce reflected light. However, in the absence of a lens hood, scattered light will adversely affect contrast in all lenses. Thus, a general digital solution will optimize contrast from reflected light by emulating the effects of a lens hood.

Because the pixels on a digital sensor behave as neutral intermediaries to record light, the aberrations on specific fixed focal length lenses will be prominent. It is therefore necessary to filter out various optical impurities. In all cases, the digital in-camera software program emulates specific filters to effectively correct specific optical aberrations.

By digitally adjusting for optical distortions, the present system advances the state of the art for fixed focal length lens optics, beyond any opportunities available in film cameras. The following chart illustrates a list of optical distortions that are corrected by in-camera digital solutions.

	Fixed Focal Length Lens Type		Zoom Lens Type		
Specific Aberrations	Wide-angle	Telephoto	Wide-angle	Wide-to-Tele	Telephoto
Spherical	X		X	X	
Comatic	X	X	X	X	X
Astigmatism	X		X		
Distortion (Pin Cushion and Barrel Distortion	X		X		
Curvature of Field	X		X		
Chromatic		X		X	X
Flare	X	X	X	X	X
Scattered light (Unpolarized)	X	X	X	X	X
Color Accuracy	X	X	X	X	X
No Lens Coatings	X	X	X	X	X

(2) Multivariate Digital Correction Using Matrix Filter System in Camera

Since typically several distinct aberrations exist in a lens, it is necessary to correct each of the aberrations. For this multi-dimensional problem there is a multivariate digital in-camera software correction solution. The problem of correcting multiple aberrations presents the additional challenge of requiring acceleration to complete multiple tasks rapidly. In most cases, the hardware employed in a camera's chip set will include an application specific integrated circuit (ASIC) which processes a particular program rapidly. It is appropriate to facilitate the combination of corrections to multiple simultaneous aberrations with an ASIC or multiple ASICs.

There is a need to optimize both resolution and contrast across the image area for accurate light reproduction. One way to do this is to stop down the lens to an optimum aperture of about f/8. However, this solution sacrifices the advantages of a fast lens design and capability, namely, limited depth of field and bokeh (smooth out-of-focus area). Though resolution is typically improved by stopping down a lens, digital sensors are generally still restricted in their latitude of contrast. Therefore, regarding both resolution and contrast, it is necessary to provide multiple adjustments of the native image with in-camera digital corrections.

While it is possible to produce mathematical algorithms for automatic correction of optical aberrations, it is also useful to have manually adjustable variables. Therefore, the present system includes a function whereby one may omit a specific correction in an image by using a lens with multiple aberrations in order to induce a particular creative effect. This factor may involve a lack of exposure compensation, a lack of correction for spherical aberration or an improperly or partially corrected apochromatic modification.

In one example of the use of multiple corrections, simultaneous application of multiple digital filters concurrently corrects multiple aberrations. In effect, this is like adding layers of different eye glasses to repair multiple types of astigmatisms for each specific ocular condition. The dynamics of correcting multiple simultaneous aberrations may be complex, but since the number and type of aberrations are constrained to a specific lens type, a centralized database may be accessed with specific corrections for each respective aberration. For example, lenses with multiple complex aberrations, such as in very wide-angle lenses, will require multiple corrections. These combinations of corrections become complex as focal length modes change in zoom lenses and as aperture changes.

The following is a list of filter types that provide digital methods of correcting image problems or creating specific effects. The list is not intended to be comprehensive or systematic.

Filter Type in Digital App.	Most Common Uses	Other Filter Types
UV (and Sky)	General Use	Polarizer
Color-enhancing (and warming)	17 mm-200 mm (in 35 mm)	Close-up
Contrast	17 mm-200 mm (in 35 mm)	Special effects filters
Black and White (Red, Orange, Yellow, Green)	17 mm-200 mm (in 35 mm)	
Infrared	17 mm-200 mm (in 35 mm)	
Color Graduated (Neutral Density)	17 mm-200 mm (in 35 mm)	
Diffusion (Soft, mist/fog, star, streak)	24 mm-135 mm (in 35 mm)	
Combinations (Neutral density and enhancing, Polarizer and UV)	17 mm-200 mm (in 35 mm)	

In the past, these optical filtration processes were added after the production process via editing software such as

Photoshop. However, in the present system, these combinations of processes are performed in-camera by user-adjusted settings. In the case of artificial color changes to an image, digital processes emulate specific optical filters by adding a specific color or a combination of colors. On the other hand, in the case of diffusion filtration, the in-camera digital process creates an emulation of optical filters. The classic example of this diffusion approach is the soft filter, which is used for portraiture. In this case, various user-adjustable settings in the camera digitally manipulate soft filtration.

(3) Depth-of-Field Optimization Using Digital Correction in Camera

In addition to correcting optically-generated aberrations with in-camera digital processes, the present system allows in-camera depth-of-field (DOF) optimization by affecting the aperture of the lens that is used.

DOF in an image is dependent on the aperture setting in a lens, in which a moderate DOF range—allowing a subject to be isolated in an image—can be manipulated, that is, extended or narrowed, by the camera's digital processing capability. In the film paradigm, one obtains a specific aperture, and thus the corresponding DOF, that is preset by the photographer. However, in the digital paradigm, by contrast, one can narrow an image's surplus DOF range in-camera by manipulating the aperture. This process can only be done in the camera, because once the digital file is sent to post-production editing, the aperture and DOF is already set and incapable of being changed. The aperture is narrowed in camera by isolating the subject and shifting the field of view (forward from the rear range of DOF and backward from the front range of the DOF). Distance information is used to recalculate an optimal DOF. In another embodiment, the camera provides feedback from an internal computational analysis that results in a specification of less DOF and takes another image (or images) with a larger aperture to accomplish reduced DOF at a specific focus point.

The camera will effectively identify a type of subject and provide an optimal aperture for this subject. For instance, for a portrait, the camera will select a shallow DOF around the subject. In the case of a distant landscape, the camera will focus on a distance at infinity and provide a nominal aperture to correspond to shutter speed that will fit the available light as matched to a specific lens. A near landscape photographed with a wide-angle lens will, on the other hand, have a near focus and a maximum DOF; specific subjects will be highlighted with ample DOF. The camera will also have the capability to bracket exposures in several successive images based on DOF variations.

The DOF manipulation thus depends on a combination of data sets including the particular lens used (wide-angle lenses have greater DOF at moderate distances than telephoto lenses), the distance information and the unique combinations of aperture and shutter speed. DOF will narrow with less distance, with use of a telephoto lens and a fast aperture; contrarily, DOF will expand with a further distance, with use of a wide-angle lens and a slower aperture.

In another embodiment of this process, test images are taken and analyzed, then later images taken with new settings optimize DOF for each image type.

(4) Exposure Optimization Using Digital Correction in Camera

One phenomenon that film currently records better than digital photo technology is exposure latitude. Film is capable of greater exposure latitude than either CCD or CMOS digital sensors, though each digital sensor type has strengths and weaknesses. For the crucial detail recorded in a scene, film provides far more depth of tonal range. Yet some of this problem—caused by the limits of digital sensors themselves and the way that photons are recorded by electrically charged pixels—can be digitally corrected and optimized in-camera.

The problem derives equally from the method of measuring exposure as well as the method of image capture by a digital sensor. In general, since there is less exposure latitude in digital sensors, as compared to film, the maximum scope is two or three stops in the image tonal range. Consequently, the camera must meter the image within constraints of the tonal range of the digital sensor, with the sacrifice of either shadow detail or highlight detail. In an image with broad exposure range, then, the image will generally be either too light or too dark because metering for one area sacrifices the other tonal category.

One way to solve this problem is to manipulate the lens aperture, because increased aperture within an optimal limit generally increases detail. An optimal aperture of f/8 provides more detail and clarity than at f/2 or at f/32. The in-camera processor may thus seek out more detail in the image by manipulating the aperture to the optimal range of f/5.6 to f/11, depending on the type of subject and the availability of light. With more detail in the original image, it is possible to interpolate the digital data in the image file by increasing both shadow and highlight detail and to gain an additional stop or two of tonal range.

In another embodiment, the tonal range of an image data set is enhanced in-camera by using meta-data to sample the range of shadow and highlight detail. The data sets are interpolated to add requested shadow detail and/or highlight detail. Obviously, some subjects require more or less shadow or highlight (or both), which the camera can correspondingly adjust. These tonal range corrections are user-adjustable.

In an additional embodiment of in-camera tonal range corrections, exposure data are bracketed by manipulating the aperture and shutter speed to lower or raise the overall exposure in one-third to one-half stop increments. This bracketing method may be correspondingly limited to a specific image type. For instance, in a portrait, the extraneous background, which ought to be out of focus, is not emphasized in the exposure data, while the main subject is carefully nuanced for balancing an optimum of both highlight and shadow, or for an exclusive emphasis on either highlight or shadow.

The overall problem of limited tonal range in digital photography stems from mismatched exposure-metering mechanisms of digital sensors with substantially restricted tonal range capabilities. One interesting example of this problem occurs in scenes with two or more stops of difference, such as a landscape with sky on top and earth on bottom. A filtration process will operate on the key parts of such an image, as described above regarding the vignetting phenomenon; the overexposed top half of the scene will be gradually underexposed while the lower half of the scene will be gradually overexposed. This scene-specific adjustment of exposure greatly increases the tonal range of digital images and is made possible via analysis of the scene and comparison to a database of typical scenes categorized by the in-camera digital processor which effects correction using the methods described herein. In this example, the corrective process emulates the use of neutral-density optical filters.

(5) Special Effects Digital Filtration of Specific Objects

Though there are several main categories of special effects optical filters, including color enhancing, infrared and diffusion, the use of diffusion filters appears to elicit the most dramatic effect. Diffusion filters are categorized as soft effect, mist/fog, black mist, gold diffusion, and star and streak, with various degrees of diffusion producing lesser or greater distortions. In effect, rather than removing optically-generated

distortions, we are deliberately creating photographically desirable distortions. It is possible to reproduce these special effects by using the digital post-capture production processes in the camera. In this case, the camera digitally emulates the special effect by applying user-adjustable filter settings.

Portraits have traditionally used some sort of soft effect filtration approach which is producible in the camera using the methods described here. After the image is captured, the camera analyzes the image's meta-data and applies a correction by interpolating the data with specific filter emulation. In the past, specific camera lenses, such as the 135 mm soft effects (also called "defocus control") lenses performed this function optically with an included adjustable lens element. This defocus control lens type will focus on the main subject and a lens element setting of the telephoto lens to produce a soft filter effect. In addition, because this lens type uses a nine blade aperture, the background that is out of focus has a pleasing bokeh in which the gradations of tone are evenly smooth. Nevertheless, a sophisticated digital camera is able to produce the same results with more information provided by a normal telephoto lens, using the method of emulating special effects in-camera.

Another novel special effect that is a further embodiment of the system is the ability of the in-camera digital corrective system to use complex data sets contained and analyzed in an image to create a three dimensional (3-D) representation of the image. The camera creates a 3-D image by arranging the DOF in a way that optimizes the aperture by using distance information and autofocus data to isolate a subject. By removing the foreground and background of the image as a center of subject focus, the DOF will emphasize the subject only as 3-D. The key to this effect is the application of specific exposure data as indicated above, because it is in the increased extension of the range of highlight and shadow that the subject in the image will attain a 3-D quality in contrast to its out of focus foreground and background.

An additional embodiment of the present system would extend the still photography in-camera special effects to video with full-motion ranges of filtration actions.

Finally, it is possible to combine different user-programmable special effects in-camera by adding the various types of diffusion methods for a specific image.

(6) Selective in-Camera Filtration of Specific Objects

The combination of sophisticated auto-focus technologies and in-camera auto-exposure systems provides the opportunity to isolate a subject by focusing on the subject and narrowing the DOF range by manipulating the aperture. In a further extension of the subject-isolating capabilities of these technologies, it is possible to digitally filter out specific objects in a scene in-camera while focusing on other selected objects that are in a specific range of DOF. In other words, one may apply filtration to correct aspects of a single object or only the background of a scene to the exclusion of an isolated object, rather than correcting a whole scene. Selective filtering of specific objects in an image by in-camera digital processing affords greater creative flexibility.

Because the camera uses distance information to isolate a specific object by focusing on the object within a range of DOF, it is possible to isolate a particular object for the purposes of applying a specific filtration preference, such as manipulating the color, correcting the optical aberration (say, if the object is in a corner of the image of a wide-angle lens), providing a special effect (such as a soft effect only on a specific object rather than the scene as a whole) or using some combination of these corrections. Once the camera isolates the selected object (using auto-focus mechanisms and distance information), the user selects programmable correction features to perform a corrective function only on the specific object (or only on the parts of the scene that are exclusive of the object). In a further embodiment, contrastively, once the object is isolated, only the background may be selectively manipulated with filtration, achieving pleasing effects. This in-camera corrective feature provides a powerful tool to rapidly manipulate an image without using post-production editing software tools.

These object-specific in-camera selective filtration capabilities are particularly dramatic with fast-moving action photography in which split-second timing produces the preferred complex effects. Selectively identifying a particular object for intensive combinations of filtration is a highlight of the present system.

(7) Digital Correction in-Camera of Intermittent Aberrations Caused by Dust on Digital Sensor

Dust on a digital sensor is a major concern for photographers. The use of zoom lenses compounds this condition, because as the zoom lens changes focal-length positions, air is transmitted, which results in the proliferation and diffusion of sensor dust. Unless photography is isolated to a clean room, the problem of dust on a digital sensor will remain prevalent. The present system provides a method to correct for this phenomenon.

In the case of dust on a sensor, a specific consistent pattern emerges on each image captured by the digital sensor. Consequently, information from various images is analyzed, and the pixels affected by dust are identified. Information from the consistent fixed pixel positions that are affected by the dust are then isolated. The specific positions with the dust are then analyzed by comparing the immediate areas surrounding the dust that are not affected by it. These unaffected areas are analyzed, and the affected areas are interpolated to provide a continuous tone. In effect, the images identify the locations with dust by using caching technology. The continuity of the location of the dust between multiple images provides information to the in-camera image processor to detect the specific pixel locations. The camera will then apply a corrective process to the isolated dust locations with adjoining exposures by interpolating these distinct locations for each specific image configuration.

In another embodiment of the present system, "hot" (too bright) or "dead" (too dark) pixels are interpolated out of the scene using the method described above. Unlike hot or dead pixels, dust is a similar but temporary version of the same problem of an artifact that requires in-camera modification. In effect, a map is built to discover, isolate and interpolate bad pixels, which are a permanent problem revealing a key limit in digital sensor technology. Separate maps are constructed for permanent pixel dysfunctions and temporary pixel aberrations (viz., dust). In both cases, the camera works from these maps to correct the aberrations on a pixel-level.

In a further embodiment of the present system, Monte Carlo analysis is applied to the problem of identifying the location of dust on specific pixels (or partial pixels) by randomly creating an initial map from information of at least two contaminated images.

In still another embodiment of the present system, the process of modifying pixel aberrations (either permanent or temporary) uses a sequence of operation which begins by correcting the major aberrations first, then repairing the minor aberrations, thereby maximizing efficiency. This is done by starting the corrective process in a specific location of the image and moving to other positions in an efficient pattern.

(8) Sequence of Corrections for Multiple (Optical and Digital) Types of Aberrations in Camera

Since it is evident that multiple digital filtration approaches may be used for specific types of problems or aberrations or to achieve specific effects, it is clear that a combination of the techniques may be employed simultaneously on specific images. The present invention allows the various optical and digital corrections to be performed in camera in a sequence of actions. The user selects the various combinations of functions required to be performed, inspects the effects, and chooses the most effective combination of effects. Thus the invention offers a combinatorial optimization of the totality of corrective filtration approaches.

After the images have been taken, it is possible to inspect them in the camera using the camera's image read-out. This makes it possible to create new files, or to adapt a RAW file, in real time, by manipulating the various corrections in sequence. This post-image-capture in-camera editing process allows multiple corrections to be applied to a range of optical and digital aberrations by combining various specific corrective techniques.

In some cases, the user can pre-set specific corrections. For instance, to correct for optical aberrations, a user may leave this function on permanently. In other cases, such as selective filtration of a specific object or optimization for DOF or exposure, there may be discriminating use of specific corrective functions. In the case of selective user choice, it is possible, by using the present invention, to select a priority sequence of corrections in layers. While specific select layers may be permanently activated, for example to automatically adjust specific optical aberrations, additional sets of layers may be manually selected in order to modify the specific aspects of each image, particularly to adjust or correct digital aberrations. This process can be performed with a single microprocessor, multiple microprocessors, multiple ASICs or a combination of microprocessors and ASICs.

An additional embodiment of the system provides multiple combinations of corrections and effects via multiple independent ASICs, which only perform specific functions, working in parallel. The various tasks are divided into specific-function ASICs for rapid processing. The advantage of this approach is accelerated processing speed in performing multiple simultaneous functions.

(II) Digital Sensor Improvement and Nano-Grids

(9) Interchangeable Digital Sensor System Using Both CCD and CMOS to Optimize Best Results

Because the main digital sensor types of CCD and CMOS, like film types, each have benefits and detriments, it is sometimes advantageous to provide the utility of both sensor types in a camera system. With the exception of a video camera, which employs three CCDs, the use of multiple sensors has not been adopted. Two generations ago, however, the idea of using a twin reflex camera for medium format photography was implemented. In this case, though focus was coupled between the lenses, one lens was used to see the subject, while the other lens took the picture. This method was used to obtain the benefits of a rangefinder camera with a single lens reflex camera.

The use of two types of sensors in a camera is compelling, because the user benefits from the strengths of both. In the present invention, one sensor is selected from among at least two different types of sensors that are rotated to an active position by the user. One advantage of this approach is that if one sensor experiences a problem, there is a reserve sensor available at the push of a button.

This capability usefully exploits the strengths of each particular sensor. For instance, in situations in which high resolution is required, a CCD may be preferable, while in cases in which increased tonal range or low noise is preferable, a CMOS sensor may be preferable. With this approach, a customer does not need to choose between different types of sensors.

The process of interchanging the two chips is performed by placing the two chips on either façade of a plane that "flips" over (i.e., rotates 180 degrees) upon demand to obtain the requirements of the chosen chip type. This mechanism would fit behind an SLR's mirror and could easily be performed as long as the mirror is in the "up" position. In another embodiment, the chip exchange process can occur by sliding alternating chips into a sleeve from a single location and replacing the non-utilized chip(s) into the reserve compartment. In either event, the camera will detect the chip exchange and will automatically reprogram software functions and settings for the usable chip.

(10) Nano-Grids for Selected Pixels on CCD or CMOS Integrated Circuits to Optimize Selective Modifications of Exposure, ISO and Aberrations in Digital Photography

Digital sensors consist of arrays of pixels, arranged in rows, which behave as tiny buckets for converting photons to electrons. As the pixels fill up with light, they are able to discern slight differences in color and exposure and transfer the energy, in the form of electrons, to storage. Charge coupled devices (CCDs) have been the predominant form of digital sensor because they use a form of electronic charge which creates the behavior of a bucket brigade of transferring data, once the buckets in a row are filled up, to successive rows for digital data storage of the electronic charge sets. CMOS digital sensors may be structured with larger bucket pixels, which can increase the depth of the light captured and thus the latitude of light exposure that is stored. However, for the relatively larger buckets to provide increased photon capture capacity, it is necessary to control the width of the opening in the top and the width of the buckets so that the amount of light captured may be modulated.

The present invention introduces a key advance in the ability of digital sensors, particularly CMOS sensors, to modulate the size of the openings of the pixels. Specifically, the present system provides for a nano-grid, or a very small matrix of filaments, which fits over the sensor. The nano-grid is carefully calibrated to match the rows of pixels on the sensor so as to limit the amount of light that each of the buckets may receive. Use of the nano-grid allows a selective closing of the large buckets in order for photons to be restricted. Selective modification of specific pixels on the neutral grid makes it possible to identify specific sets of pixels to correct for various exposure or lens aberrations.

In this embodiment of the present system, data about a specific lens are provided to the camera in order to correct specific lens aberrations, while exposure data is used to modify image capture using nano-grids for optimum image performance.

