AO 120 (Rev. 08/10)

TO:	REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK
Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450	

In Compliance with 35 U.S.C. § 290 and/or 15 U.S.C. § 1116 you are hereby advised that a court action has been filed in the U.S. District Court for the Western District of Washington on the following

☐ Trademarks or ☑ Patents. (☐ the patent action involves 35 U.S.C. § 292.):

DOCKET NO.	DATE FILED	U.S. DISTRICT COURT
2:22-cv-00942	7/7/2022	for the Western District of Washington

PLAINTIFF	DEFENDANT
Reald Spark, LLC	Microsoft Corporation

	PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1	10,740,985 B2	August 11, 2020	RealD Spark, LLC
2			
3			
4			
5			

In the above—entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY ☐ Amendment ☐ Answer ☐ Cross Bill ☐ Other Pleading	
PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1		
2		
3		
4		
5		

In the above—entitled case, the following decision has been rendered or judgement issued:

DECISION/JUDGEMENT

CLERK	(BY) DEPUTY CLERK	DATE
Ravi Subramanian	Sherri Tye	7/11/2022

Copy 1—Upon initiation of action, mail this copy to Director Copy 3—Upon termination of action, mail this copy to Director
Copy 2—Upon filing document adding patent(s), mail this copy to Director Copy 4—Case file copy

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.
16/057,566	08/11/2020	10740985	409001	5211

145234 7590 07/22/2020

RealD Spark, LLC
9777 Wilshire Blvd.
Suite 400
Beverly Hills, CA 90212

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):

Eric Sommerlade, Oxford, UNITED KINGDOM;
RealD Spark, LLC, Beverly Hills, CA;
Alexandros Neophytou, Oxford, UNITED KINGDOM;

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.

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)

145234 7590 04/01/2020

RealD Spark, LLC
9777 Wilshire Blvd.
Suite 400
Beverly Hills, CA 90212

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.

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

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/057,566	08/07/2018	Eric Sommerlade	409001	5211

TITLE OF INVENTION: Adjusting a digital representation of a head region

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	$0.00	$500	07/01/2020

EXAMINER	ART UNIT	CLASS-SUBCLASS
PRINGLE-PARKER, JASON A	2618	345-428000

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 Penny L. Lowry
2 Neil G.J. Mothew
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: RealD Spark, LLC

(B) RESIDENCE: (CITY and STATE OR COUNTRY): Beverly Hills, CA

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 /Penny L. Lowry/ Date July 1, 2020

Typed or printed name Penny L. Lowry Registration No. 57186

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

Microsoft Exhibit 1002 - Page 3
Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

Electronic Patent Application Fee Transmittal

Application Number:	16057566
Filing Date:	07-Aug-2018
Title of Invention:	Adjusting a digital representation of a head region
First Named Inventor/Applicant Name:	Eric Sommerlade
Filer:	Penny Lea Lowry/Kristal Veliz
Attorney Docket Number:	409001

Filed as Small Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
UTILITY APPL ISSUE FEE	2501	1	500	500

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**500**

Electronic Acknowledgement Receipt	
EFS ID:	39886638
Application Number:	16057566
International Application Number:	
Confirmation Number:	5211
Title of Invention:	Adjusting a digital representation of a head region
First Named Inventor/Applicant Name:	Eric Sommerlade
Customer Number:	145234
Filer:	Penny Lea Lowry/Kristal Veliz
Filer Authorized By:	Penny Lea Lowry
Attorney Docket Number:	409001
Receipt Date:	01-JUL-2020
Filing Date:	07-AUG-2018
Time Stamp:	14:22:49
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	DA
Payment was successfully received in RAM	$500
RAM confirmation Number	E202071E23027141
Deposit Account	
Authorized User	
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Issue Fee Payment (PTO-85B)	409001_Issue_Fee_Transmittal.pdf	265761 d438bfa7dd77d5cd105058e85a19c5754b0ead83	no	1
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	29975 fd7bd9e401f443bf103680526cea9a71b906a4d8	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	295736		

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.

PTO/AIA/01 (08-12)
Approved for use through 01/31/2014. OMB 0651-0032
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.

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention	Adjusting a digital representation of a head region

As the below named inventor, I hereby declare that:

This declaration is directed to:

- ☐ The attached application, or
- ■ United States application or PCT international application number 16/057566 filed on August 7, 2018

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

LEGAL NAME OF INVENTOR

Inventor: Eric Sommerlade Date (Optional): 24. Mar. 2020

Signature: _____

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. 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 1.11 and 1.14. This collection is estimated to take 1 minute 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.

PTO/AIA/01 (06-12)
Approved for use through 01/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office, U.S. DEPARTMENT OF COMMERCE
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- ☐ The attached application, or
- ■ United States application or PCT international application number 16/057566 filed on August 7, 2018.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

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LEGAL NAME OF INVENTOR

Inventor: Alexandros Neophytou Date (Optional): _____

Signature: _____

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

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

Electronic Acknowledgement Receipt

EFS ID:	39042677
Application Number:	16057566
International Application Number:	
Confirmation Number:	5211
Title of Invention:	Adjusting a digital representation of a head region
First Named Inventor/Applicant Name:	Eric Sommerlade
Customer Number:	145234
Filer:	Penny Lea Lowry/Stefan Bump
Filer Authorized By:	Penny Lea Lowry
Attorney Docket Number:	409001
Receipt Date:	02-APR-2020
Filing Date:	07-AUG-2018
Time Stamp:	11:56:08
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	Oath or Declaration filed	409001_Declarations_X.pdf	1399896 713d6c7a1a6be283df1c83fb4ae544eeb4177566	no	2

Warnings:

Information:	
Total Files Size (in bytes):	1399896

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New Applications Under 35 U.S.C. 111

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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

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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

145234 7590 04/01/2020

RealD Spark, LLC
9777 Wilshire Blvd.
Suite 400
Beverly Hills, CA 90212

EXAMINER	
PRINGLE-PARKER, JASON A	
ART UNIT	PAPER NUMBER
2618	

DATE MAILED: 04/01/2020

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/057,566	08/07/2018	Eric Sommerlade	409001	5211

TITLE OF INVENTION: Adjusting a digital representation of a head region

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	$0.00	$500	07/01/2020

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.

Microsoft Exhibit 1002 - Page 12
Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

PART B - FEE(S) TRANSMITTAL

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

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

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

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

145234 7590 04/01/2020

RealD Spark, LLC
9777 Wilshire Blvd.
Suite 400
Beverly Hills, CA 90212

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.
16/057,566	08/07/2018	Eric Sommerlade	409001	5211

TITLE OF INVENTION: Adjusting a digital representation of a head region

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
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EXAMINER	ART UNIT	CLASS-SUBCLASS
PRINGLE-PARKER, JASON A	2618	345-428000

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. _____

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

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.
16/057,566	08/07/2018	Eric Sommerlade	409001	5211

145234 7590 04/01/2020

RealD Spark, LLC
9777 Wilshire Blvd.
Suite 400
Beverly Hills, CA 90212

EXAMINER	
PRINGLE-PARKER, JASON A	
ART UNIT	PAPER NUMBER
2618	

DATE MAILED: 04/01/2020

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)

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Notice Requiring Inventor's Oath or Declaration	Application No. 16/057,566	Applicant(s) Eric Sommerlade	
	Examiner PRINGLE-PARKER, JASON A	Art Unit 2618	

This notice is an attachment to the Notice of Allowability (PTOL-37), or the Notice of Allowability For A Design Application (PTOL-37D).

An inventor's oath or declaration in compliance with 37 CFR 1.63 or 1.64 executed by or with respect to each inventor has not yet been submitted.

An oath or declaration in compliance with 37 CFR 1.63, or a substitute statement in compliance with 37 CFR 1.64, executed by or with respect to each inventor (for any inventor for which a compliant oath, declaration, or substitute statement has not yet been submitted) MUST be filed no later than the date on which the issue fee is paid. See 35 U.S.C. 115(f). Failure to timely comply will result in ABANDONMENT of this application.

A properly executed inventor's oath to declaration has not been received for the following inventor(s):

If applicant previously filed one or more oaths, declarations, or substitute statements, applicant may have received an informational notice regarding deficiencies therein.