Nano-grids may be selectively switched at different pixel sites, akin to continuously programmable field programmable gate array (CP-FPGA) semiconductors, which modify architecture in order to optimize effective operation by constantly manipulating the chip's gates.

Nano-grids may be used for specific image modes, for example, nocturnal imaging, which requires more time to read a sufficient amount of light. In this case, a specific software module may provide lens and exposure data to the camera, which then determine the precise composition of nano-grid correction to provide to specific sets of pixels on the digital sensor. In effect, nano-filaments move to positions to effectively block out the full capacity of the pixel buckets

and thus change the pixel effects. With use of preset nano-grid positions for particular applications, the identification of specific vectors of nano-filaments is performed, and exposure adjustments are made on specific images in hardware.

The nano-grid is overlaid over the surface of the pixel architecture. The nano-grid is used not only in specific pre-set positions, but it also provides feedback to the post-capture system for analysis and repositioning to achieve the desired effects. One effect of the nano-grid is to manually expand or narrow the range of a set of pixel buckets; this process in turn effectively modifies not only the exposure range but also sharpness at high ISO, thereby dramatically reducing noise. Consequently, it becomes possible, by modifying the pixel bucket width and height, to obtain extremely sharp images with excellent contrast and tonal range even in poor lighting, a feat heretofore impossible.

The nano-grid performs these mechanical functions by moving the nano-filaments in an arc, like expandable windshield wipers. Though nano-grids are particularly useful in CMOS chips, they are also useful with CCDs. In fact, with the advent of nano-grids, CCD pixel size (and density in pixel-rows which will affect the overall sensor size) may be expanded and thus made substantially more versatile.

In a further embodiment of the present invention, multiple screens, or grids, would be placed over the digital sensor. The use of multiple nano-grids provides increased capacity to perform the function of closing off the pixel buckets and, in fact, to completely close off selected pixels to make the image effect completely dark. The combinations of nano-grids behave as multiple screens that move left and right to achieve the desired effect. Although there is a need to periodically calibrate the screens to effect their precise positions, this system will employ an electric charge to push the nano-filaments to the desired locations.

Nano-filaments move to block the space allowing photons to hit the pixel in order to limit the amount of light capacity available to the pixel. The complete darkening of the pixel will result in a total black color in the resulting image.

Exposure data feedback is provided to the digital sensor to effect the precise positioning of the nano-grid(s). In a further aspect of the present system, the camera's computer will anticipate the exposure data by statistically extrapolating from the pattern created by at least three data sets. A microprocessor (or ASIC) controlled nano-grid mechanism will use the feedback to anticipate specific nano-grid positions in order to optimize the exposure and corrective functions.

In one application of the nano-grid, the problem of vignetting in wide-angle lenses may be solved by activating nano-filaments in nano-grid(s) primarily in the corners to correct for the darkening from the limits of the optical aberrations, while still maintaining very low noise in a high ISO (low light) photographic situation. The use of the nano-grid would thus contribute to solving multiple problems.

Nano-grids will also be useful in accurately correcting for both color and exposure detail. In fact, with nano-grids, the capacity of digital sensors' range should be substantially increased, because the chips' pixel bucket sizes can be modulated. Therefore, not only will the lighting and color be accurate, but sharpness and optical aberrations will also be optimized, in ways not possible before.

(11) Integrated Nano-Grids in Digital Sensor

In a further embodiment of the system, nano-grids may be integrated into the digital sensor. In this form of the nano-grid, the nano-filaments are constructed within the pixel buckets in order to increase their accuracy and responsiveness. The nano-filaments mechanically move in various directions to perform the main operation of modulating light into their respective pixels. This method of organizing nano-grids and nano-filaments increases the rapidity of response to feedback. In effect, each pixel has a mask, or flexible lid, contained in it, which may open and close, to allow more or less light into the pixel bucket.

The integrated nano-filaments are activated by oscillation between positive and negative charges. In the context of a CMOS sensor, the transistor networks oscillate between positive and negative charges. This architecture allows a "push-pull" design of nano-filaments in which the negative charge "pulls" and the positive charge "pushes" the activation of the nano-filaments. This charge-enabled nano-grid (CENG) advantageously allows modulating gates (i.e., filaments) integrated into the pixel to reduce spaces between pixels, thereby allowing more pixels to be packed on the same surface area. The net benefit of the use of integrated CENG filaments is that specific sets of nano-filaments will produce specific effects on-demand and allow far more tonal detail than has been possible before.

In a further embodiment of the present system, sophisticated digital sensors may contain combinations of nano-grids that appear on top of the sensor as well as nano-grids that are integrated into the digital sensor. This combination will provide maximum latitude for processing the greatest effect available.

(12) Combinations of Nano-Grids and Digital Corrections Applied to Digital Imaging System

Whereas it is possible to exclusively implement nano-grids to control the amount of light penetrating specific pixels, and it is possible to exclusively provide digital corrections as specified above regarding correcting optical or digital aberrations, a further embodiment of the present invention combines the two processes in order to optimize imaging.

Combining these two complex processes makes it possible to modify pixel capacity to maximize exposure latitude, to expand exposure modification and to apply digital correctives for optical and digital aberrations. Hence selective exposure far beyond the limits of present film or digital photography is made possible. The restrictions of film can thus be transcended by using the present system, whereas use of a static and limited digital system would not be sufficient to facilitate these complex corrections.

The unique combinations of these processes also illustrate a complex system that provides feedback from both the environment and the photographer. The photographer may select preset exposure settings that will activate a range of options in both the nano-grids and the digital corrective system, while the lens aberration corrective system is automatically implemented. Once the camera detects specific conditions, such as a broad range of exposure latitude, from very bright to very dark, in the scene, it computes the precise number and location of nano-grids needed to modulate the pixels for optimum exposure with highlight and shadow detail and extreme sharpness, even in relatively low light. The dynamics of these multiple processes present trade-offs in selecting the best available set of selected modifications.

(13) Tri-Well Pixels

As indicated above, one of the key problems with current digital sensors involves dynamic range. There is a need to limit the scope of the space in the pixel well, into which light is captured, then converted into electrons. The challenge with current technologies is to balance details in shadow and highlight areas, particularly to acheive low noise at relatively high ISO speeds.

In addition to the concept of nano-grids, both in surface screen and integrated embodiments, as specified in (10) to (11) above, the present system introduces the notion of three

side-by-side differentially-sized buckets within each pixel intended to optimize dynamic range for increased sensitivity. In the most common configuration, the three different-sized buckets are arranged with the largest bucket (in both width and height) in the center, with the second and third largest buckets on either side. The buckets are elliptical and concave in architecture to increase efficiency of fitting together in a round pixel structure. Their structures are semi-circular and elongated. The largest and tallest bucket will be tasked with maintaining the details in highlights, and the smallest will be tasked with maximizing the details in shadows, while the mid-sized bucket will be tasked with maintaining the middle range of exposure details. The pixel will have data from all three buckets available, but will select the data from one or more buckets depending on the exposure details.

The system is analogous to the high fidelity sound technology in speakers with crossovers, whose several frequencies are used by the tweeters, mid-range(s) and woofers; the crossover point at which the frequency changes from one component to another can be modified based on the specific mechanics of each component.

In the case of the multiple buckets in a single pixel, the buckets are connected by filaments to a central grid which captures and stores the electrons. When the photographic scene displays increased light, image data from the larger buckets are selected to be recorded by the processor, while in cases of darkness and increased need for sensitivity, the smaller buckets are selected to be recorded; the mid-sized bucket is used in normal light situations of most cases. Further, this multi-aspect architecture can use pixels in varying positions on the sensor differently, particularly to facilitate processing far more dynamic range and to produce uniform tonal range in scenes that vary more than two or three stops. This novel multi-aspect model solves a number of key problems involving exposure dynamics in digital photography.

In another embodiment of the system, there may be more than three buckets in a pixel, so as to divide out the functions further and create even finer tonal continuity. In a further embodiment of the system, several pixels in a super-pixel allow red, green and blue colors to be segregated by each sub-pixel. This approach will be useful particularly in CCD semiconductors because of limits of this architecture, which require coupling circuitry between pixels to pass a charge between rows of pixels. In this case, outputs will vary between the micro-pixels to facilitate the differential processing required.

While cases of two side-by-side pixels might solve these exposure latitude problems, they represent an inadequate solution, much as a speaker with only two components limits the dynamic range output dramatically in contrast with a speaker with five components. This is similar to comparing a diode and a transistor.

(III) Digital System Improvements that Link Multiple Digital Corrections

(14) Auto Pre-Programmed Modules for Specific Functions in Digital Imaging System

To process the functions specified in this integrated digital imaging system, it is necessary for automated pre-programmed modules to detect the specific lens type and the specific digital sensor(s) used to assess the appropriate corrections or alterations. The purpose of the pre-programmed modules is to access a preset library of (a) typical corrections of lenses, (b) typical scene types with appropriate exposure modes, (c) specific effects that may be selected and (d) specific sensor functions. It is important to match a particular lens to a particular sensor type so that adjustments are calibrated to this pairing. The processing software is stored in either a microprocessor or an ASIC in order to process the images after they are captured by the sensor but before they are transferred to storage on a memory device.

In another embodiment, the system processes image corrections after the digital data is stored and constantly accesses the original stored data file in the production of a corrected file. This process allows for immediate data processing and storage which affords more time to accomplish specific corrective functions. There are thus cases when real-time correctives are neither necessary nor possible. Such increased processing capability may also facilitate a more complete corrective task.

In an additional embodiment, because similar correctives and effects may be provided to images that share the specific combination of lens and sensor, in order to accelerate the process of optimizing the images, batches of similar images may be processed together. This batch processing method may include the creation of duplicate images for each image captured, including a RAW image that contains no changes to the native image capture and a simultaneous auto-corrected image. The optimized image may be simultaneously compressed, to maximize storage capabilities, while the RAW image may be left uncompressed so as to maintain original detail.

(15) Apparatus and Process for Affecting Pre-Sensor Optical and Digital Corrections in Digital Imaging System

Given the nature of light transmission, not all optical corrections are optimized by modification after the image is captured by the sensor. Though a range of important corrections and effects may be made after image capture, such as correction for optical or digital aberrations, there are several types of corrections that are required to be made before the light reaches the sensor. One example of this pre-sensor digital correction involves the use of a low-pass or anti-aliasing filter that resides in front of the digital sensor to minimize moiré and aliasing digital problems (although the use of this filter adversely affects image sharpness).

In the case of optical corrections, one class of filter that requires use before the digital sensor is the polarizing filter, because once light is captured on the digital sensor, the polarizing effect will not be available. Another type of correction that involves use of a filter or lens before the digital sensor is the close-up filter. This latter solution allows a lens's closest focusing plane to be closer to the front of a lens and has the effect of diminishing the rear plane of the depth of field. The close-up filter may be optimized for use with floating rear-element group lenses which allow increasingly close focusing. In one embodiment of the system, specific pre-sensor optical filters may be used to provide polarization and close up corrections. The use of in-camera optical (circular) polarization would help standardize this valuable process and eliminate the need to maintain several external polarizer filters for each lens mount.

Since the present system entails an embodiment which uses nano-grids to perform specific exposure modifications before the light hits the digital sensor, it is possible to use these nano-grids for the applications of polarization and close-up filter. These filtration capabilities occur between the lens and the digital sensor.

In order to optimize the use of pre-sensor filtration, an image is initially tested and analyzed before the optimized corrections are activated and the pre-sensor changes are made. This process is analogous to the use of automated flash photography in which a feedback mechanism is provided; a scene is evaluated, and the initial flash data analyzed and modified to correspond to the correct exposure before a final flash is produced.

Because the camera system processes post-capture data, in order to optimize images for optical and digital problems, as well as continuously makes changes to pre-sensor filtration, multiple ASICs work in parallel to make the conversion of the image after capture. The use of parallel ASICs to perform specific correction processes solves the problem of capturing images and making post-capture corrections while simultaneously adapting the pre-sensor filtration system.

As an alternative embodiment of the system, a microprocessor (and software) may perform specific pre-sensor adjustments while the ASIC(s) performs specific corrective functions. In another embodiment, the ASIC(s) may perform the specific pre-sensor adjustments while a microprocessor (and software) will perform the specific corrective functions.

(16) Integrated Digital Imaging System for Optical and Digital Corrections with Feedback Dynamics

Because the present system consists of, and uses, complex sub-systems, including an auto-focus mechanism, an auto-exposure mechanism, a shutter mechanism, an automatic flash mechanism, a digital sensor mechanism, a digital processing mechanism and a digital storage mechanism, it is possible to realize interaction dynamics that contain feedback. The interactive process of operating these sub-systems involves a learning progression. The image is analyzed, solutions are tested and an optimal solution is selected and implemented, all in real time. By choosing a specific logic vector in a decision tree involving an initial variable, the process begins again with another key variable in real-time until the final image is captured and optimized.

In order to accomplish these complex processes, specific variables, such as aperture data, shutter speed data, lens data, digital sensor data and subject type are registered and analyzed by the camera. As environmental data changes, the camera mechanisms adapt to the environmental and the photographer's situation.

In order to accelerate these processes, the camera learns to anticipate the user's behaviors, the user's preferences and the subject's behaviors. By providing user-adjusted setting modifications for optical and digital corrections, the camera establishes a reference point for processing rapid image changes. In particular, the camera's software will analyze trends in the user's pattern of behaviors and preferences as well as pattern changes in the subject's behaviors. Anticipation processes are programmed into the autofocus and automated flash systems because of the extremely rapid reaction-time requirements of these specific mechanisms.

In one embodiment of the system, a method of processing a chain of rapid image captures is to employ computer-caching techniques in which a first image is processed in a normal way while later images are processed in an accelerated way. This is possible because the first image provides data to the system to analyze; these data then allow the system to anticipate further similar images and to use similar auto-focus and auto-exposure data. The optical and digital corrections are performed in a batch fashion by applying similar changes to near-identical image problems in order to dramatically accelerate the processing speed of a chain of images. This caching and anticipation approach is very useful in fast-paced action photography.

Another embodiment of the process of rapidly capturing a chain of images in sequence employs multi-threading techniques. Dividing the functions between specific subsystem ASICs allows multiple corrections to be performed in a parallel cascade for efficient task completion. One advantage of breaking down functions to specific processors is the acquired ability to start on one function and, while the system is in the process of completing a task, to begin other tasks. This process eliminates the lag between the specific subsystems.

(17) Adaptive User Pattern Learning with User-Programmable Functions in Digital Imaging System

In order to optimize its functions, the camera needs to learn about the user's preferences. When the user uses the camera, the camera evaluates the use patterns. Since the camera is programmed with a database of common user patterns, it can identify common uses and anticipate common uses of similar users by employing a "collaborative filtering" mechanism (i.e., if you like this camera setting, you should like this other setting because similar users who have liked the first setting have also liked the second setting). By anticipating common uses of each camera user, the camera optimizes its functions for each use and for each user. In effect, the camera's learning of user preferences is a sort of guided process of experimentation. Evolving algorithms learn about the user from actual use patterns.

One positive effect of this learning process of the camera about the user's patterns of behavior is that the filtration process becomes adaptive. The camera builds an initial map of the user's preferences from the user's actual selections. From the starting point of common types of personal selections, the camera uses standard templates of main types of uses that are fulfilled for each user's applications. For instance, if a photographer typically takes portraits with a traditional portrait lens, the camera will be aware of this and will activate filtration processes that are optimal for this type of portraiture photography, such as instilling limited depth of field on a subject and out-of-focus foreground and background. Contrarily, if landscape images are selected, depth of field will be increased substantially and the lens focused on either infinity or a medium point depending on the specific type of subject matter. The camera builds a model for each user based on the accumulation of experience.

In order for the camera to learn about the preferences of a specific user, the camera must adjust to each particular user, much as each individual identity must log onto a computer network privately.

Since the dynamics of the combined subsystems are complex, and adaptive, it is necessary that automated adjustments be interactive. Once detection of the lens type, the sensor type, the exposure settings, the user and the subject is made, optical and digital distortions are identified and specific combinations of corrections are applied both before and after the digital sensor in order to optimize the image. All of this is accomplished in less time than the blink of an eye.

(18) Software Privacy Function in Digital Imaging System

Because digital camera systems are able to use software and wireless mechanisms for their operation, it is possible to activate aspects of the camera remotely. Conversely, it is possible to disable operations of the camera remotely.

The present invention embodies a capability to externally disable the camera remotely in specific locations that require privacy, such as secret government areas (courthouses), private homes or businesses that are image-free zones. In these cases, a signal from an external source is provided to disable the shutter from firing. This black-out capability will allow external control of access to specific sites. As a condition of access, only a camera with this feature may be admitted to public buildings, so that even if the camera is permitted to operate, permission is only conditional. For instance, the owner of the building may allow the camera to function only in a specific set of rooms but not in others. Cameras without this feature may not be allowed in private spaces where control must be externally restricted.

This blocking feature will require the addition of specific blocking software, which may be automatically downloaded as one enters specific buildings. Similarly, in order to be granted permission to access the camera, or specific functions of the camera, the downloading of a "key" may be required.

Moreover, a further embodiment of the system may make it necessary to download software keys to get access to filtration capabilities in the camera in order to obtain optimum images. For example, the user may be required to pay a fee to download software in real time that will permit her to access a particular function in the camera to obtain a critical image. A spectrum of quality and complexity in filtration capabilities may be made obtainable for a range of fees on-demand. Therefore, the external downloading of software for the camera need not be limited to a black out function.

(IV) Dynamic Digital Imaging System Improvements that Apply to Zoom Lenses and Video Imaging

(19) Dynamics of Zoom Lens Corrections in Digital Imaging System

Whereas the optical aberrations of prime (fixed focal length) lenses were discussed above, the modulation of optical aberrations of zoom lenses is another problem to consider. As a wholly different species of lens, zoom lenses have become extremely complex optical mechanisms consisting of multiple groups of lens elements. The general problem with zoom lenses is the trade-off that must be made: To minimize the distortions of the widest possible focal length, distortions become maximized at the longest possible focal length, and vice-versa. Consequently, zoom lens architecture is inherently compromised on image quality. Over the years, lens designers have developed lens formulas that have dramatically improved image quality and that compete with typical prime lenses. As an example of this evolution in quality, the class of 70-200 f/2.8 35 mm zoom lenses, now in their sixth generation, has supplied substantial improvements over earlier telephoto zooms. However, in general, zoom lenses have more aberrations than primes and thus require increased optical corrections. The need to solve the problem of zoom lens aberration correction is accentuated by their increased use in photography because of their simplicity and versatility.

The dynamics of the zooming process present specific difficulties for the purposes of correcting optical aberrations in digital imaging systems. With fixed-focal length lenses, the camera can detect the lens and provide an immediate consistent modification for a varying range of apertures. In the case of zooms, however, where the focal-length is not fixed, the adjustments must correlate to the changes in the focal length. In effect, this condition presents a continuous resampling process. When combined with changing scenes, the zooming process requires far faster responses to changing inputs by the camera system. This process resembles the tracking of a kaleidoscope's changing image structures as the wheel on the device is constantly turned.

In order to solve the problem of distortion at the wide-angle part of select zoom lenses, manufacturers have been using aspherical elements which are complex shapes that require special production techniques. On the other hand, in order to solve the problem of chromatic aberration in select telephoto lenses, manufacturers have used extra low dispersion glass elements, particularly at the front of the zoom lens. Since there are generally three main classes of zoom lenses—wide-angle to wide-angle, wide-angle to telephoto and telephoto to telephoto—aspherical elements have been used in wide-angle zoom lenses, while extra low dispersion glass has been used in the telephoto zoom lenses and both kinds of lens elements have been included in the wide-angle to telephoto zoom lenses.

The changing focal lengths of zoom lenses add a variable to the complex set of variables of the interacting sub-systems in the digital imaging system. The digital camera system must therefore track the movement of the changes in the focal lengths in zoom lenses and continuously make modifications to the varied optical aberrations in these types of lenses. Unlike in fixed focal length lenses, the aberrations change at different focal lengths in zoom lenses, and the camera must track these changes.