The following deficiencies are noted:

INFORMAL ACTION PROBLEMS

- A properly executed inventor's oath or declaration has not been received for the following inventor(s): **Eric Sommerlade** and **Alexandros Neophytou**.
  Applicant may submit the inventor's oath or declaration at any time before the Notice of Allowance and Fee(s) Due, PTOL-85, is mailed.

Questions relating to this Notice should be directed to the Application Assistance Unit at 571-272-4200.

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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. 16/057,566	Applicant(s) Sommerlade et al.	
	Examiner JASON A PRINGLE-PARKER	Art Unit 2618	AIA (FITF) Status Yes

-- 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 2/21/20.
   ☐ 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 1,3-12,18,27,32-33,37-39 and 144 . 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 _____.

/JASON A PRINGLE-PARKER/
Primary Examiner, Art Unit 2618

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/057,566	Sommerlade et al.
	Examiner	Art Unit
	JASON A PRINGLE-PARKER	2618

CPC - Searched*		
Symbol	Date	Examiner

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner

* 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
Inventor	11/19/2019	JP
EAST	11/19/2019	JP
Google/Google Scholar (see EAST terms)	03/19/2020	JP
EAST	03/19/2020	JP
Interference	03/19/2020	JP

Interference Search			
US Class/CPC Symbol	US Subclass/CPC Group	Date	Examiner
	See search history	03/19/2020	JP

/JASON A PRINGLE-PARKER/ Primary Examiner, Art Unit 2618	

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IPR2023-01046 - U.S. Patent No. 10,740,985

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/057,566	Sommerlade et al.
	Examiner	**Art Unit**
	JASON A PRINGLE-PARKER	2618

CPC							
Symbol						**Type**	**Version**
G06T	/	19	/	20		F	2013-01-01
G06T	/	7	/	337		I	2017-01-01
G06N	/	3	/	0454		I	2013-01-01
G06N	/	3	/	08		I	2013-01-01
G06T	/	2207	/	20081		A	2013-01-01
G06T	/	2219	/	2004		A	2013-01-01
G06T	/	2219	/	2012		A	2013-01-01
G06T	/	2219	/	2021		A	2013-01-01

CPC Combination Sets								
Symbol						**Type**	**Set**	**Ranking**	**Version**
	/		/						

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	19	
/JASON A PRINGLE-PARKER/ Primary Examiner, Art Unit 2618	19 March 2020	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1

U.S. Patent and Trademark Office — Part of Paper No.: 20200319

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IPR2023-01046 - U.S. Patent No. 10,740,985

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/057,566	Sommerlade et al.
	Examiner	**Art Unit**
	JASON A PRINGLE-PARKER	2618

INTERNATIONAL CLASSIFICATION				
CLAIMED				
G06T19/20	/	19	/	20
G06T7/33	/	7	/	33
G06N3/04	/	3	/	04
G06N3/08	/	3	/	08
CPCONLY	/	NLY	/	

NON-CLAIMED				
	/		/	

US ORIGINAL CLASSIFICATION	
CLASS	**SUBCLASS**

CROSS REFERENCES(S)						
CLASS	**SUBCLASS (ONE SUBCLASS PER BLOCK)**					

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	19	
/JASON A PRINGLE-PARKER/ Primary Examiner, Art Unit 2618	19 March 2020	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1

U.S. Patent and Trademark Office — Part of Paper No.: 20200319

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IPR2023-01046 - U.S. Patent No. 10,740,985

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/057,566	Sommerlade et al.
	Examiner	**Art Unit**
	JASON A PRINGLE-PARKER	2618

☐ 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	1	9	10		19		28	17	37						
	2	10	11		20		29	18	38						
2	3	11	12		21		30	19	39						
3	4		13		22		31								
4	5	12	14		23	14	32								
5	6		15		24	16	33								
6	7		16		25		34								
7	8		17		26		35								
8	9	13	18	15	27		36								

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	19	
/JASON A PRINGLE-PARKER/ Primary Examiner, Art Unit 2618	19 March 2020	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	1