The present system is designed to make the corrections to these changing aberrations in zoom lenses by noting the changed focal length at specific times of each lens. For a fixed focal length lens, the camera refers to a database of information to provide information to correct specific types of aberrations; for a zoom lens, the camera's database contains multiplex information for each focal length in each respective zoom lens type. This is as if each zoom lens contains a combination of multiple lenses of specific focal lengths. When the zoom is moved to a new focal position, the camera reads the lens as a specific focal length and makes corrections to aberrations based on this specific setting. Although the camera reads the zoom lens at a specific moment in time and adjusts the necessary modifications to correct for aberrations at that specific focal length at that time, overall the zoom lens requires the camera to rapidly make these adjustments.

Since zoom lenses employ dynamic processes of change, it is possible to track a moving subject in real-time by changing focal length from a stationary vantage. These changed focal length positions are tracked by the auto-focus system, but also by the auto-exposure system in the camera. The present system thus allows for zoom tracking in order to anticipate the direction of zoom lens changes, much as the focus on the moving subject involves focus tracking mechanisms. These systems use fuzzy logic and evolutionary algorithms to anticipate the movement of the subject and thus of the focal length change of zoom lens. In this way it is possible to accelerate the lens aberration correction process using zoom lenses.

Because the zoom lenses typically increase aberrations precisely because of the lens design compromises, these types of lenses are ideally suited to the present digital imaging system. The present system allows the zoom lens to be used at high quality without needing to stop down the aperture, thereby resulting in superior photographic opportunities.

(20) Dynamic Changes in Video Corrections of Digital Imaging System

While the zoom lens presents the need to provide a dynamic solution to the process of making corrections to optical aberrations, video photography provides another case of a process that requires dynamic solutions. The same principles that apply to still photography apply to video; auto-focus variability, aperture and depth-of-field variability aspects, shutter speed variability aspects, differences in lens focal length and artificial lighting variability suggest that video be viewed as merely a very rapid (30 to 60 frames per second) application of still photography. Nonetheless, video presents new classes of dynamic problems, most notably regarding the matter of tracking changing subjects in real time.

The process of shifting subject positions, even if the camera is stationary, presents a change of multiple variables that require the automated subsystems (auto-focus, auto-exposure, auto-flash, etc.) to be integrated. Feedback is presented by subjects in the external environment with changing focus and exposure variables. In these cases, even with a modulating shutter speed, the three main variables of change are a

zoom lens to continuously change the focal length, auto-focus to track a subject and aperture modifications to continuously change depth-of-field.

The unique dynamics of these complex sub-systems presents particular challenges for a digital imaging system to produce rapid results with the use of advanced ASICs and microprocessors. By incorporating techniques that track objects with advanced auto-focus mechanisms, anticipate zoom lens changes and predict optimal exposures as well as make automatic corrections to both optical and digital aberrations in real time, the present system continuously optimizes the video imaging process.

(21) "Stationary-Scene Object-Motion" Caching Process, with Application to Video, in Digital Imaging System

Because video imaging processes employ full motion activity, particularly of subjects in the environment, tracking a subject in a video system is problematic. Once a subject is identified and selected, the subject is automatically tracked with auto-focus and auto-exposure mechanisms by a zoom lens apparatus. There is a particular need to identify and track a subject within a broad stationary scene.

The present system accomplishes this task by using anticipatory object-trajectory tracking. The parts of the stationary scene that are not being tracked are cached. In other words, precisely because the background of the scene is stationary, this part of the scene is not tracked for focus or exposure. On the other hand, the object in motion is identified and tracked by subtracting the extraneous data of the stationary scene. Multiple objects are tracked by comparing data about these combinations of objects and their relations and determining the appropriate exposure and focus settings.

While Monte Carlo processes use random settings to self-organize an initial map, which are useful as a baseline for the purpose of anticipating tracking data sets, the present system subtracts the known information about the specific object(s) being tracked from the stationary background in the environment. In other words, the background data is "blanked out" in a caching process while the main subject(s) are tracked. By so using these techniques, the camera system can efficiently calculate the modifications needed to optimize the video scene.

In a further embodiment of the system, a chip-set is enabled in video display devices (i.e., video monitors) to implement select corrections for optical and digital distortions. The user may modify settings for automating the process of achieving optimum video images.

(V) Digital Image Networking

(22) Network Coordination of Fixed Sensor Grid to Track Multiple Objects in Digital Video Imaging System

While the previous discussion has focused on employing a single camera to capture images, the present system is also useful for networking sensors in a sensor grid in order to track multiple objects. Specifically, the present system may be used in surveillance and reconnaissance situations to track objects over time. Using a grid of image sensors with overlapping range parameters makes it possible to organize a complex network of sensors for surveillance activities.

After selecting specific objects to track, the system follows the objects as they move from location to location, appropriately modulating the focus, the lens focal length, the ISO and the exposure settings. As the subject moves from one section of a grid to another, the sensors are coordinated to "hand off" the object to other sensors on the grid, much like a cellular phone network hands off calls between cells.

In another embodiment of the present system, the cameras in the network may be mobile instead of stationary in a fixed sensor grid. In this case, self-organizing aspects of the mobile sensor grid track mobile objects in real time. One application of this complex system, which draws on earlier work in collective robotics, is in cinematography, which requires multiple transportable perspectives of mobile subjects. The complex dynamics of a mobile sensor network provides complex feedback in this manifestation of the present system.

(23) Automatic Wireless Off-Porting of Back-Up Images to External Data Bank

Because the present system uses digital files, it is possible to move these files to an external site for storage. The present system has capabilities to off-port images to an external data bank automatically. This feature is valuable in order to preserve on-board storage capability.

Whether implemented in a local area network (LAN) or a wide area network (WAN), by using a built-in wireless router, the present digital imaging system may be set to send data files directly and automatically to hard-drive storage either in a device in the same room or uploaded to the Internet for storage around the world. This capability is critical for managing massive files of large sensor data sets and preserving valuable in-camera storage space. When automatically sending data files to a nearby computer, the computer may act as a data-port relay to automatically resend the images to an Internet site for storage. The system will maintain the option of keeping some images in the camera and sending duplicate copies of digital files of images to another site for storage as a backup. This automatic back-up process provides insurance for the photographer.

In another embodiment of the system, just as image files are off-loaded to external storage, software files are periodically downloaded to the camera in order to update the camera settings and the database system. For example, as the camera manufacturer provides new lenses for the camera, it becomes necessary to load new updated settings to accommodate corrections for the new lenses. Similarly, as the camera requires new software updates with improved algorithms to further optimize the corrective functions of both the optical and digital mechanisms, the camera will automatically accept these. This feature is particularly important to both manufacturer and user because the ability to update software capability periodically will protect a user from needing to upgrade major hardware such as with a lens replacement.

(24) Image Organization System

The present digital imaging system does not merely allow for the storage of image data files on external storage. Because of the problems of protecting storage and the need to make multiple back-ups in the digital sphere, it is also necessary to store digital image files in multiple database locations. The images are organized in a main database by various criteria, such as time, location, subject-type, etc., and then rerouted to various locations around the world for safe storage. While specific sets of images may be stored together, the need to identify the locations is less important than the need to have control of the main database list which identifies the locations.

In order to maintain security, the digital imaging files may periodically be rotated randomly between locations. Only the main database list, which is constantly updated, maintains information on their location. In fact, specific digital bits of a single image may be maintained at different locations in order to maintain further security. Thus, on many computers around the world bits of each image may be stored, and continuously rotated, with constantly updated registries maintaining their complex hybrid whereabouts. These rotation storage functions are performed by a randomizer logic engine.

In a further embodiment of the present system, once the digital files are off-loaded from the camera system to external

storage, specific images may be automatically identified and further specific corrections automatically provided.

In yet another embodiment of the system, the images that are off-loaded from the camera to the external storage system are organized according to various criteria, such as accuracy of focus or exposure or quality of image type, in order to be automatically prioritized. The camera, with the assistance of an initial setting of user priorities, will automatically order new images with a higher or lower priority relative to other images and camera settings. Thus, at the end of a day, the images may be displayed in an order preferred by the user. Lesser images will be automatically routed to a lower position as they do not meet specific criteria, and better images will be routed to a relatively higher position in the organization of files. This feature of automatically assisting in the organization of the digital image files is a very useful one which will save photographers time.

(25) Wireless Digital Image System Automatically Generating Prints from Image Capture

The present digital imaging system not only automatically off-loads digital image files to remote locations for storage; the system also will allow one to photograph an image (or sequence of images) in one location (i.e., Paris) and instantly print it in another location (i.e., Los Angeles) for publication in real time. In addition, an image may be captured by the camera and instantly uploaded to a pre-programmed Web site for publication by using wireless technologies. In addition, it is possible to automatically print the digital image file anywhere in the world virtually the moment the image is taken. This system makes this instantaneity particularly possible precisely because the image corrections are automated in-camera. Since there is no need in most cases to further edit the image files, they are thus generally ready for immediate release.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic drawing of a digital imaging system.

FIG. **2** is a flow chart of an analog to digital signal process.

FIG. **3** is an image of the vignetting corrective filter in an optical lens.

FIG. **4** is a list of wide angle 35 mm lens types.

FIG. **5** is a flow chart of the digital corrective process.

FIG. **6** is a schematic diagram of different types of optical aberrations in different configurations of the same lens.

FIG. **7** is a flow chart of the process of digital image capture, processing and storage.

FIG. **8** is a flow chart illustrating the process of selecting filtration settings.

FIG. **9** is a pair of diagrams showing the varied depth of field optimization at different apertures.

FIG. **10** is a flow chart showing exposure optimization using digital correction in camera.

FIG. **11** is a flow chart illustrating the use of in-camera special effects filtration.

FIG. **12** is a flow chart showing the selective in-camera filtration of specific objects.

FIG. **13** is a flow chart describing the exposure adjustment of an image using in-camera filtration.

FIG. **14** is a flow chart showing the process of in-camera special effects filtration.

FIG. **15** is a flow chart showing the process of in-camera digital correction for sensor dust.

FIG. **16** is a diagram showing a digital camera with an ASIC array.

FIG. **17** is a diagram illustrating a digital camera with interchangeable CCD and CMOS sensors.

FIG. **18** is a diagram of a digital camera with a nano-grid before the sensor.

FIG. **19** is a diagram of a nano-grid.

FIG. **20** is a diagram showing the feedback loop connecting the processor and the nano-grid.

FIG. **21** is a diagram illustrating the tri-pixel architecture in a digital sensor.

FIG. **22** is a flow chart showing the pre-programmed modules for in-camera functionality.

FIG. **23** is a diagram showing the pre-sensor modification process in a digital camera.

FIG. **24** is a flow chart showing the integration of optical and digital corrections with feedback.

FIG. **25** is a flow chart showing the interactive feedback mechanism of integrated corrections.

FIG. **26** is a flow chart describing the adaptive user pattern learning process to process images.

FIG. **27** is a flow chart describing the feedback process in filtering images.

FIG. **28** is a flow chart showing software privacy function in a digital imaging system.

FIG. **29** is a flow chart showing the dynamics of zoom lens corrections in digital imaging.

FIG. **30** is a diagram illustrating object tracking in dynamic changes in video corrections.

FIG. **31** is a flow chart showing objecting tracking of a digital imaging system.

FIG. **32** is a flow chart showing the caching process of an object in motion in a stationary scene.

FIG. **33** is a diagram showing network coordination of fixed sensor grid tracking multiple objects.

FIG. **34** is a diagram showing the wireless communication features of the digital imaging system.

FIG. **35** is a flow chart showing an image organization system.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates the overall structure of the system. Object data (**100**) in the domain of objects being photographed by the camera constantly change. In some cases, the lighting changes, while in other cases, the positions of the objects change. At **120** the flash will artificially light the objects. Flashes may be either on the camera or remote from the camera. A camera sensor (**130**) will detect external data changes. An optical lens (**110**) feeds analogue imaging data to the digital sensor(s) (**175** and **180**). In some cases, a mirror (**170**) will swivel in order to directly input imaging data to the digital sensor after the shutter (**150**) is fired. In some cases, a filter (**160**) stands between the lens and the digital sensor(s). A digital signal processor (DSP) (**195**) is connected to at least one sensor (A or B). A database (**190**) is connected to at least one sensor (A or B) as well. The digital sensors are connected to an ASIC (**195**) and/or a microprocessor (**193**) in order to process the image and control the camera. The digital image data is passed from the digital sensor to either the ASIC or microprocessor and then stored in memory (**197**). The presence or absence of specific elements of this mechanism is not required for the correct functioning of this system. Consequently, a number of the drawings contained herein will focus only on specific sub-assemblies of the overall digital imaging system mechanism.

The present invention is intended to operate with a spectrum of camera types. These camera categories include digital still cameras without a mirror mechanism or without an optical interface. The present system applies to cameras with single lens reflex mechanisms. In addition, the present system

applies to video cameras, both with or without mirror mechanisms, including camcorders. Finally, many of the functions disclosed in the present system are integrated into specific imaging sensors. The system applies to image sensors that are integrated with complex system functions, including those described herein, with "system on a chip" (SoC) capabilities in a single microelectronic integrated circuit. The invention also applies to networks of sensors, networks of cameras or integrated networks of both sensors and cameras.

FIG. **2** describes digital image signal processing. After an analog signal (**200**) is captured, it is converted to a digital signal by an analog-to-digital converter (**210**). The signal is then forwarded to the digital signal processor (**220**) and filtered (**230**). The digital signal is then stored in memory (**240**).

In FIG. **3**, the correction to the optical vignetting problem is shown. In vignetting, the lens (**300**) makes the edges of the image significantly darker as the light falls off, a phenomenon particularly prominent on wide angle lenses. As represented here, the concentric circles of filtration correction are darker in the middle (**310**) of the image in order to counteract the vignetting effect. The overall image aperture is reduced from one half to two stops in order to compensate for the maximum light fall off depending on the amount of vignetting effect from each lens type.

FIG. **4** shows a list of several different wide angle lenses in a database. In the 35 mm domain, the 14 mm (**400**), 20 mm (**410**), 24 mm (**420**), 28 mm (**430**) and 35 mm (**440**) lenses, each with f/2.8 apertures are listed in the database. Each lens type presents a distinct formulation involving different sets of optical data that require different aberration corrections.

The digital corrective process is described in FIG. **5**. After a specific lens type is identified (**500**) and a database is referenced (**510**), the lens type is matched with the specific optical aberrations (**520**). The digital filter then applies a correction to specific optical aberrations (**530**). As an example, the vignetting effect is corrected by gradually darkening the center of the image in concentric rings (**540**).

FIG. **6** shows the database configuration of several different types of 24 mm f/2.8 lenses (**600** to **630**) with different optical configurations. Each lens type has a different set of manifestations of optical aberrations including vignetting (**640**), spherical aberration (**650**), pin cushion distortion (**660**), barrel distortion (**670**) and comatic aberration (**680**). For each lens, there will be a unique combination of optical aberrations compared to each lens type from different optical configurations. The database is accessed to provide the multi-objective optimization solution for correcting several different optical aberrations for each specific lens formula.

In FIG. **7**, after a camera captures an image (**700**) and uses a digital sensor to create a digital file (**710**), the digital file is forwarded to the digital signal processor semiconductor (**720**). The DSP applies the filtration (**730**) to correct the optical aberrations from the lenses. The revised digital file is then sent to storage (**740**).

Digital filtration is performed by employing the DSP hardware as well as specific software in order to attain specific aberration corrections. In an optical filter, which typically sits at the front of a lens and performs a single function of modifying the optical characteristics of the lens, the electronic filter will process the image after it is converted from an analogue representation to a digital signal. Common digital filters include a low pass filter or anti-aliasing filter. In most cases digital imaging filtration is a discrete time application and is processed in a time-signal sequence.

One example of a digital filtration process is a fast Fourier transform (FFT). The digital signal is modified by applying an algorithm to extract the frequency spectrum. The original function is then reconstructed by an inverse transformation of the original signal. The signal can be manipulated to perform various conversions. This process is used to sharpen or soften an image. For instance, by differentiating the frequency spectrum, the high frequency can be emphasized by limiting the low frequency, as in a high pass filter. Digital filtration is typically performed by the DSP after the image is captured and before the image file is stored. However, in the present system, there is some filtration before the digital sensor that captures the image as well as some filtration processing after the sensor sends the file to the DSP.

In order to accelerate the filtration process, the digital file will be broken into parts, with each part processed simultaneously. Filtering a one-dimensional image will treat data from each column of a digital sensor separately. When the data is treated like a two dimensional image, the data file may be treated with different techniques. For instance, different quadrants of the image may be analyzed and filtered separately. In addition, the highlights and the shadows in the varied frequency range may be analyzed and filtered separately as well. Similarly, a two dimensional image file may be analyzed by starting in a corner and working in each contiguous quadrant in a circular (clockwise or counterclockwise) order. Further, the filtration process may begin in the corners and work inwards or begin in the center of the image and work outwards. For instance, in wide angle lens filtration to correct optical aberrations, the outer edges will be the most prominent distortions that will require the most corrections; therefore, the filtration process will work by starting on the corners first.

The present invention also addresses the multi-functional corrections in an image by applying multiple simultaneous techniques. This is done either by performing a sequential filtration process or a simultaneous filtration process. In either case, the image is re-filtered to make more than one pass in order to correct different types of aberrations.

Different types of aberrations require different types of filtration. In the case of pin cushion distortion and barrel distortion, which are inverse appearing aberrations, the filtration process will adjust the edges of affected digital files captured with wide-angle lenses. The optimized images will be accessed by the database and compared to the actual image files. The filtration will be applied to each image file to closely correct the distortions bit by bit. In effect, the corrected digital images will be reverse engineered to discover the unique distortions as they establish a pattern by comparing the input digital images and the database of optimized images. The digital image correction will be applied once the aberration is assessed.

Each lens provides data to the camera microprocessor and DSP about its unique characteristics. The lens is pre-programmed with aberration data pertaining to that lens type and even to each particular lens (ascertained through a testing process). The lens then provides this specific data to the camera for processing of optical aberrations. In one additional embodiment, the lens will also contain software to correct its aberrations that will also be sent to the camera processors in order to be applied to specific digital file filtration. As information and techniques are made available, new software to ascertain and correct each lens's unique optical aberrations will be forwarded to the camera and stored in the lens, thereby providing an upgrade path to continuously improve the optical qualities of lenses by employing a sort of after-manufacture digital correction.

FIG. **8** shows the process of selecting filtration settings. After the user selects the specific filtration settings (**800**), the user marks the specific filtration setting and accepts the sel-

ting (810). The user may continue to select multiple settings. When the user has selected all preferences (820) and accepts the settings the user returns to the main menu.

In FIG. 9 varied depth of field optimization at different apertures is described. In the first drawing, the object (930) has a depth of field (940) that has a broad range of clarity around the object. The camera (900) evaluates the distance data (920) and the object to establish an optimal depth of field range between f/8 and f/11. In the second drawing, the object (980) has a narrower depth of field range (990) based on distance data (970) and object data from the camera (950) to determine an optimal depth of field range between f/2.8 and f/5.6. The camera's automatic alteration of the aperture to narrow the depth of field is based on a range of factors, including the focus on the object, the object's motion, the distance to the camera, shutter speed constraints and the light on the object. Modulating aperture automatically in the camera provides a blurring of the background and the foreground so that the object can stand out without distraction.

Exposure optimization using digital correction is shown in FIG. 10. After the camera assesses an object's distance from the camera (1000) and identifies the optimal aperture of the image to maximize the dynamic range (1010), the aperture is either increased (1020) or decreased (1030) and the correction applied (1040).

In-camera special effects filtration is illustrated in FIG. 11. Once the image exposure is assessed by using the camera exposure meter (1100), the camera corrects the image by either underexposing the image by one third stops to one stop if the image is overexposed (1110) or overexposing the image by one third stops to one stop if the image is underexposed (1120). The camera finally takes a picture and stores the image (1130).

FIG. 12 shows the selective in-camera filtration of specific objects. After the camera identifies specific objects (1200), the camera assesses distance to the objects (1210). This is done by sending out an infrared light signal, bouncing it off the object, and measuring the distance data from the camera to the object. The camera isolates the objects on a one-dimensional Euclidian plane (1220) and then selects the optimum aperture to isolate objects and to blur the background and foreground (1230). The camera tracks the motion of objects (1240) and activates a digital sensor (1250) thereby capturing the image. The image data is sent to a post-sensor processor (1260) where the camera applies specific filtration only to the designated objects (1265) and stores the file in memory (1270). Alternatively, the camera will apply specific filtration only to the background (not to the objects) (1275) and then stores the file in memory (1280). The effect of only applying filtration to an object or to its background is to isolate the subject. The type and degree of special effects, which are selected by user-adjustable in-camera software, will be determined by the user's palate of filtration choices.

Image exposure adjustment using in-camera filtration is described in FIG. 13. Once the camera assesses a two stop difference in parts of the image (1300), the camera's microprocessor accesses the database of similar scenes (1310) and then selects the optimal metering for the image and the user activates the digital sensor (1320), capturing an image. The camera provides the filtration to part of the image by adjusting the exposure in the processor (1330) and then stores the image (1340). In scenes such as sky on top, a neutral density filter is often required to remove the two stop difference between the bright top of the image and the darker bottom of the image. By reducing the brightness at the top, the exposure is evened out. By using the present system, this process is accomplished in the camera.

In-camera special effects filtration is described in FIG. 14. After a user selects a special effects filtration technique (1400), the camera assesses image meta-data (1410), analyzes image data (1420) and the user captures the image (1430). The camera's post-capture processor applies special effects filtration technique to part of the image (1440) and the camera stores the image in memory (1450).

Digital correction for sensor dust is described in FIG. 15. The pattern of dust on the pixels of a digital sensor (1500) is assessed. The specific pixels that are obscured by the dust are identified (1510) and a map is built of a digital sensor pixel frame by comparing information from at least two image samples to identify obscured pixels (1520) and the camera takes an image (1530). Information from pixels that are adjacent to dust-affected pixels are used to interpolate data on affected pixels (1540) and image data is processed and stored in memory (1550).

FIG. 16 shows an ASIC array in a digital imaging system. Once the digital sensor (1620) captures an image, the digital file is sent to multiple application specific integrated circuits (1630, 1640, 1650 and 1660) for processing of several digital signals simultaneously. In one embodiment of the invention, each ASIC corrects a single optical aberration. In another embodiment, the ASICs will divide the digital file and perform specific functions on parts of the image file and reunite the file before storing the completed image in memory (1670).

In FIG. 17, the camera is illustrated with multiple interchangeable digital sensors. The CCD (1720) is shown in the forward position capturing the digital image in this drawing. However, the CMOS (1730) digital imaging sensor may swivel around (1740) to replace the position of the CCD in order to be used to capture the image. The image is then processed (1750) and stored in memory (1760). The advantages of interchanging the digital sensors are to have the opportunity to benefit from the strengths of each sensor type without sacrificing the weaknesses of either. In some cases, the scene will be optimized for the exposure range of a CMOS digital sensor, while at other times, the scene will be optimized for the detail of the CCD.

In FIG. 18, the nano-grid (1820) appears in front of the digital sensor (1830). The lens will send analog image data to the sensor through the nano-grid. Once the digital data from the sensor is processed (1840) it is sent to memory (1850). FIG. 19 shows a nano-grid (1900). Nanofilaments are shown at 1920. The modulation effects of the nanofilaments are shown at 1910. Nanofilaments will change their position in order to allow more or less light through the system. Nano-grids fit before, or in some cases, adjacent to and on top of the digital sensor. Nano-grids behave as adjustable screens and may be used to polarize light between the lens and the digital sensor. Nano-grids are activated by electrical charge pulses sent to nanofilaments.

In FIG. 20, the feedback loop connecting the processor and the nano-grid is shown. Analog optical data passes through the nano-grid (2020) to the digital sensor (2030) to the processor (DSP) (2040). A feedback loop (2050) is created by analyzing the data at the processor and modulating the performance of the nano-grid. For example, the image may be very bright initially, but the DSP will require that the image needs to be darker in order to be properly exposed. In this case, it will activate the nano-grid to modulate its grid structure in order to darken the image so as to let less light through the filaments by adjusting the filament structure. Once properly exposed, the camera will capture a digital image and send the file to memory (2060) for storage.

In FIG. **21**, a tri-pixel architecture is described. The large (deeper) oval bucket in the center (**2110**) will capture highlight exposure, the medium sized oval bucket at the right (**2120**) will capture a normal exposure range and the small (shallower) oval bucket at the left (**2130**) will capture the shadow exposure range. These three separate wells are contained within each pixel. In most cases, a pixel well is like a bucket, capturing light data and passing the data sets to the digital processor. By splitting the exposure range into three distinct wells within each pixel, the data is more accurately captured and organized in order to accommodate the broader range of exposure data. This system will be able to increase the range of digital imaging up to four stops, from the typical two stops. By maximizing the range of exposure data, the image collection will display more tonal range that is more associated with films' broader exposure range.

FIG. **22** shows the pre-programmed module for in-camera functionality. After the camera detects the lens type and the sensor type (**2200**), the camera focuses on an object (**2210**) and the processor accesses the library of scene and filter types (**2220**). The user pre-selects specific in-camera modifications (**2230**) and activates the camera to capture an image (**2240**). The processor makes filtration adjustments after the sensor takes the image (**2250**) and the image file is stored (**2260**) in memory.

Much like the nano-grid that is present before the digital image sensor, the pre-sensor modification to an image is shown in FIG. **23**. An optical filter (**2320**) such as a polarizer filter is shown in a position between the lens and the digital sensor (**2340**). The image is captured and the optical filter is activated by the processor (**2350**), which determines whether to activate the filter after analyzing a particular scene. Other filtration (**2330**), such as the use of the nano-grid, is also interchangeable with the optical filter in a position before the digital sensor. In another embodiment of the present invention, the filter assembly is sequential, with both, or multiple, filters being activated in order so as to obtain the maximum filtration effect. The DSP will compute the optimal combination of filtration resources based on the available resources in the camera. In another embodiment, the optical filter assembly will fit out of the line of sight between the lens and the digital sensor and will be activated by the DSP on-demand to swing into the optical image path much like a mirror mechanism.

FIG. **24** shows the integration of optical and digital corrections with feedback. Once the camera meters a scene (**2400**), the camera auto-focuses and obtains distance data to the object (**2410**), analyzes the lens data, the aperture data and the shutter speed data and accesses the library of images (**2420**). The camera assesses the optical aberrations (**2430**), activates the digital filters to correct aberrations (**2440**) and takes the picture (**2450**). The camera analyzes the image and optimizes the image using the processor (**2460**). This is performed by comparing the image data to the library of images and assessing the needed filtration required to optimize the image. The image is then stored in memory (**2470**).

The interactive feedback mechanism of integrated correction is described in FIG. **25**. After an analysis of the initial image (**2500**), the identification of optical aberrations (**2510**) is made. The camera's database is accessed to retrieve the corrections (**2520**) and the interactive feedback mechanism is activated (**2530**). Corrections to filters are applied before the sensor captures the next image (**2540**). In addition, correction to the image signal via the DSP is made after the sensor data is captured (**2550**) and the image is stored in memory (**2560**).

The adaptive user pattern learning process is shown as images are processed in FIG. **26**. A batch of images (**2600**, **2610**, **2620** and **2630**) is shown. The first image is processed (**2640**) and data from image **1** is analyzed and metadata is mapped (**2650**). Image **2** is then analyzed and its metadata is compared to the image **1** metadata (**2660**). Similar metadata in images **1** and **2** programmed in the processor (**2670**) and image **2** is rapidly processed by using similar metadata from image **1** (**2680**). Images **3** and **4** are analyzed and their metadata are compared to image **1** and rapidly processed (**2690**).

In FIG. **27**, the feedback process of filtering images is shown. After the camera analyzes the user behaviors, user preferences and subject behaviors (**2700**), the camera's processor analyzes trends in the pattern of user behavior and preferences and creates a map (**2710**). The camera's processor anticipates the user behavior and subject behavior (**2720**) by applying evolutionary computation and fuzzy logic algorithms. The camera's processor then applies a collaborative filtering process to a new image (**2730**) and the user takes and optimizes the image (**2740**).

FIG. **28** shows a software privacy function in a digital imaging system. The camera automatically downloads software as it enters a building or specified area (**2800**). The camera's features are deactivated in specific locations by the software (**2810**) while allowing the camera to perform specific camera functions by accessing software keys (**2820**). The camera then performs specific functions (**2830**) that are available in the restricted area while other specific functions are disabled (**2850**).

In FIG. **29**, the dynamics of zoom lens corrections are described. After a lens detects a zoom lens type (**2900**), the camera detects a particular focal length setting of the zoom lens (**2910**) and accesses a data library in the database to modify aberrations to optimize the zoom lens at a specific focal setting (**2920**). The camera applies a correction to a lens setting (**2930**) and continuously tracks the lens changes in the lens focal length (**2940**). The camera then applies the changed corrections to the changed focal lengths in the zoom lens (**2950**) and analyzes patterns of the user and subject behaviors (**2960**). Using fuzzy logic and evolutionary computation, the camera anticipates behaviors and rapidly optimizes image corrections by applying digital filtration (**2970**).

FIG. **30** shows object tracking in the dynamic changes of video corrections. An object moves from position **1** (**3010**) to position **6** (**3060**) in sequence. The camera (**3000**) is stationary, yet it records the object's motion as it is moving within the field of vision.

In FIG. **31**, object tracking is described. Once the camera tracks an object with auto-focus mechanisms and supplies distance information (**3100**), it tracks the user's zoom lens use patterns, anticipates the focal length changes (**3110**) and, using evolutionary computation and fuzzy logic algorithms, predicts optimal exposures (**3120**) and captures images in real time, continuously tracking the object (**3130**).

FIG. **32** shows the caching process of a moving object in a stationary scene. After the main objects are tracked by the camera (**3200**), the background of a stationary scene is cached in the camera (**3210**). The camera subtracts the data about objects from the background of the scene (**3220**). The background scene is then "blanked out" and cached in memory (**3230**) and the main objects are optimized by applying digital filters.

FIG. **33** describes the network coordination of a fixed sensor grid tracking multiple objects. The object in motion is represented in positions A through D (**3370**, **3380**, **3390** and **3395**). The fixed sensors are at positions **1-6** (**3300**, **3310**, **3320**, **3330**, **3340** and **3350**). The image data is fed remotely into the central imager (**3360**). The sensors track the object by

taking image data at each fixed sensor position in the network. As the object moves through the field of the network, each sensor records the object.

In FIG. **34**, wireless communication features of the digital imaging system are described. The camera (**3400**) sends digital image data files wirelessly to a computer (**3410**). Files are also uploaded from the camera to the Internet in accessible locations (**3450**), while software files are downloaded from the Internet to the camera, both automatically and through manual intervention. Files are automatically downloaded if the user sets the camera to receive automated software updates. One advantage of loading files automatically to the Internet is that the images are then automatically published (**3460**) at a remote location, or locations, for viewing.

FIG. **35** describes an image organization system. After images are captured by the camera (**3500**), the image files are organized according to metadata in an external computer database (**3510**). The image files are then sorted by category and sent to the database of a distributed network (**3520**) for off-site storage.

Reference to the remaining portions of the specification, including the drawings and claims, will realize other features and advantages of the present invention. Further features and advantages of the present invention, as well as the structure and operation of various embodiments of the present invention, are described in detail below with respect to accompanying drawings.

It is understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims. All publications, patents, and patent applications cited herein are hereby incorporated by reference for all purposes in their entirety.

I claim:

1. A digital imaging system for correcting optical image aberrations comprising:

a digital camera mechanism, an optical lens mechanism, a digital sensor, a microprocessor, a digital signal processor, system software, a database management system and a memory storage sub-system;

wherein the optical lens mechanism is a fixed focal length lens;

wherein a microprocessor uses system software to identify at least one optical aberration by accessing the database;

wherein the microprocessor uses the database to identify at least one algorithm to use to correct the at least one optical aberration;

wherein when the image file is captured by the digital sensor the digital file is forwarded to the digital signal processor;

wherein the image file with the at least one optical aberration is corrected by applying digital filtration by using at least one algorithm in the digital signal processor; and

wherein the modified digital file consisting of the digital data optimized from the at least one optical aberration that are corrected from the original optical image is stored in memory.

2. The system of claim **1**:

wherein the optical aberrations include at least one of spherical, comatic, lens distortion, astigmatism, curvature of field, pin cushion, barrel distortion, chromatic aberrations, scattered light, red eye, dust and/or flare types of optical aberrations.

3. The system of claim **1**:

wherein the optical aberration is vignetting;

wherein the digital signal processor applies neutral density filtration from one third of a stop to three stops in the center of the image and/or wherein the digital signal processor applies an algorithm to lighten the corners of the image or the digital signal processor applies both neutral density filtration in the image center and/or an algorithm to lighten the corners of the image; and

wherein the image exposure is optimized to correct the vignetting.

4. The system of claim **1**:

wherein the digital signal processor applies at least one fast Fourier transform (FFT) algorithm to correct the at least one optical aberration.

5. The system of claim **1**:

wherein each lens type is registered in the camera database;

wherein the multiple optical aberrations of each lens is listed in the database;

wherein the filtration solutions to the lens optical aberrations are listed in the database;

wherein the filtration of each lens optical aberration is applied by the digital signal processor; and

wherein after the digital signal processor applies the filtration to correct the optical aberrations the corrected digital file is forwarded to storage in memory.

6. A digital imaging system for correcting image aberrations comprising:

a digital camera mechanism, an optical lens mechanism, a digital sensor, an integrated circuit, a digital signal processor, system software, a database management system and a memory storage sub-system;

wherein the optical lens mechanism is a zoom lens or a fixed focal length lens;

wherein the image data file is forwarded from the digital sensor to storage in memory;

wherein at least one optical and/or digital aberration in the image file are identified by comparing image files in the database management system by using the system software and the integrated circuit;

wherein the at least one filtration algorithms required to correct the at least one optical and/or digital aberration are sent from the integrated circuit to the digital signal processor;

wherein the at least one optical and/or digital aberration from the optical lens mechanism are corrected by using the digital signal processor to apply digital filtration algorithm, and

wherein the modified digital file consisting of the digital data optimized from the at least one aberration that are corrected from the original optical image is stored in memory.

7. The system of claim **6**:

wherein the optical aberrations include spherical, comatic, lens distortion, astigmatism, chromatic aberrations, curvature of field, pin cushion, barrel distortion, scattered light, red eye, dust and/or flare types of optical aberrations.

8. The system of claim **6**:

wherein the digital aberrations include moiré and/or aliasing.

9. The system of claim **6**:

wherein the digital signal processor applies a fast Fourier transform (FFT) algorithm to correct optical and/or digital aberrations.

10. The system of claim 6:
wherein the digital signal processor applies color filtration to the image file.
11. The system of claim 6:
wherein the digital image file are filtered to correct at least one optical and/or digital aberrations after initial capture and before the image file is initially sent to storage.
12. The system of claim 6:
wherein the integrated circuit may be a microprocessor, an application specific integrated circuit or a system on a chip.
13. The system of claim 6:
wherein the optical aberration is vignetting;
wherein the digital signal processor applies neutral density filtration from one third of a stop to three stops in the center of the image and/or wherein the digital signal processor applies an algorithm to lighten the corners of the image or the digital signal processor applies both neutral density filtration in the image center and/or an algorithm to lighten the corners of the image; and
wherein the image exposure is optimized to correct the vignetting.
14. A digital imaging system for correcting image aberrations comprising:
a digital camera mechanism, an optical lens mechanism, a digital sensor, a microprocessor, a digital signal processor, system software, a database management system and a memory storage sub-system;
wherein the optical lens mechanism is a zoom lens;
wherein the zoom lens changes focal length positions;
wherein when the image file is captured by the digital sensor the file is forwarded to the digital signal processor and to memory;
wherein the microprocessor uses system software to access the database to identify at least one optical aberration in the image file at any focal length of a zoom lens configuration;
wherein the microprocessor accesses the database to obtain at least one filtration correction algorithm to the optical aberrations and forwards the at least one filtration algorithms to the digital signal processor;
wherein the image file is forwarded to the digital signal processor which applies at least one filtration algorithm to optimize the image and corrects the at least one optical aberration at the specific focal length in the zoom lens configuration; and
wherein the modified image file consisting of the digital data optimized from the at least one optical aberration of a specific focal length of the zoom lens that are corrected from the original optical image is stored in memory.
15. The system of claim 14:
wherein the optical aberrations include vignetting, spherical, comatic, lens distortion, chromatic aberrations, curvature of field, pin cushion, barrel distortion, scattered light, red eye, dust and/or flare types of optical aberrations.
16. The system of claim 14:
wherein the digital signal processor applies a fast Fourier transform (FFT) algorithm to correct optical and/or digital aberrations.
17. The system of claim 14:
wherein each focal length of a zoom lens is analyzed for a different set of optical aberrations.
18. The system of claim 14:
wherein the optical aberration is vignetting;
wherein the digital signal processor applies neutral density filtration from one third of a stop to three stops in the center of the image and/or wherein the digital signal processor applies an algorithm to lighten the corners of the image or the digital signal processor applies both neutral density filtration in the image center and/or an algorithm to lighten the corners of the image; and
wherein the image exposure is optimized to correct the vignetting.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,451,339 B2
APPLICATION NO. : 12/586221
DATED : May 28, 2013
INVENTOR(S) : Neal Solomon

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

Item (60) please add the following header and paragraph:
--PRIORITY APPLICATION
This application is a continuation of U.S. Patent Application Serial Number 11/825,521, filed Jul. 6, 2007, which claims the benefit of U.S. Provisional Patent Application Number 60/807,065, filed Jul. 11, 2006, the disclosure of both are incorporated herein in their entireties by reference.--

In the Specification

In Column 1, Lines 7-9, delete "claims the benefit of priority under 35 U.S.C. section 119 from U.S. patent application Ser. No. 11/825,521 filed on Jul. 11, 2007 and" and insert --is a continuation of U.S. Patent Application Serial Number 11/825,521, filed Jul. 6, 2007, which claims the benefit of U.S.-- therefor

Signed and Sealed this
Eighteenth Day of June, 2019

Andrei Iancu
Director of the United States Patent and Trademark Office

US007612805B2

(12) **United States Patent**
Solomon

(10) **Patent No.: US 7,612,805 B2**
(45) **Date of Patent: Nov. 3, 2009**

(54) **DIGITAL IMAGING SYSTEM AND METHODS FOR SELECTIVE IMAGE FILTRATION**

(76) Inventor: **Neal Solomon**, P.O. Box 21297, Oakland, CA (US) 94620

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/825,521**

(22) Filed: **Jul. 6, 2007**

(65) **Prior Publication Data**

US 2008/0174678 A1 Jul. 24, 2008

Related U.S. Application Data

(60) Provisional application No. 60/807,065, filed on Jul. 11, 2006.

(51) **Int. Cl.**
H04N 5/228 (2006.01)

(52) **U.S. Cl.** **348/222.1**; 348/273; 348/342; 348/208.11; 348/333.08; 348/335; 348/340

(58) **Field of Classification Search** 348/222.1, 348/231.99, 224.1, 273, 342, 208.11, 333.08, 348/335, 340
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,023,977	A *	2/2000	Langdon et al.	73/629
6,055,330	A *	4/2000	Eleftheriadis et al.	382/154
6,508,764	B1 *	1/2003	Thiele et al.	600/437
2007/0002158	A1 *	1/2007	Robinson	348/335
2007/0080280	A1 *	4/2007	Havens	250/201.1
2007/0236574	A1 *	10/2007	Alon et al.	348/207.99

OTHER PUBLICATIONS

"EF Lenswork III: The Eyes of EOS", 4th Ed., 2004. Canon Inc. Lens Product Group; pp. 170-177.