U.S. Patent and Trademark Office — Part of Paper No.: 20200319

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EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	1	input ADJ2 patch WITH target ADJ2 feature	US-PGPUB; USPAT	OR	ON	2020/03/19 10:44
L2	0	interativ$4 WITH render$4 WITH algorithm	US-PGPUB; USPAT	OR	ON	2020/03/19 10:44
L3	186	iterativ$4 WITH render$4 WITH algorithm	US-PGPUB; USPAT	OR	ON	2020/03/19 10:44
L4	31	reference ADJ2 data WITH compress$4 ADJ2 representat$4	US-PGPUB; USPAT	OR	ON	2020/03/19 10:59
L5	95	first ADJ2 neural ADJ2 network WITH algorithm SAME second ADJ2 neural ADJ2 network	US-PGPUB; USPAT	OR	ON	2020/03/19 11:00
L6	31	("20020013691" | "20030197779" | "20030218672" | "20050053274" | "20070019882" | "20070244606" | "20110199460" | "20120105486" | "20120219180" | "20120223956" | "20120236133" | "20130070046" | "20130076853" | "20130163659" | "20140016871" | "20140267584" | "20150077526" | "20150269737" | "20150339512" | "20160125227" | "20160196465" | "20170134720" | "20170364149" | "20180035886" | "6283858" | "9224060" | "9224248" | "9378574" | "9740282" | "9872007" | "9986812").PN.	US-PGPUB; USPAT	OR	ON	2020/03/19 11:01
S1	1	"16057566"	US-PGPUB; USPAT	OR	ON	2019/11/08 10:41
S2	16	((("SOMMERLADE") near3 ("Eric")) OR (("NEOPHYTOU") near3 ("Alexandros"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2019/11/08 10:41
S3	16	((("SOMMERLADE") near3 ("Eric")) OR (("NEOPHYTOU") near3 ("Alexandros"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2019/11/08 10:41
S4	697	real ADJ2 time SAME (eye OR gaze) SAME (meeting OR conferenc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 11:09
S5	35	real ADJ2 time SAME (eye OR gaze) WITH	US-	OR	ON	2019/11/08

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		(chang$4 OR adjust$4 OR modify$4) SAME (meeting OR conferenc$4)	PGPUB; USPAT			11:10
S6	1214	(head OR face) AND input ADJ2 patch	US-PGPUB; USPAT	OR	ON	2019/11/08 11:43
S7	169	(head OR face) AND input ADJ2 patch SAME output ADJ2 patch	US-PGPUB; USPAT	OR	ON	2019/11/08 11:43
S8	0	("2017/0195662").URPN.	USPAT	OR	ON	2019/11/08 11:44
S9	14	("2013/0076853").URPN.	USPAT	OR	ON	2019/11/08 11:47
S10	29	("2012/0223956").URPN.	USPAT	OR	ON	2019/11/08 11:57
S11	4	("20050147955" | "20060239591" | "20120223956" | "7392204").PN. OR ("9378574").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 11:59
S12	5014	real ADJ2 time SAME (cosmetic OR make ADJ2 up)	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 11:59
S13	1280	real ADJ2 time WITH (cosmetic OR make ADJ2 up)	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 11:59
S14	304	S13 AND ((G06F17/5009 OR G06F16/54 OR G06F9/5072 OR G06F3/011 OR G06F16/258 OR G06F3/04817 OR G06F3/0482 OR G06F11/1441 OR G06F11/1474 OR G06F16/164 OR G06F16/168 OR G06F16/25 OR G06F16/29 OR G06F16/444 OR G06F17/11 OR G06F17/50 OR G06F17/5036 OR G06F1/3265 OR G06F2009/4557 OR G06F2009/45591 OR G06F2009/45595 OR G06F2201/805 OR G06F2201/85 OR G06F2217/78 OR G06F3/013 OR G06F3/015 OR G06F3/016 OR G06F3/04812 OR G06F3/04815 OR G06F3/0484 OR G06F3/04842 OR G06F3/04845 OR G06F3/04847 OR G06F3/0485 OR G06F3/0487 OR G06F3/12 OR G06F8/30 OR G06F8/38 OR G06F9/453 OR G06F9/45558 OR G06F9/4856 OR G06F9/505 OR G06F9/5077 OR G06F9/5083 OR G06F9/5088 OR G06F9/541 OR G06F9/547 OR G06T19/20 OR G06T2207/30201 OR G06T13/40 OR G06T15/005 OR G06T15/04 OR G06T17/10 OR G06T17/20 OR G06T11/60 OR G06T19/006 OR G06T2210/16 OR G06T7/11 OR G06T7/90 OR G06T17/205 OR G06T1/0007 OR G06T19/00 OR G06T19/003 OR G06T2207/10024 OR G06T2215/16 OR G06T3/40 OR G06T7/251 OR G06T7/73 OR G06T11/00 OR G06T11/001 OR G06T11/40 OR G06T15/02 OR G06T15/10 OR G06T15/80 OR G06T17/00 OR G06T17/05 OR	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 12:00