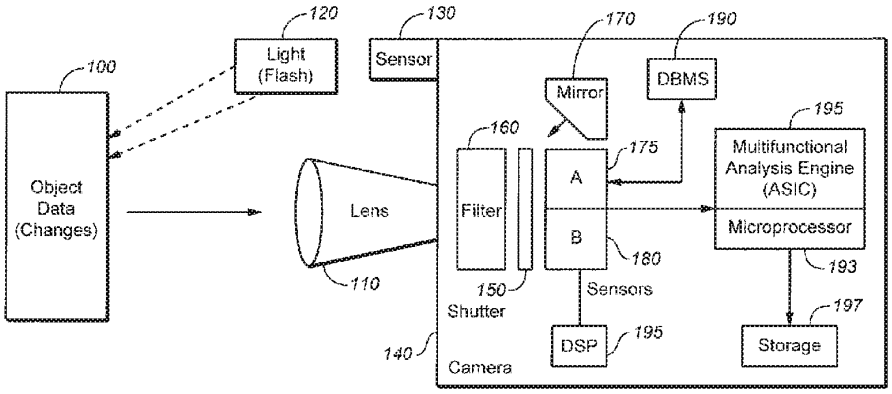
* cited by examiner

Primary Examiner—Jason Chan
Assistant Examiner—Usman Khan

(57) **ABSTRACT**

A system is disclosed for the automated correction of optical and digital aberrations in a digital imaging system. The system includes digital filtration and digital system corrections to optical and digital aberrations. The system addresses issues in still and video photography that are presented in the digital imaging environment.

32 Claims, 19 Drawing Sheets



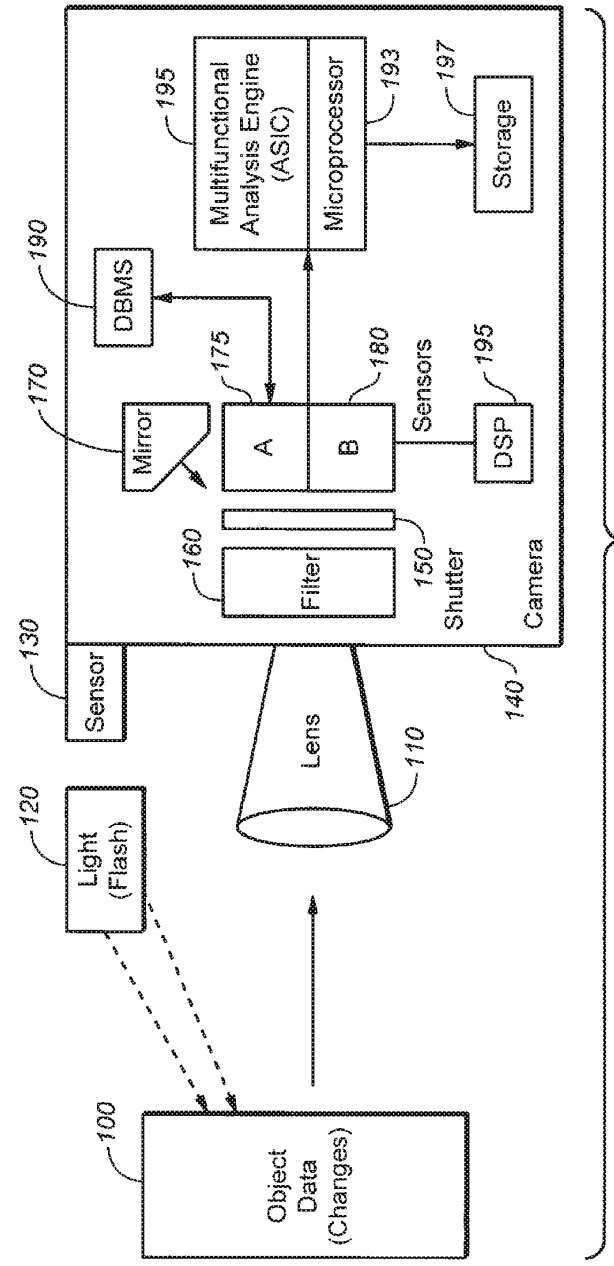

Object Data (Changes)
100
Light (Flash)
120
Sensor
130
Lens
110
Camera
140
Filter
160
Shutter
150
Mirror
170
A
175
B
180
Sensors
DSP
195
DBMS
190
Multifunctional Analysis Engine (ASIC)
195
Microprocessor
193
Storage
197

FIG. 1

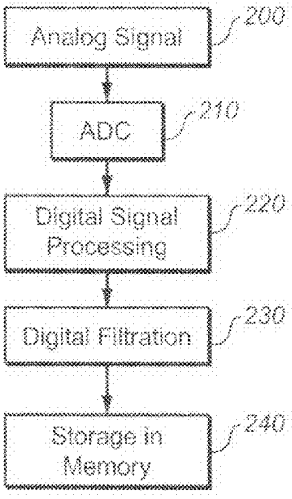


FIG. 2

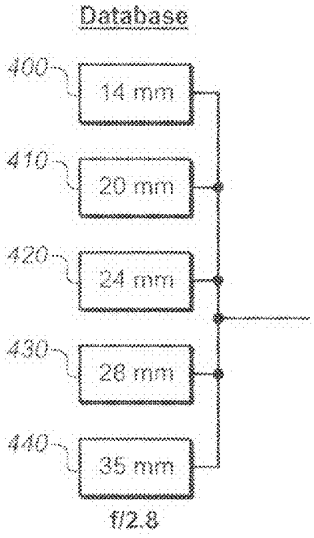


FIG. 4

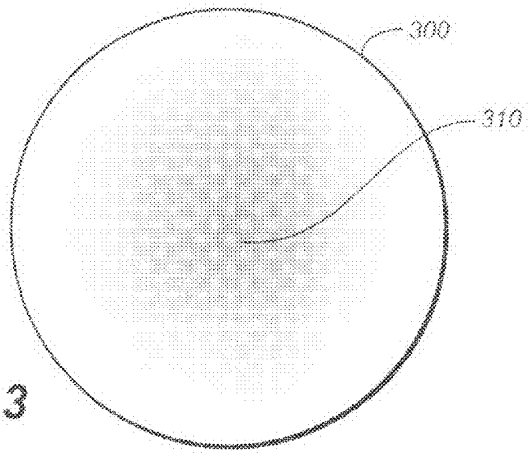


FIG. 3

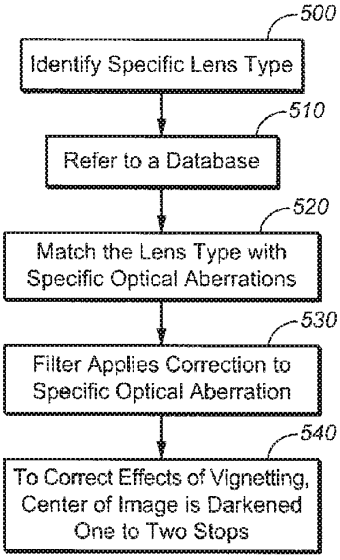


FIG. 5

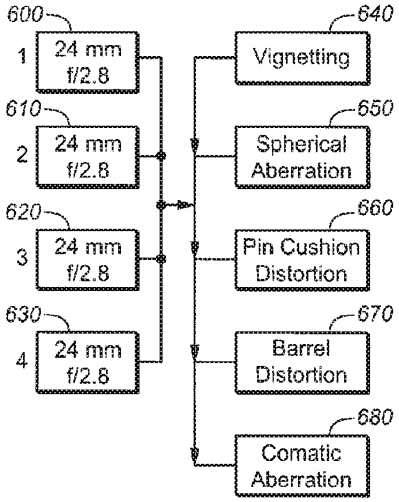


FIG. 6

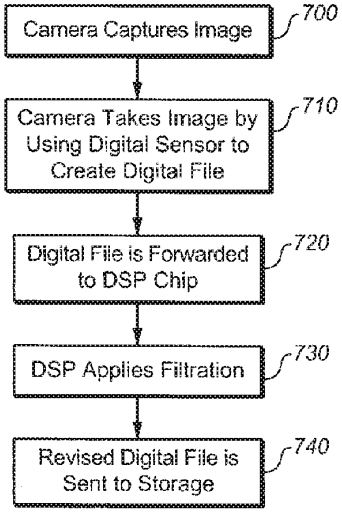


FIG. 7

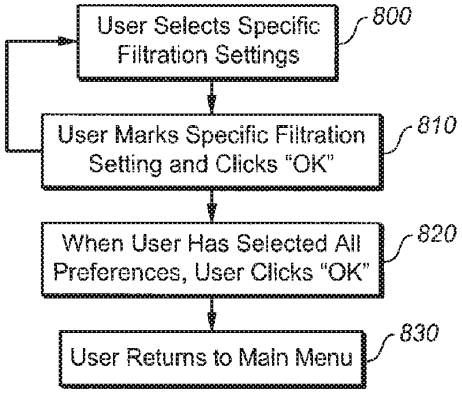

User Selects Specific Filtration Settings
800
User Marks Specific Filtration Setting and Clicks "OK"
810
When User Has Selected All Preferences, User Clicks "OK"
820
User Returns to Main Menu
830

FIG. 8

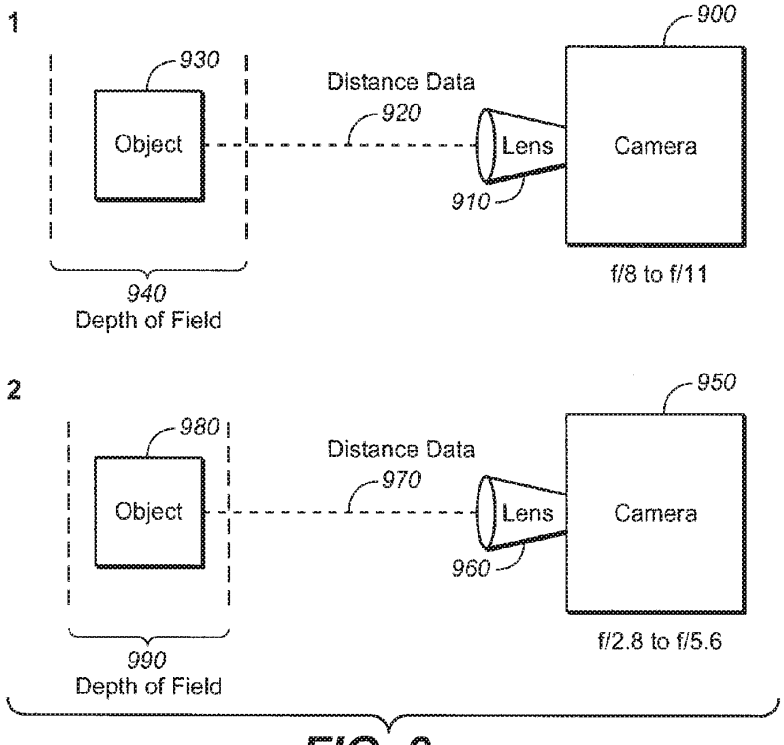

1
900
930
Distance Data
920
Object
Lens
Camera
910
940
Depth of Field
f/8 to f/11
2
950
980
Distance Data
970
Object
Lens
Camera
960
990
Depth of Field
f/2.8 to f/5.6

FIG. 9

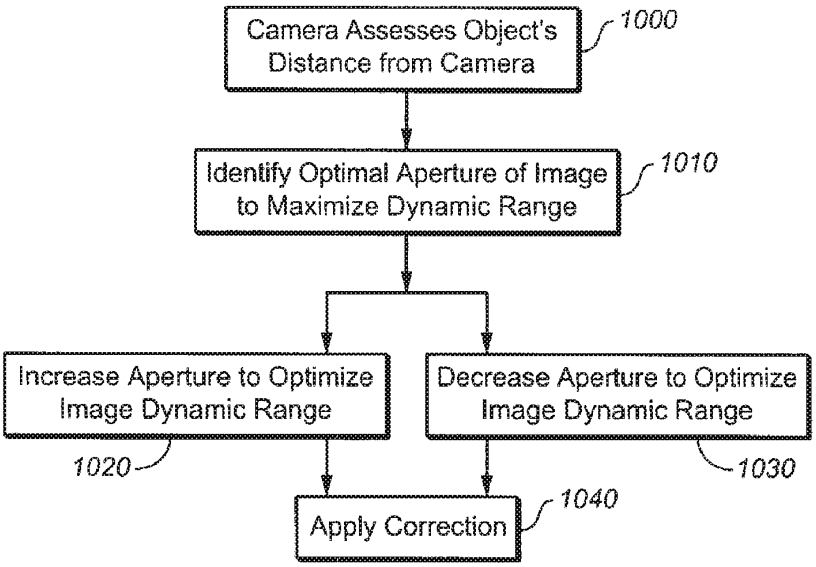

Camera Assesses Object's Distance from Camera
1000
Identify Optimal Aperture of Image to Maximize Dynamic Range
1010
Increase Aperture to Optimize Image Dynamic Range
1020
Decrease Aperture to Optimize Image Dynamic Range
1030
Apply Correction
1040

FIG. 10

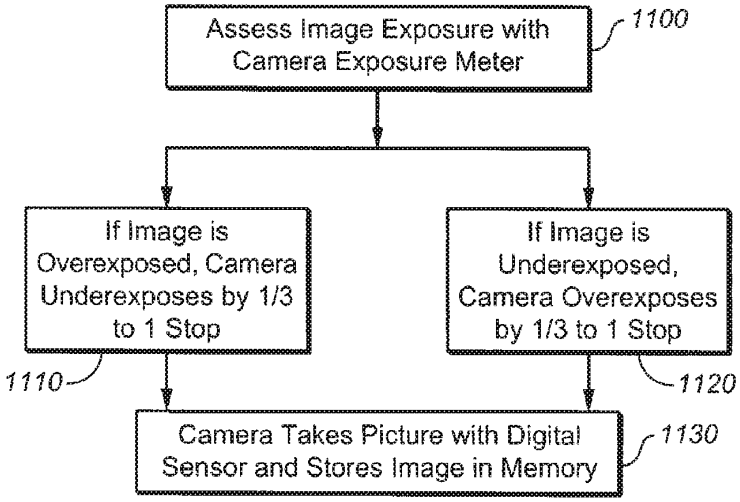

Assess Image Exposure with Camera Exposure Meter
1100
If Image is Overexposed, Camera Underexposes by 1/3 to 1 Stop
1110
If Image is Underexposed, Camera Overexposes by 1/3 to 1 Stop
1120
Camera Takes Picture with Digital Sensor and Stores Image in Memory
1130

FIG. 11

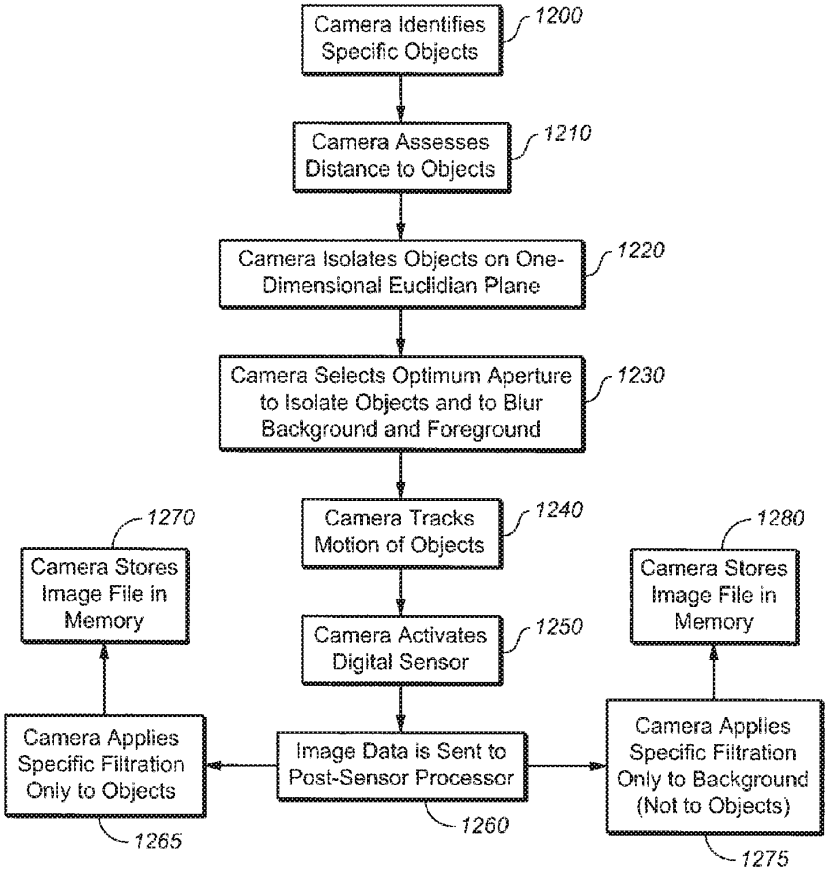

Camera Identifies Specific Objects
1200
Camera Assesses Distance to Objects
1210
Camera Isolates Objects on One-Dimensional Euclidian Plane
1220
Camera Selects Optimum Aperture to Isolate Objects and to Blur Background and Foreground
1230
Camera Tracks Motion of Objects
1240
Camera Activates Digital Sensor
1250
Image Data is Sent to Post-Sensor Processor
1260
Camera Applies Specific Filtration Only to Objects
1265
Camera Stores Image File in Memory
1270
Camera Applies Specific Filtration Only to Background (Not to Objects)
1275
Camera Stores Image File in Memory
1280

FIG. 12

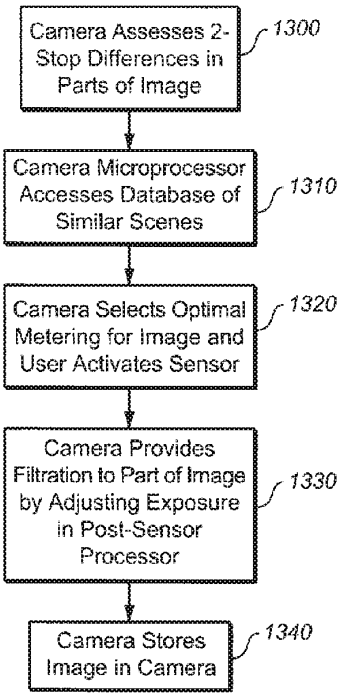

Camera Assesses 2-Stop Differences in Parts of Image
1300
Camera Microprocessor Accesses Database of Similar Scenes
1310
Camera Selects Optimal Metering for Image and User Activates Sensor
1320
Camera Provides Filtration to Part of Image by Adjusting Exposure in Post-Sensor Processor
1330
Camera Stores Image in Camera
1340

FIG. 13

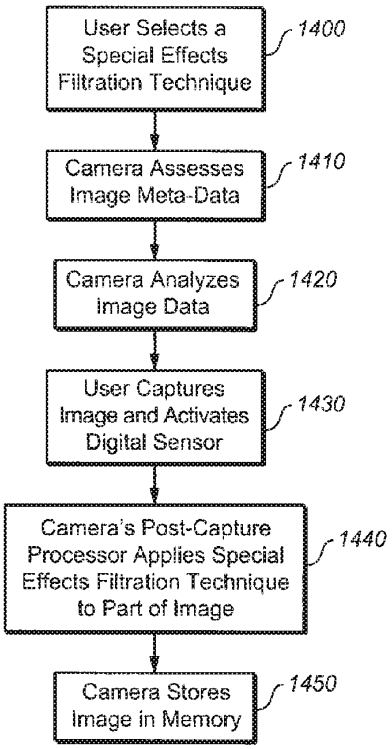

User Selects a Special Effects Filtration Technique
1400
Camera Assesses Image Meta-Data
1410
Camera Analyzes Image Data
1420
User Captures Image and Activates Digital Sensor
1430
Camera's Post-Capture Processor Applies Special Effects Filtration Technique to Part of Image
1440
Camera Stores Image in Memory
1450

FIG. 14

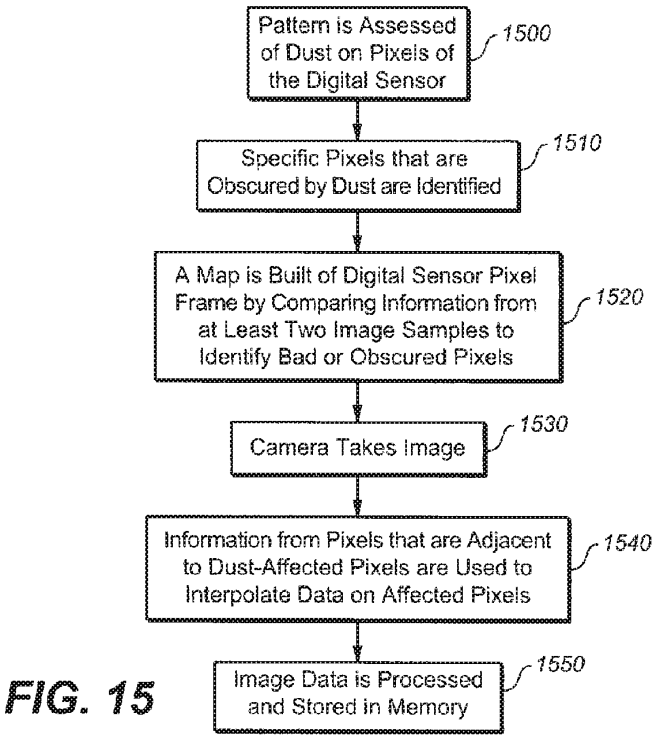

Pattern is Assessed of Dust on Pixels of the Digital Sensor
1500
Specific Pixels that are Obscured by Dust are Identified
1510
A Map is Built of Digital Sensor Pixel Frame by Comparing Information from at Least Two Image Samples to Identify Bad or Obscured Pixels
1520
Camera Takes Image
1530
Information from Pixels that are Adjacent to Dust-Affected Pixels are Used to Interpolate Data on Affected Pixels
1540
Image Data is Processed and Stored in Memory
1550

FIG. 15

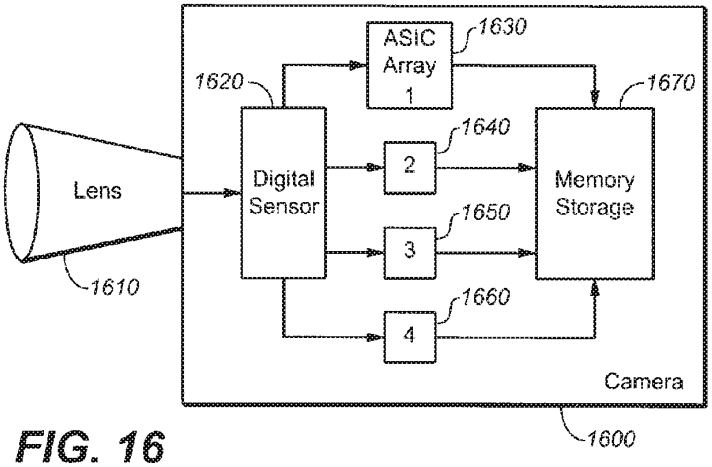

ASIC Array 1
1630
1620
1670
1640
Lens
Digital Sensor
2
Memory Storage
1650
3
1660
4
1610
Camera
1600

FIG. 16

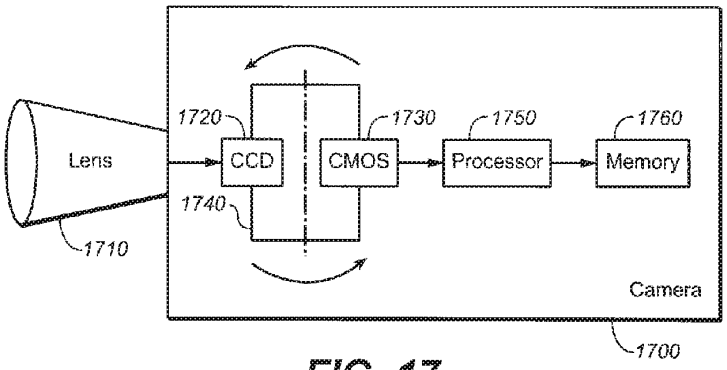

Lens
1710
1720
CCD
1740
1730
CMOS
1750
Processor
1760
Memory
Camera
1700

FIG. 17

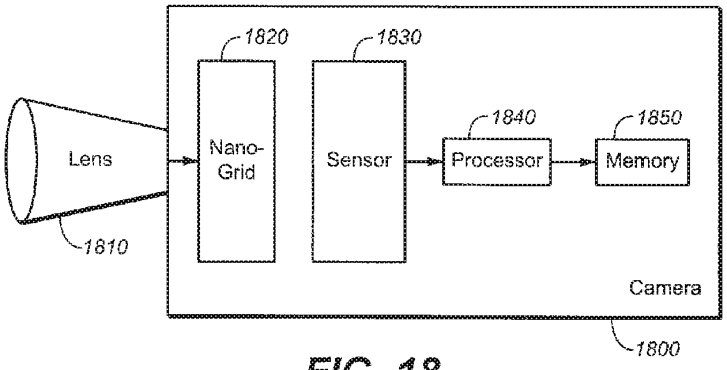

Lens
1810
1820
Nano-
Grid
1830
Sensor
1840
Processor
1850
Memory
Camera
1800

FIG. 18

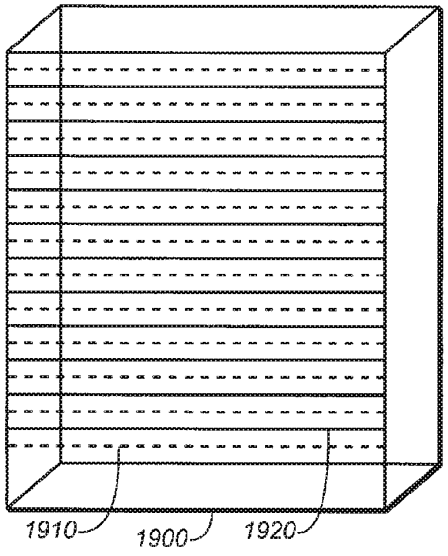

1910
1900
1920

FIG. 19

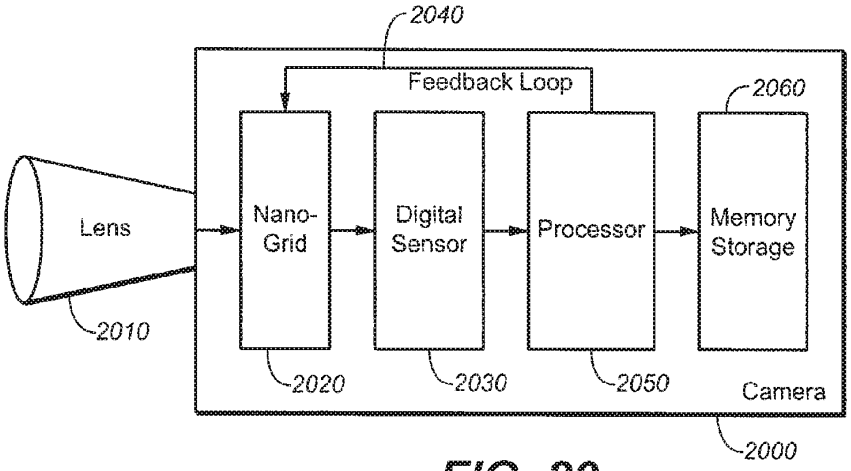

2040
Feedback Loop
2060
Lens
Nano-Grid
Digital Sensor
Processor
Memory Storage
2010
2020
2030
2050
Camera
2000

FIG. 20

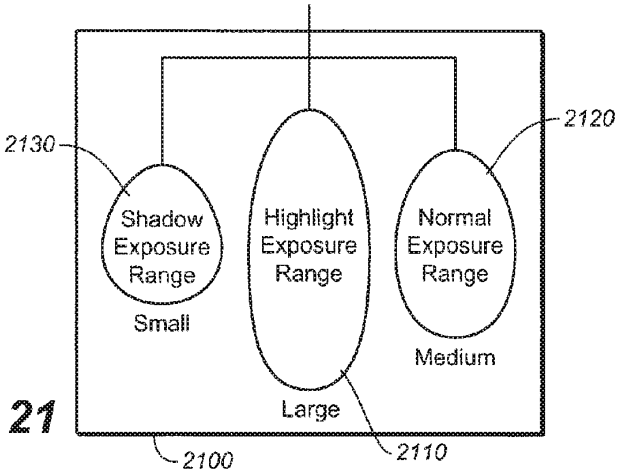

2130
2120
Shadow Exposure Range
Small
Highlight Exposure Range
Large
Normal Exposure Range
Medium
2100
2110

FIG. 21

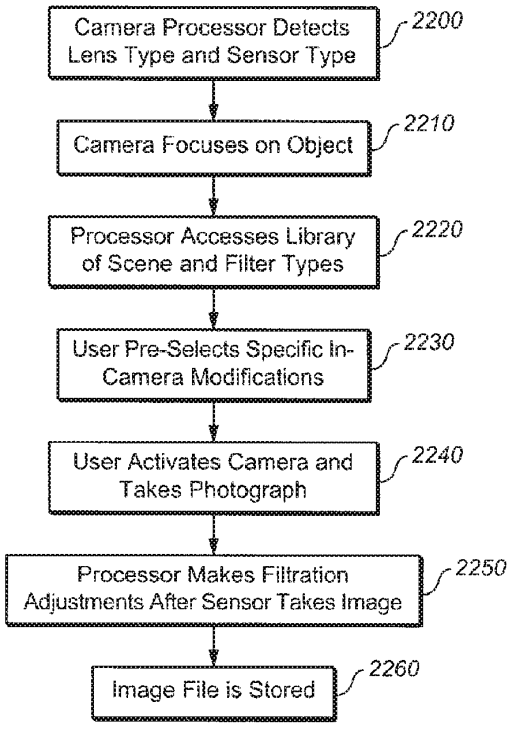

Camera Processor Detects Lens Type and Sensor Type
2200
Camera Focuses on Object
2210
Processor Accesses Library of Scene and Filter Types
2220
User Pre-Selects Specific In-Camera Modifications
2230
User Activates Camera and Takes Photograph
2240
Processor Makes Filtration Adjustments After Sensor Takes Image
2250
Image File is Stored
2260

FIG. 22

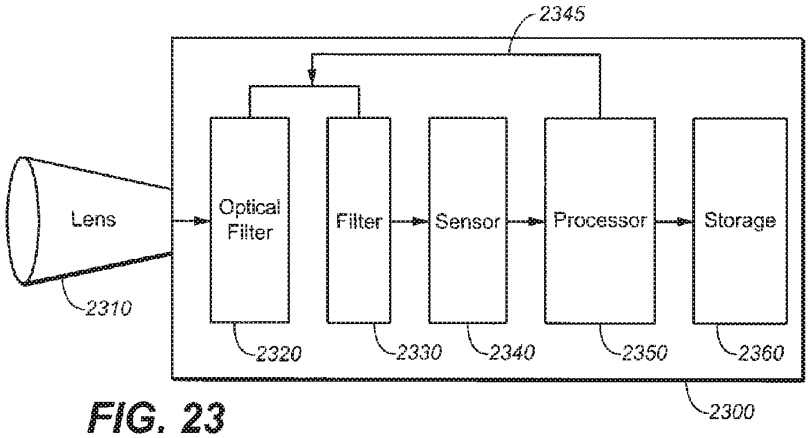

2345
Lens
Optical Filter
Filter
Sensor
Processor
Storage
2310
2320
2330
2340
2350
2360
2300

FIG. 23

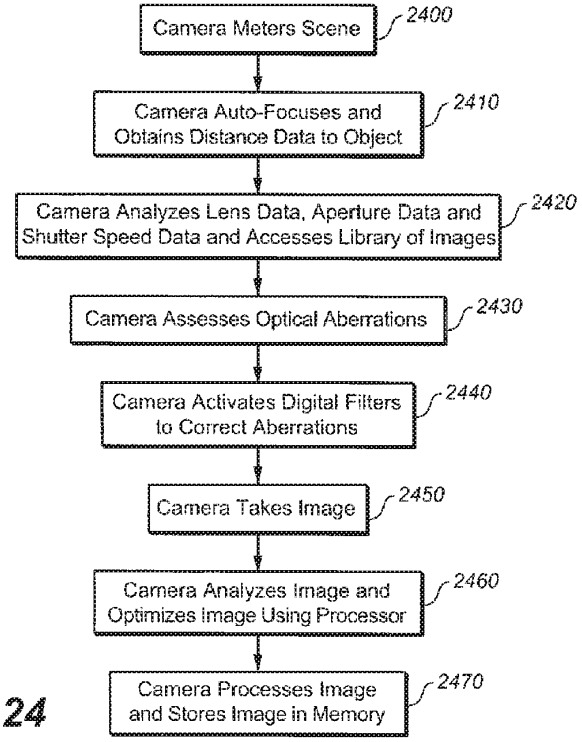

Camera Meters Scene
2400
Camera Auto-Focuses and Obtains Distance Data to Object
2410
Camera Analyzes Lens Data, Aperture Data and Shutter Speed Data and Accesses Library of Images
2420
Camera Assesses Optical Aberrations
2430
Camera Activates Digital Filters to Correct Aberrations
2440
Camera Takes Image
2450
Camera Analyzes Image and Optimizes Image Using Processor
2460
Camera Processes Image and Stores Image in Memory
2470

FIG. 24

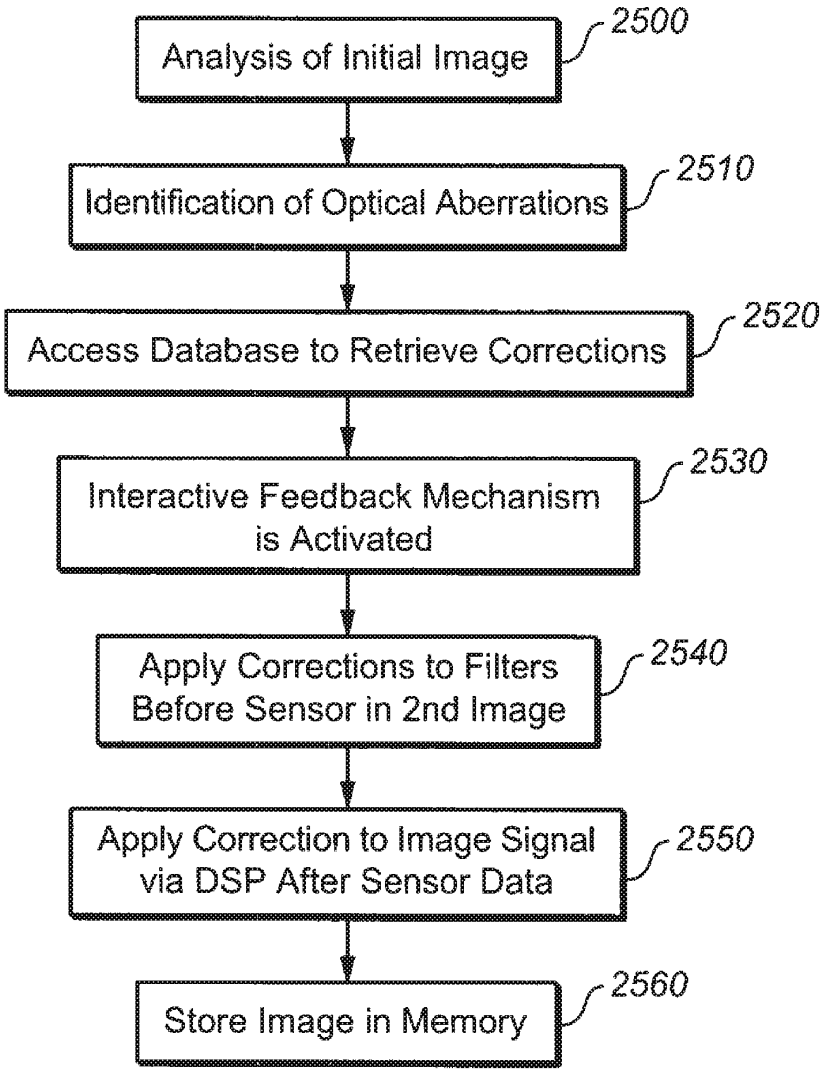

Analysis of Initial Image
2500
Identification of Optical Aberrations
2510
Access Database to Retrieve Corrections
2520
Interactive Feedback Mechanism is Activated
2530
Apply Corrections to Filters Before Sensor in 2nd Image
2540
Apply Correction to Image Signal via DSP After Sensor Data
2550
Store Image in Memory
2560

FIG. 25

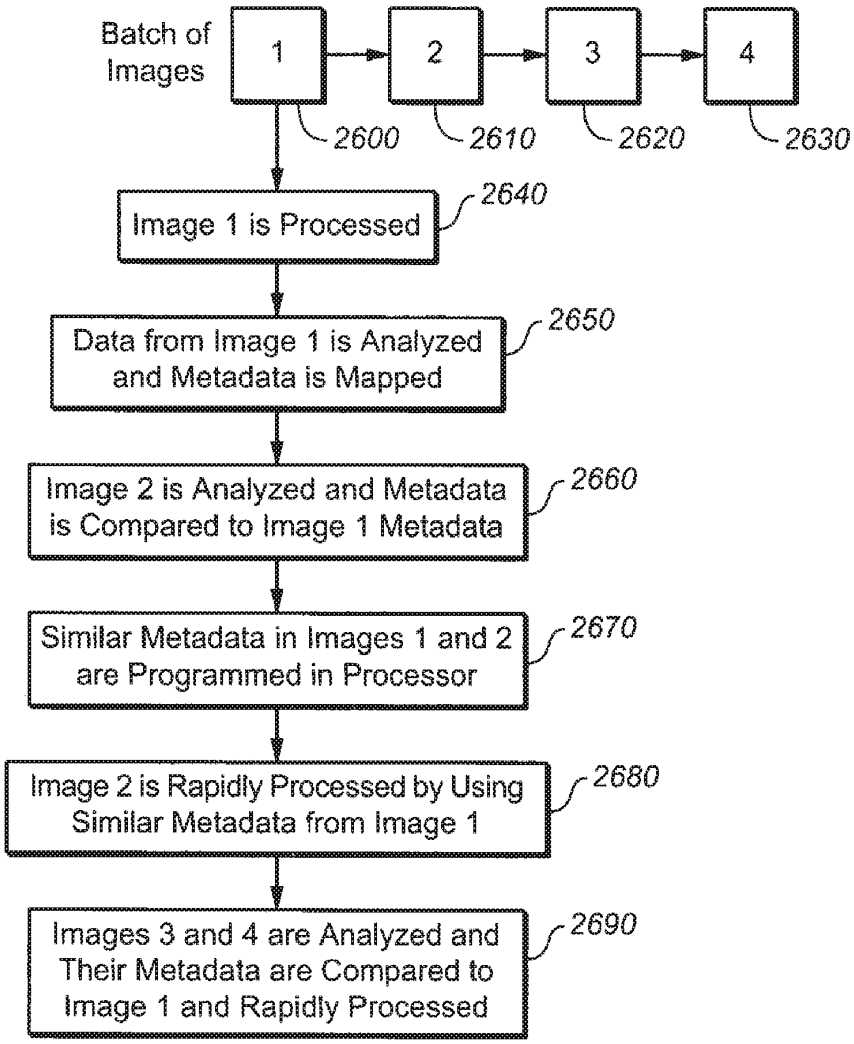

Batch of Images
1
2
3
4
2600
2610
2620
2630
Image 1 is Processed
2640
Data from Image 1 is Analyzed and Metadata is Mapped
2650
Image 2 is Analyzed and Metadata is Compared to Image 1 Metadata
2660
Similar Metadata in Images 1 and 2 are Programmed in Processor
2670
Image 2 is Rapidly Processed by Using Similar Metadata from Image 1
2680
Images 3 and 4 are Analyzed and Their Metadata are Compared to Image 1 and Rapidly Processed
2690