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		G06T2200/24 OR G06T2207/10016 OR G06T2207/10021 OR G06T2207/20081 OR G06T2207/20221 OR G06T2207/30088 OR G06T2210/32 OR G06T2210/36 OR G06T2219/2004 OR G06T2219/2016 OR G06T7/0012 OR G06T7/0014 OR G06T7/174 OR G06T7/40 OR G06T7/55 OR G06T7/75).CPC.)				
S15	2	"20160125227"	US-PGPUB; USPAT	OR	ON	2019/11/08 12:17
S16	41	real ADJ2 time WITH (cosmetic OR make ADJ2 up) AND machine ADJ2 learning AND (neural ADJ2 network OR vector ADJ2 machine OR adversarial)	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 12:47
S17	6738	compressed ADJ2 representation	US-PGPUB; USPAT	OR	ON	2019/11/08 13:59
S18	1	regression ADJ2 fern WITH cluster ADJ2 centre	US-PGPUB; USPAT	OR	ON	2019/11/08 14:01
S19	4	regression ADJ2 fern	US-PGPUB; USPAT	OR	ON	2019/11/08 14:01
S20	182	machine ADJ2 learning WITH look ADJ2 up ADJ2 table	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 14:04
S21	38768	compress$4 WITH instructions	US-PGPUB; USPAT	OR	ON	2019/11/08 14:15
S22	6045	S21 AND ((G06F3/067 OR G06F3/0659 OR G06F3/0631 OR G06F3/0653 OR G06F12/1408 OR G06F3/0608 OR G06F3/061 OR G06F3/0619 OR G06F3/064 OR G06F3/0647 OR G06F3/0665 OR G06F3/0673 OR G06F3/0679 OR G06F3/0683 OR G06F3/0689 OR G06F9/3887 OR G06F9/4401 OR G06F9/5072 OR G06F11/141 OR G06F11/3414 OR G06F12/0862 OR G06F12/0893 OR G06F12/10 OR G06F12/109 OR G06F13/161 OR G06F13/1668 OR G06F13/1694 OR G06F13/4022 OR G06F13/4068 OR G06F13/409 OR G06F13/42 OR G06F13/4282 OR G06F15/8061 OR G06F16/182 OR G06F16/9014 OR G06F17/16 OR G06F1/183 OR G06F21/602 OR G06F2207/4824 OR G06F2209/5019 OR G06F2209/5022 OR G06F2212/1008 OR G06F2212/1024 OR G06F2212/1041 OR G06F2212/1044 OR G06F2212/152 OR G06F2212/202 OR G06F2212/401 OR G06F2212/402 OR G06F2212/7207 OR G06F3/0482 OR G06F3/0604 OR G06F3/0611 OR G06F3/0613 OR G06F3/0616 OR G06F3/0625 OR G06F3/0629 OR G06F3/0638 OR G06F3/0643 OR G06F3/0644 OR	US-PGPUB; USPAT	OR	ON	2019/11/08 14:16

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IPR2023-01046 - U.S. Patent No. 10,740,985