FIG. 26

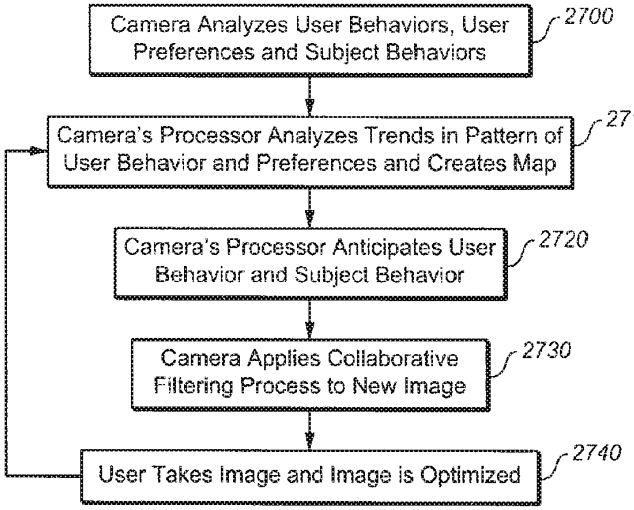

Camera Analyzes User Behaviors, User Preferences and Subject Behaviors
2700
Camera's Processor Analyzes Trends in Pattern of User Behavior and Preferences and Creates Map
2710
Camera's Processor Anticipates User Behavior and Subject Behavior
2720
Camera Applies Collaborative Filtering Process to New Image
2730
User Takes Image and Image is Optimized
2740

FIG. 27

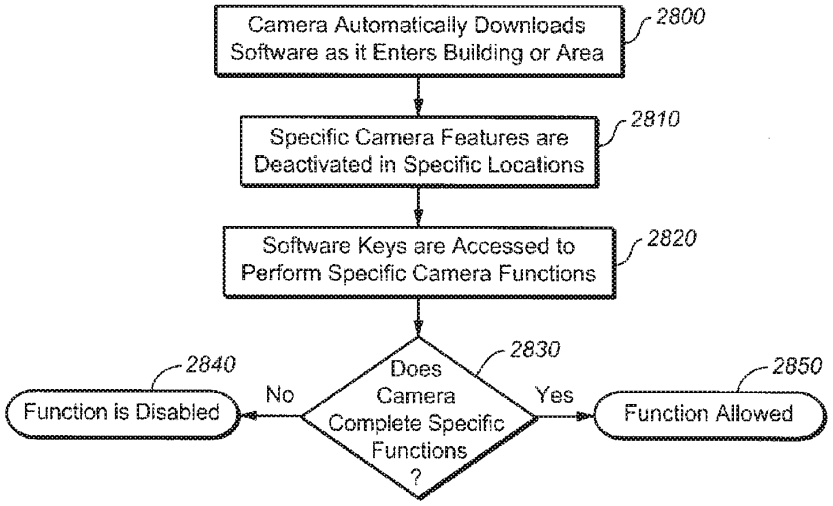

Camera Automatically Downloads Software as it Enters Building or Area
2800
Specific Camera Features are Deactivated in Specific Locations
2810
Software Keys are Accessed to Perform Specific Camera Functions
2820
Does Camera Complete Specific Functions ?
2830
No
Yes
Function is Disabled
2840
Function Allowed
2850

FIG. 28

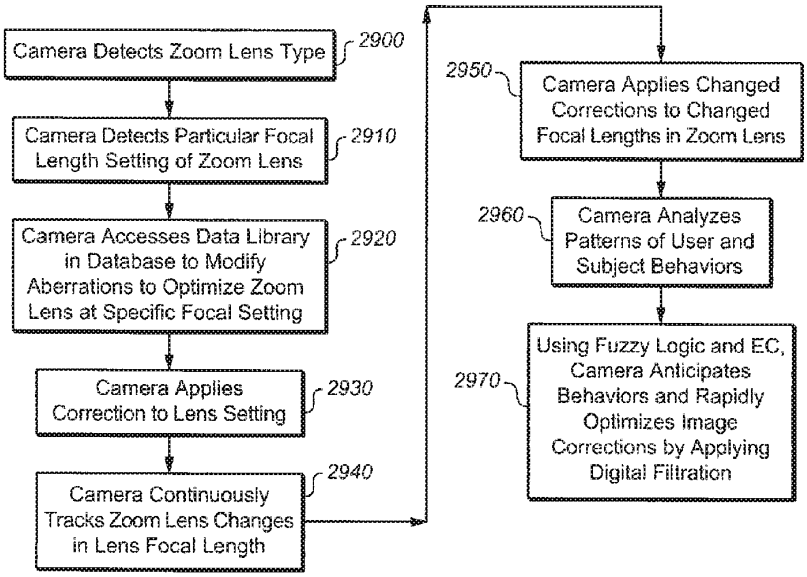

Camera Detects Zoom Lens Type
2900
Camera Detects Particular Focal Length Setting of Zoom Lens
2910
Camera Accesses Data Library in Database to Modify Aberrations to Optimize Zoom Lens at Specific Focal Setting
2920
Camera Applies Correction to Lens Setting
2930
Camera Continuously Tracks Zoom Lens Changes in Lens Focal Length
2940
2950
Camera Applies Changed Corrections to Changed Focal Lengths in Zoom Lens
2960
Camera Analyzes Patterns of User and Subject Behaviors
2970
Using Fuzzy Logic and EC, Camera Anticipates Behaviors and Rapidly Optimizes Image Corrections by Applying Digital Filtration

FIG. 29

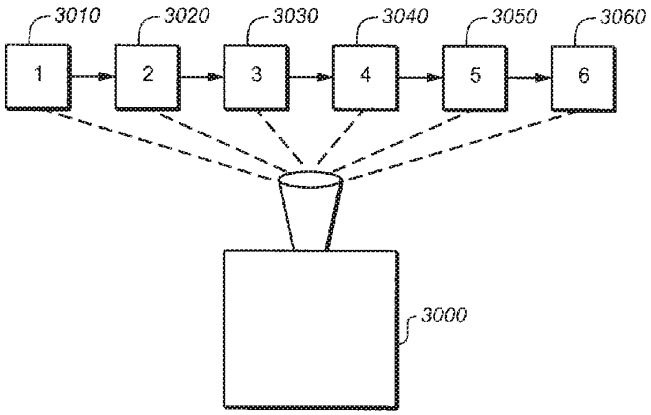

3010
3020
3030
3040
3050
3060
1
2
3
4
5
6
3000

FIG. 30

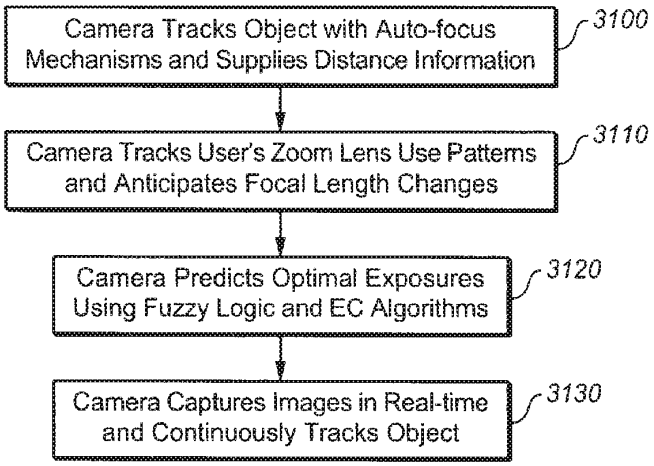

Camera Tracks Object with Auto-focus Mechanisms and Supplies Distance Information
3100
Camera Tracks User's Zoom Lens Use Patterns and Anticipates Focal Length Changes
3110
Camera Predicts Optimal Exposures Using Fuzzy Logic and EC Algorithms
3120
Camera Captures Images in Real-time and Continuously Tracks Object
3130

FIG. 31

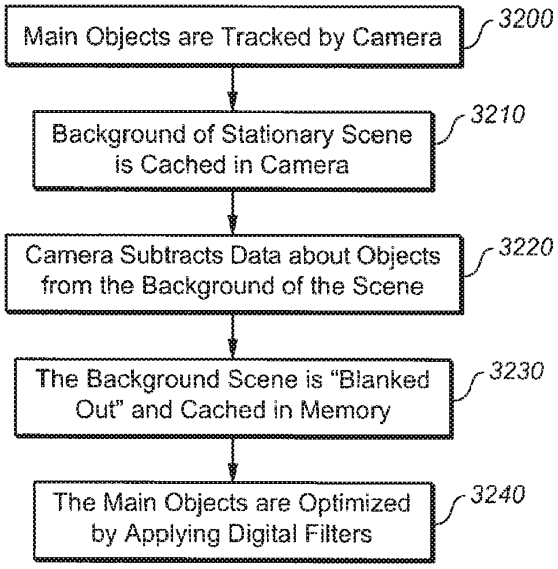

Main Objects are Tracked by Camera
3200
Background of Stationary Scene is Cached in Camera
3210
Camera Subtracts Data about Objects from the Background of the Scene
3220
The Background Scene is "Blanked Out" and Cached in Memory
3230
The Main Objects are Optimized by Applying Digital Filters
3240

FIG. 32

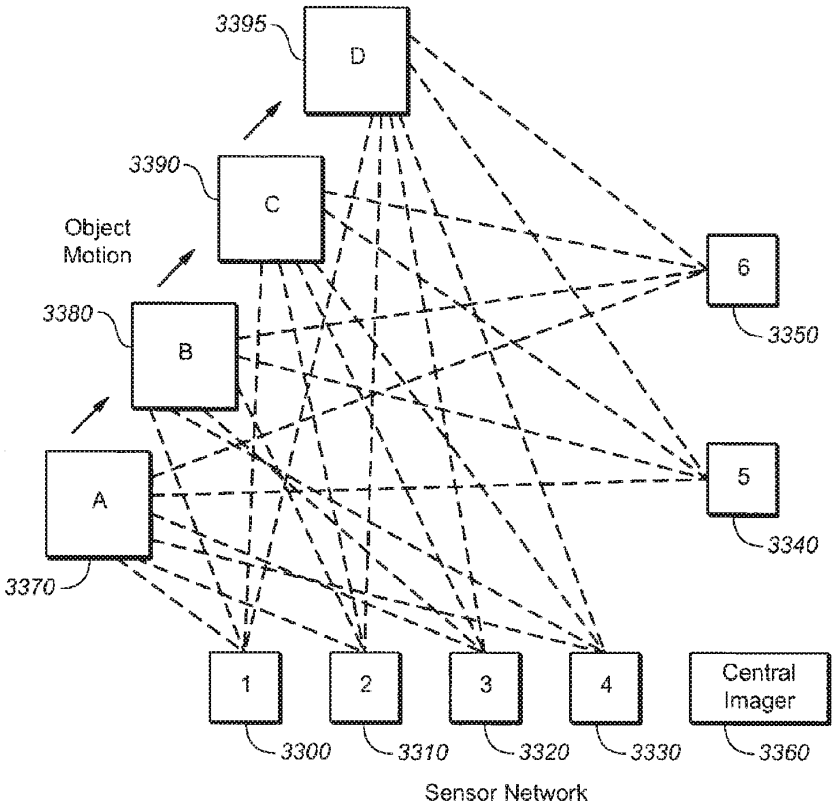

3395
D
3390
C
Object
Motion
3380
B
A
3370
6
3350
5
3340
1
2
3
4
Central
Imager
3300
3310
3320
3330
3360
Sensor Network

FIG. 33

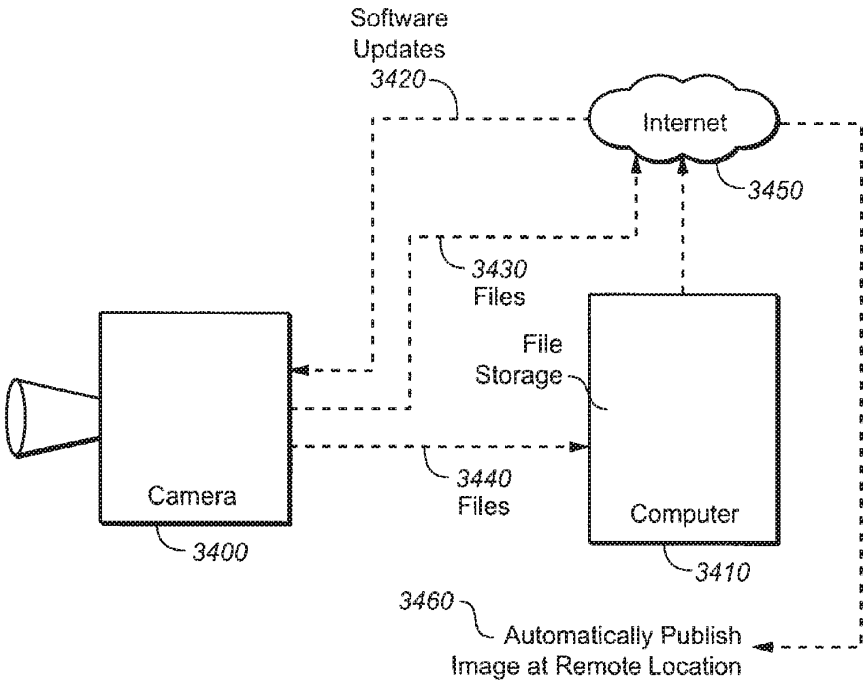

Software
Updates
3420
Internet
3450
3430
Files
File
Storage
Camera
3400
3440
Files
Computer
3410
3460
Automatically Publish
Image at Remote Location

FIG. 34

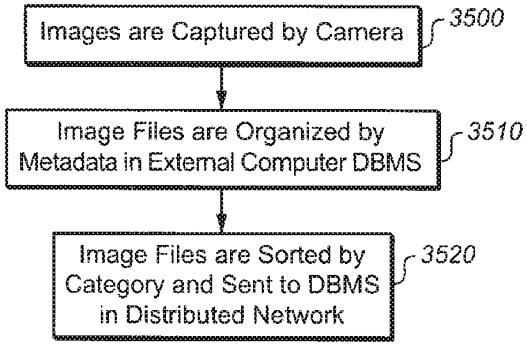

Images are Captured by Camera
3500
Image Files are Organized by
Metadata in External Computer DBMS
3510
Image Files are Sorted by
Category and Sent to DBMS
in Distributed Network
3520

FIG. 35

DIGITAL IMAGING SYSTEM AND METHODS FOR SELECTIVE IMAGE FILTRATION

CROSS-REFERENCES TO RELATED APPLICATIONS

The present application claims the benefit of priority under 35 U.S.C. section 119 from U.S. Provisional Patent Application Ser. No. 60/807,065, filed on Jul. 11, 2006, the disclosures of which are hereby incorporated by reference in their entirety for all purposes.

FIELD OF THE INVENTION

The present invention pertains to imaging systems. The invention presents electronic methods to optimize optical processing, the digital capture of light and post-capture image organization of digital data sets. The system may be used in any device that captures, records, replicates, scans, reproduces, accesses, organizes, modifies, edits or stores images digitally. The invention applies to any imaging system that includes interaction between optics, digital image sensors, post-capture integrated circuits and digital storage components. The system includes self-organizing apparatus for optical image collection, electronic organization and optimization of digital data using integrated circuits and software applications. The system applies to consumer and professional still and video photography, including cinematography, to the processing of images with digital sensors, and to copying and scanning technologies. The system also applies to complex grids of multiple video cameras and satellites for surveillance and reconnaissance.

BACKGROUND OF THE INVENTION

The history of photography in the twentieth century is a story of finding solutions for optimizing optical problems. The main challenges have involved improving lens configurations to optimize image quality for film capture. As an example of this, lens aberrations have been reliably corrected by creating aspherical lens elements in wide-angle lenses and by creating apochromatic lens elements in telephoto lenses. The use of lens element coatings has also improved optical quality. Similarly, the evolution of zoom lenses has included improvement in optical quality via the combining of complex optical element configurations; as the optical quality of zoom lenses improved dramatically, their simplicity and utility led them to dominate lens sales. Complex computer-aided design (CAD) software has been used to test a broad range of possible lens configurations so as to optimize the optical performance in terms of clarity and contrast of each lens type, as much as optically possible within economic constraints.

In the last twenty-five years, an additional revolution has occurred with the advent of auto-focus (AF) technology in still photographic and video cameras. Invented by Minolta in the early 1980s, AF technology was a photographic application of technology developed for the U.S. military. The AF system used an infrared light sensor to reflect light onto an object that allowed a camera's lens to focus on the object by employing a motor in the camera. Canon eventually developed improved methods of auto focus by using electronic means (viz., micro ultrasonic motors) to increase speed and accuracy. This AF technology was integrated with automatic exposure (AE) technology which developed complex algorithms in a "program" mode to combine shutter and aperture data to match each lens with particular subject matter, as well as an aperture-priority exposure mode and a shutter-priority exposure mode. Of course, the photographer could use manual focus and manual exposure at any time, but these improvements increased the creative process and the competitive advantages of camera makers and photographers that employed them. Ultimately, the combination of these developments allowed ordinary photographers to achieve high quality standards.

AE was improved by Nikon, particularly with the use of a "3D color matrix" system, which included a library of pre-programmed image types. The combination of the improved AF and AE subsystems allowed a dramatic simplification of photographic imaging because the photographer no longer labored over the time-consuming focus and the exposure variables. Automated film advance, in the form of built in motor drives, increased the working speeds of camera operation as well. Nearly all consumer and professional cameras became automated to some degree by the mid-1990s, including formats beyond the 35 mm film standard.

In the last decade, a new technology of image stabilization (IS) has emerged to help correct the problem of vibrations caused camera shake that lead to image blur. This technology is implemented in lenses by the use of gyros to reorient the light plane to compensate for camera shake; when combined with the earlier automated camera technologies such as AF and AE, IS further improves the photographic experience, particularly for larger lenses.

In addition to these advances in camera automation, technologies improved in the category of artificial flash as well. With microprocessors and sensors employed to measure minute variances, the development of photographic flash systems allowed the photographer to control the lighting in an environment to some degree. Nikon's use of distance information in its flash system advanced the state of the art in flash photography. The combination of AF and AE with automated flash mechanisms provided increased efficiency and simplicity in image capture processes.

The last several years have witnessed a revolution in digital photography. Because of its simplicity, potential quality improvement, immediate feedback and cost savings, digital photography has captured an increasing market share relative to film-based cameras. Kodak holds a number of patents involving the charge coupled device (CCD) for converting and recording light into electronic format. A competing technology for digital capture is complementary metal-oxide semiconductor (CMOS) which, though developed by Fairchild Semiconductor over forty years ago, is predominantly used in photographic cameras by Canon. Although there are trade-offs in the application of CCD and CMOS digital sensors for image capture, they both find wide acceptance in the market.

In order to correct for digital artifacts in image capture mechanisms, anti-aliasing filters are placed in front of digital sensors. Despite this improvement, digital imaging still has some challenges to overcome in competing with the image quality of film.

At the present time, the most recent advances in digital imaging for professional still photography have come from Hasselblad, which offers a Phase One camera back with a 39 MP digital sensor from Kodak. This system uses software that automatically corrects for digital capture limitations to produce a quality image. Their "digital APO correction" (DAC) technology performs an analysis of meta-data to color-correct the digital capture resulting in moiré-free images.

At the limits of current technology, a Canadian company, Dalsa, has produced a 111MP (10,560 by 10,560 pixels) CCD digital sensor that measures four inches square. This technology must be mated with large format-type lenses with large

image area, and may be used for satellite surveillance applications and for other astronomical applications.

With both the larger sensor surface area of a medium format camera system and the high-quality fixed focal-length lenses of Zeiss, Schneider and Rodenstock, the quality of even the top optics will be a limiting barrier to advanced digital sensors' ability to perceive maximum resolution. Without new improvements in optical and digital technologies, further progression of photographic camera systems will be limited.

Photographic Problems

Though every major advance in photography has solved an important problem, there are still remaining photographic problems to be solved in order to meet the goals of optimizing optical imaging quality while increasing simplicity and efficiency and lowering cost. Despite the advent and evolution of digital imaging, a number of problems have emerged in the digital realm in addition to earlier problems involving optics. Nevertheless, an opportunity exists to solve some of these problems via digital approaches. These problems are generally categorized as optical or digital.

Optical Problems

In the case of optics, lens aberrations are characterized according to lens type, with wide-angle lens problems differentiated from telephoto lens problems. Some of the problems affecting wide-angle lenses arose from the creation of the single lens reflex (SLR) camera. Before the SLR, the rear element of a lens could be placed in a rangefinder to protrude to a point immediately in front of the film plane in order to correct for aberrations. While the advantages of the mirror mechanism include ability to see exactly what one is photographing, because the mirror of the SLR flips up during exposure, the rear element of the lens must be placed in front of the mirror's plane of movement. This mechanical fact limits lens designs in most 35 mm and medium-format camera systems and particularly affects wide-angle lens configurations.

It is very difficult to control the five aberrations of Seidel—spherical aberration, distortion (barrel distortion and pin cushion distortion), comatic aberration, astigmatism and curvature of field. In wide-angle SLR lenses as they are currently designed, these aberrations are particularly prominent.

For wide-angle lenses, optical vignetting affects peripheral illumination. Though optical vignetting will affect even retrofocus wide-angle lenses in rangefinders, it is particularly prominent in SLR cameras. According to the Cosine law, light fall-off in peripheral areas of an image increases as the angle-of-view increases. While optical vignetting can be reduced by stopping down the lens, the aberrations in rectilinear wide-angle lenses generally exhibit more distortion the wider the lens.

In the case of wide-angle lenses, the depth of field range is much broader, with close focusing causing aberrations without stopping down the aperture. To solve this problem, close-distance focusing is improved by the creation of floating groups of lens elements. The rear lens group elements float to correct close-distance aberrations. With wide-angle lenses that have wide apertures, floating lens elements improve lens aberrations in focusing on distance points also.

Modulation transfer function (MTF) curves represent a quantitative methodology used to assess the resolution and contrast of lens performance at specific apertures. Each lens type has a specific lens element composition, formula and behavior as measured by MTF. In general, MTF measures lens sharpness to 30 lines/mm and contrast to 10 lines/mm.

Because different colors of the visible light spectrum behave uniquely, the goal of lens design is to have all colors accurately hit a film plane or digital sensor plane. The particular challenge for telephoto lenses is that the red and green light colors strike the film plane at different times than blue light colors; thus a compensation must be made in the lens configuration to adjust for chromatic aberrations. Camera lens manufacturers have used extra low dispersion glass and fluorite glass elements in telephoto lenses primarily to adjust the red color light spectra to the film plane. In addition, telephoto lenses use carefully designed lens coatings to limit light diffraction-based aberrations.

Due to their construction, super-telephoto lenses are very large and heavy. While modifying the materials used in the lens barrels could reduce size and weight problems, a technological improvement in telephoto lens design was developed by Canon with the addition of diffractive optical (DO) elements, which behave as a sort of highly-refined fresnel lens magnifier. Though the MTF analyses of wide-angle lenses show dramatic latitude in performance of even high quality SLR lenses, with particular loss in resolution and contrast toward the edges of the image, high quality telephoto lenses show control of aberrations. However, the price of these lenses is prohibitively high.

In the case of zoom lenses, as many as four distinct groups of lens elements correct various optical aberrations. These lens element groups include (a) a focusing group, (b) a magnification variation group, (c) a correction group and (d) an image formation group. Modulating the focal length range of a zoom lens enables the lens to perform within the scope of operation, yet the zoom lens architecture has limits. In particular, the zoom lens configuration sacrifices resolution and wide potential aperture. Generally, the degree of resolution and contrast at the smaller angle of view is traded away in favor of competence at a wider angle of view, or vice-versa. This explains why MTF analyses of zoom lenses generally show a dramatic lowering in resolution and contrast relative to excellent fixed focal length lenses.

Digital Problems

Digital photography has built on the edifice of film camera systems. For instance, the size of the sensor is generally limited to the size of the optical circumference of a lens system. In the case of 35 mm lenses that are designed for a specific angle of view, the largest that a digital sensor in a 35 mm lens system could be, is 24 mm by 36 mm, with a corresponding maximum image circle of 43 mm. In the case of medium format lenses, the largest digital sensors would duplicate the corresponding film plane size, whether 6×4.5 cm, 6×6 cm, 6×7 cm, 6×8 cm, 6×9 cm, 6×12 cm or 6×17 cm (which results in an effective image circle as large as 7 inches).

Digital sensors that are smaller than the limits of a corresponding lens system have been introduced. For example, Nikon digital sensors are smaller than 24 mm×36 mm, or advanced photo system (APS) size. Efficient stacking of pixels allows a smaller sensor to eventually match the performance of a corresponding film system, while using the smaller circumference of the same lenses. Since the outside edges of the lens typically degrade resolution and contrast, this model using the smaller digital sensor can have an advantage of using primarily the centralized "sweet spot" of the image area. However, this smaller sensor size sacrifices the peripheral effects of a wide-angle lens, so a 14 mm becomes a 21 mm in a 1.5× conversion-sized sensor in a 35 mm lens system. On the other hand, with telephoto lenses, the angle of view is limited to the center 65% of the image. This gives the

appearance of upconverting a telephoto lens by 1.5× and thus provides an impression of increased magnification; a 400 mm f/2.8 lens appears as a 600 mm f/2.8 lens on a camera with a cropped digital sensor. Ultra-wide-angle lenses have been introduced with smaller image areas than 35 mm to compensate for smaller sensor size.

Though invented over thirty years ago by Dr. Bayer, the charge coupled device (CCD) that is used in many digital cameras generally emulates the behavior of film. Specifically, since most photographic film has three layers of green, red and blue, with green representing fifty percent of the emulsion and red and blue twenty-five percent each, the CCD architecture also configured pixels to capture fifty percent of the green photonic visible light spectrum and twenty-five percent each for pixels recording red and blue light. Human eyes see more green than red and blue, so both film and digital sensors seek to emulate the way that we see. Each light color is captured by a different pixel in the CCD, just as there are three emulsion layers of film. In recent years, Foveon has developed a digital sensor for image capture that further seeks to emulate film by structuring the pixels into three layers, again with fifty percent capturing green light and twenty-five percent each capturing red and blue light.

Unfortunately, unwanted artifacts are also captured by the digital image capture process. These include banding and moiré effects that present false patterns and colors. Moiré patterns are created because the dot pattern of a sensor will intermittently overlap with the pattern of a subject to create a third pattern; these effects are optically-generated digital distortions that represent the effect of light hitting a pixel without correction. In order to compensate for these effects, digital sensors have employed low pass filters consisting of liquid crystal structures; however, these filters tend to have the effect of softening image resolution. Additionally, RGB or CMYG color filters are placed in front of digital sensors to ensure the accurate capture of colors.

CMOS digital sensors present an alternative to CCDs. By employing alternating positive and negative transistor networks, the CMOS sensors use less power. While they do not have the low noise ratio of the CCD, they do have greater light exposure latitude, in both range of ISO and dynamic range of detail in highlight and shadow. More importantly, CMOS sensors contain the circuitry, including analog to digital converter (ADC) and digital to analog converter (DAC), for post-processing digital images on the chip itself and enabling increased micro-miniaturization of the digital imaging process. An increase in the bit rate of the CMOS chip up to 32-bit makes possible a much richer color palate and level of detail than with earlier generation CCDs.

CMOS sensors can be full-frame, matching the lens specifications for the camera systems for which they are designed. A relatively bigger sensor has a wider depth of field capability, so the background can appear as a blur to set apart the main subject. Given these capabilities, one problem that emerges is that a digital sensor's enhanced capabilities to capture details may exceed the maximum optical resolution capabilities of many lenses. Nevertheless, CMOS sensors still require an anti-aliasing filter to be used in front of the sensor, which marginally degrades resolution.

Over the years, cameras have gotten smaller. While in the 19th century cameras were 11×14 or 8×10, literally capturing images on large emulsion plates, cameras of today are smaller and more automated. Yet the larger the film size, the bigger the enlargement potential and the increase in relative detail in the overall image. Similarly in digital photography, the larger the sensor, the more detail available and the bigger the output print can be enlarged. Because of this correspondence of digital sensor to film, the evolution of digital photography has been restricted to respective film camera systems, with 35 mm and medium format systems dominating the field because well-developed lens systems have already been organized for these camera formats. The potential exists, however, to develop 35 mm camera system digital sensors that rival film-based medium format or large format camera system quality or to surpass the limits of 35 mm camera systems with medium format camera system digital sensors. The relative size, cost and automation advantages of 35 mm camera systems generally show that these systems not only are competitive, but that these markets are increasingly accelerated relative to larger format systems. For example, the development of large aperture lenses, super-telephotos, rapid auto-focus, refined automated exposure and image stabilization systems in 35 mm systems has solved various problems that have emerged in the last century and has improved image quality and camera system efficiency.

However, in the digital imaging realm additional problems have emerged, including the need to improve color (hue and saturation) quality, exposure highlight range, contrast range and other tonal adjustments. In addition, digital image capture brings its own set of aberrations, including moiré and banding effects and noise and ISO range limits. Additional aberrations are linked to the unique design of each type of digital sensor, with trade-offs presented between types of CCDs or CMOS chips. Moreover, there are still optical problems in the digital realm, namely, a range of optical aberrations created particularly by wide-angle and zoom lenses as well as the limits of very large, costly and heavy super-telephoto lenses.

In order to transcend the optical and digital limits of present camera systems, software systems have been developed that deal with the problems in post-production. While the most notable of these post-production digital editing software programs is Adobe Photoshop, each camera manufacturer has its own proprietary program. In the main, these post-production software programs are limited to color correction and sharpening/softening of images. Additionally, some of these software programs are able to emulate specific artificial filter techniques to produce creative modifications of an original image. Nevertheless, manipulating unfiltered RAW image files in post-production processes is time-consuming and expensive and requires considerable skill.

One unintended effect of using digital sensors to capture images in digital photography is that dust accumulates on the sensor surface and thereby obstructs a clear optical image. The vacuum behavior of increasingly ubiquitous zoom lenses moves dust in lenses that are not internally sealed and the existence of dust is a prevalent feature of digital photography. Dust on the sensor is a non-trivial problem that requires tedious post-production correction for each image. The existence of dust on a digital sensor is an inconvenient impediment to achievement of optical imaging quality.

What is needed to correct these various optical and digital aberrations and unfiltered image files is in-camera modification capability for each specific image problem. The present invention describes a digital imaging system to optimize optical results.

Applications of the Present Invention

The present invention has several practical applications. The digital imaging system applies to consumer and professional still and video camera technologies, to cellular telephones and to personal digital assistants (PDAs). Since video technologies are evolving into digital formats, including HDTV and its successors, the present invention would be

applicable to these technologies. The present invention also applies to networks of remote camera sensors for surveillance. The system also applies to native digital cinematography and telecine conversion from analogue to digital media. The system may be applied to image scanning and image copying technologies. Finally, the present system may be applied to any optical digital capture, processing and storage sub-system technologies, including groups of sensors or satellites.

Advantages of the Present Invention

There are several important advantages of the present invention. The present system dramatically improves image quality. This digital imaging system eliminates, or minimizes, post-production processes. In addition, the system presents substantial cost savings as well as time savings relative to existing digital imaging systems because of the automation of integrated in-camera optical and digital corrections of aberrations.

With the present system, in-camera digital filters will largely replace optical filters. With less distortion, cost and weight/size than current optical filters and with far more control and quality results, the present system demonstrates that in-camera digital filtration out-performs better than external filters. The in-camera filter system is also an improvement over post-production digital filter systems which require substantial time, cost and skill to implement.

By using the present invention, users will be able to use lens apertures that are wider open, because lens aberrations will be corrected. In turn, this increased latitude will allow more efficient (2+ stops) use of available light and will allow slower lenses to achieve quality images that have traditionally been in the domain of expensive fast lenses. The process of photography will be made generally more efficient.

The present system allows camera manufacturers to design different, predominantly smaller, lenses. Moreover, with providing a system for digital corrections, camera lenses may use less expensive optics and still obtain good results. This process will, in turn, accelerate the adoption of low-cost digital photographic systems and, in the aggregate, increase the overall size of the digital photographic market. Similarly, there will be an increase in the effectiveness of zoom lenses, which are already becoming popular. With the present system, 35 mm optics may obtain the quality typically recognized by 4×5 film camera systems. The present system will thus facilitate photographic digital imaging to supplant the film era.

Its application to digital scanning and copying will allow the present system to become ubiquitous as a system to improve imaging.

Because the system presents an integration of several critical subsystems that are centered on digital imaging processes, the system has applications to video photography, satellite systems and surveillance systems. The dynamics of the operation of the subsystems of the present digital imaging system reveal the refinement, efficiency and optimization of the digital photographic paradigm.

Importantly, since the present system uses apparatus and methods that are implemented with software processes, in-camera software can be constantly upgraded and remotely downloaded, while image files can be automatically uploaded, organized and published.

If the goal of the evolution of photographic technology is to increase the number and quality of excellent images, the present system will revolutionize photography.

Solutions to Digital Imaging Problems that the Present System Presents

The present system provides in-camera digital corrections to both optical and digital aberrations. In the case of optical aberrations, distinct lens-specific imperfections are caused by wide-angle, telephoto and zoom lens types. In the case of digital aberrations, specific digital artifacts, such as aliasing and dust, must be corrected.

The present invention also designs specific improvements to digital sensor design. These hardware architecture modifications allow digital imaging to maximize both optical resolution and image exposure range.

Post-capture in-camera filtration is only part of the solution. There is also a need to modify the digital sensor, whether CCD or CMOS, with specific filtration in some cases, including a low pass anti-aliasing filter and a polarizing filter. This post-optic pre-sensor filtration works with post-sensor in-camera filtration processes.

In the context of specific complex processes, such as in zoom lens modifications of focal length and in full-motion video processing, additional corrections are performed using the digital imaging system which continuously optimizes performance.

Finally, the present system reveals approaches to improve network coordination and wireless external storage and publication capabilities for digital imaging systems.

BRIEF SUMMARY OF THE INVENTION

The present invention is divided into several main subsystems: (1) digital filters to correct optical and digital aberrations; (2) digital sensor improvements and nano-grids; (3) digital system improvements that link multiple digital corrections; (4) dynamic digital imaging system improvements that apply to zoom lenses and video imaging; and (5) digital image network improvements. There are several distinct improvements for each category of sub-system listed.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic drawing of a digital imaging system.

FIG. **2** is a flow chart of an analog to digital signal process.

FIG. **3** is an image of the vignetting corrective filter in an optical lens.

FIG. **4** is a list of wide angle 35 mm lens types.

FIG. **5** is a flow chart of the digital corrective process.

FIG. **6** is a schematic diagram of different types of optical aberrations in different configurations of the same lens.

FIG. **7** is a flow chart of the process of digital image capture, processing and storage.

FIG. **8** is a flow chart illustrating the process of selecting filtration settings.

FIG. **9** is a pair of diagrams showing the varied depth of field optimization at different apertures.

FIG. **10** is a flow chart showing exposure optimization using digital correction in camera.

FIG. **11** is a flow chart illustrating the use of in-camera special effects filtration.

FIG. **12** is a flow chart showing the selective in-camera filtration of specific objects.

FIG. **13** is a flow chart describing the exposure adjustment of an image using in-camera filtration.

FIG. **14** is a flow chart showing the process of in-camera special effects filtration.

FIG. **15** is a flow chart showing the process of in-camera digital correction for sensor dust.

FIG. **16** is a diagram showing a digital camera with an ASIC array.

FIG. **17** is a diagram illustrating a digital camera with interchangeable CCD and CMOS sensors.

FIG. **18** is a diagram of a digital camera with a nano-grid before the sensor.

FIG. **19** is a diagram of a nano-grid.

FIG. **20** is a diagram showing the feedback loop connecting the processor and the nano-grid.

FIG. **21** is a diagram illustrating the tri-pixel architecture in a digital sensor.

FIG. **22** is a flow chart showing the pre-programmed modules for in-camera functionality.

FIG. **23** is a diagram showing the pre-sensor modification process in a digital camera.

FIG. **24** is a flow chart showing the integration of optical and digital corrections with feedback.

FIG. **25** is a flow chart showing the interactive feedback mechanism of integrated corrections.

FIG. **26** is a flow chart describing the adaptive user pattern learning process to process images.

FIG. **27** is a flow chart describing the feedback process in filtering images.

FIG. **28** is a flow chart showing software privacy function in a digital imaging system.

FIG. **29** is a flow chart showing the dynamics of zoom lens corrections in digital imaging.

FIG. **30** is a diagram illustrating object tracking in dynamic changes in video corrections.

FIG. **31** is a flow chart showing object tracking of a digital imaging system.

FIG. **32** is a flow chart showing the caching process of an object in motion in a stationary scene.

FIG. **33** is a diagram showing network coordination of fixed sensor grid tracking multiple objects.

FIG. **34** is a diagram showing the wireless communication features of the digital imaging system.

FIG. **35** is a flow chart showing an image organization system.

DETAILED DESCRIPTION OF THE INVENTION

(I) Digital Filters to Correct Optical and Digital Aberrations

(1) Lens-Specific Digital Correction of Fixed Focal-Length Lens for Specific Optical Aberrations in Camera.

Each lens has some sort of aberrations because of the trade-offs involved in producing lenses of usable size and practical commercial cost. The challenge of building lenses for SLR camera systems lies in accounting for particular restrictions and compromises, particularly for wide-angle and zoom lenses. In the case of wide-angle fixed focal length lenses, several main kinds of aberrations occur, including spherical aberration, distortion (pin cushion distortion and barrel distortion), astigmatism, curvature of field (manifesting as the reduced corner exposure of vignetting) and comatic aberration (a distortion evident with long exposures). The extremes of each of these aberrations have to be corrected in post-production.

In the case of vignetting, a type of aberration in which the corners of an image are exposed a stop less than the image's center area, software can digitally emulate a center-neutral density filter to compensate for the light fall-off on the edges. This operation identifies the degree of light fall-off for each specific lens and adjusts the brighter areas in the center of the lens by appropriate exposure compensation. A consequence of this digital equivalent of the traditional optical solution to vignetting is that the image will require exposure metering of the subject at a level consistent with the outside edges of the image rather than the typical inner section. In the present system, the camera will use pre-set calculations compensating (generally one stop) for the specific gradations of the curvature of the field for each lens, with an increasing compensation correlated to an increased angle of view. Similarly, barrel distortion and pin-cushion distortion, which also manifest in image corners, are corrected using processes of employing pre-set calculations, to compensate for optical distortion, particularly in wide-angle and zoom lenses.

In addition to integrating into the camera the traditional process of image correction for exposure gradations of vignetting, the present invention offers two further embodiments. First, instead of darkening the center to match the darker corners, the in-camera digital compensation system will lighten the corners to match the exposure of the center of the image. In the second embodiment, the in-camera digital compensation system will both lighten the corners somewhat and darken the center of the image somewhat, to produce a more pleasing and realistic effect. The in-camera digital corrections of the vignetting problem dramatically improve the traditional optical solution of a center-weighted neutral density filter, which typically degrades image quality as it evenly illuminates the full image.

Since each lens has specific aberrations, depending on manufacturer and even differences in the specimens themselves, the camera software system will have preprogrammed general corrections for each specific lens type. For instance, while a 20 mm f2.8 lens varies among manufacturers, the general optical aberrations will be similar. An effective software solution is one which brings the optical image quality to a level consistent with a benchmark as measured by low MTF curves for each lens in its class in terms of both resolution and contrast throughout the image. To exemplify this benchmark, retrofocus rangefinder lens performance results of wide-angle lenses, which lack a shutter mechanism to design around, can be used for comparison. To accommodate the mirror in the SLR design type, the rear nodal point in SLR lenses are shifted forward, creating distortion. In contrast, the present system suggests applying a digital solution to compensate for this problem.

In a general sense, this process of correction is similar to correcting an ocular astigmatism with reading glasses. However, rather than using an optical solution to an ocular problem, the present system reveals a digital solution to an optical problem.

In the process, the camera identifies a specific lens and refers to a database that matches the lens type with the specific aberrations. The aberrations are consistent throughout all images for each formula of a specific prime lens type and are thus corrected by adjusting for each specific aberration category. Generally, the larger the angle of view of a lens, the greater the distortion and the greater the need for in-camera digital corrections.

In addition to the kinds of distortions created in wide-angle lenses, other types of distortion occur primarily in large aperture telephoto lenses, most notably chromatic aberrations that require apochromatic corrections. Rather than employing large, heavy and expensive extra dispersion glass, such as fluorite elements, the present system allows each lens type to be digitally corrected for these types of aberrations. The in-camera digital process works by identifying a specific lens and comparing the lens pattern to an internal database. Mathematical calculations compensate for the shift in red and green light that apochromatic corrections require for very low