		G06F3/065 OR G06F3/0655 OR G06F3/0658 OR G06F3/0664 OR G06F3/0688 OR G06F8/65 OR G06F9/30021 OR G06F9/30036 OR G06F9/466 OR G06F9/5016 OR G06F9/5044 OR G06F9/505 OR G06F9/5077 OR G06F9/544 OR G06F11/10 OR G06F11/1469 OR G06F11/3664 OR G06F11/3688 OR G06F11/3692 OR G06F16/221 OR G06F16/2282 OR G06F16/2322 OR G06F16/24578 OR G06F16/252 OR G06F16/258 OR G06F16/27 OR G06F16/285 OR G06F16/743 OR G06F16/904 OR G06F16/9577 OR G06F17/18 OR G06F17/2247 OR G06F17/2252 OR G06F17/2288 OR G06F17/5036 OR G06F1/20 OR G06F1/3231 OR G06F2009/45579 OR G06F2009/45583 OR G06F21/36 OR G06F21/60 OR G06F21/604 OR G06F21/606 OR G06F21/6245 OR G06F21/6272 OR G06F21/629 OR G06F2201/805 OR G06F2212/1052 OR G06F3/0605 OR G06F3/0626 OR G06F3/0634 OR G06F3/0635 OR G06F3/0641 OR G06F3/0652 OR G06F3/0661 OR G06F3/0685 OR G06F7/483 OR G06F7/4876 OR G06F8/4441 OR G06F8/61 OR G06F8/654 OR G06F8/658 OR G06F8/71 OR G06F9/30025 OR G06F9/30032 OR G06F9/3004 OR G06F9/30043 OR G06F9/30072 OR G06F9/30079 OR G06F9/30087 OR G06F9/30181 OR G06F9/3834 OR G06F9/3857 OR G06F9/45558 OR G06F9/50 OR G06F9/5027 OR G06F9/52 OR G06T9/00 OR G06T1/0007 OR G06T1/60 OR G06T2207/10036 OR G06T2207/20021 OR G06T2207/20024 OR G06T7/223).CPC.)				
S23	2979	compress$4 WITH instructions SAME (reduc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 14:28
S24	1596	compress$4 WITH instructions WITH (reduc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 14:29
S25	324	compress$4 ADJ4 instructions WITH (reduc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 14:29
S26	1	compress$4 ADJ4 instructions WITH (reduc$4) AND machine ADJ2 learning	US-PGPUB; USPAT	OR	ON	2019/11/08 14:30

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L7	20	((("SOMMERLADE") near3 ("Eric")) OR (("NEOPHYTOU") near3 ("Alexandros"))).INV.	US-PGPUB; USPAT	OR	ON	2020/03/19 11:03
L8	44	real ADJ2 time WITH (cosmetic OR make ADJ2	US-	OR	ON	2020/03/19

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

		up) AND machine ADJ2 learning AND (neural ADJ2 network OR vector ADJ2 machine OR adversarial)	PGPUB; USPAT			11:04
L9	31	reference ADJ2 data WITH compress$4 ADJ2 representat$4	US-PGPUB; USPAT	OR	ON	2020/03/19 11:04
L10	95	first ADJ2 neural ADJ2 network WITH algorithm SAME second ADJ2 neural ADJ2 network	US-PGPUB; USPAT	OR	ON	2020/03/19 11:04

3/19/2020 11:07:01 AM
C:\Users\jparker4\Documents\EAST\Workspaces\16\16057566.wsp

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

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

PTO/SB/08a (02-18)
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT
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Application Number	16057566
Filing Date	2018-08-07
First Named Inventor	Eric Sommerlade
Art Unit	2618
Examiner Name	PRINGLE-PARKER, JASON A.
Attorney Docket Number	409001

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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	6283858	B1	2001-09-04	Hayes Jr. et al.	Entire Document
	2	9224060	B1	2015-12-29	Ramaswamy	Entire Document
	3	9224248	B2	2015-12-29	Ye et al.	Entire Document
	4	9378574	B2	2016-06-28	Kim et al.	Entire Document
	5	9740282	B1	2017-08-22	McInerny	Entire Document
	6	9872007	B2	2018-01-16	Woodgate et al.	Entire Document
	7	9986812	B2	2018-06-05	Yamanashi et al.	Entire Document

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	1	20020013691	A1	2002-01-31	Warnes	Entire Document
	2	20030197779	A1	2003-10-23	Zhang et al.	Entire Document
	3	20030218672	A1	2003-11-27	Zhang et al.	Entire Document
	4	20050053274	A1	2005-03-10	Mayer et al.	Entire Document
	5	20070019882	A1	2007-01-25	Tanaka et al.	Entire Document
	6	20070244606	A1	2007-10-18	Zhang et al.	Entire Document
	7	20110199460	A1	2011-08-18	Gallagher	Entire Document
	8	20120105486	A1	2012-05-03	Lankford et al.	Entire Document
	9	20120219180	A1	2012-08-30	Mehra	Entire Document
	10	20120223956	A1	2012-09-06	Saito et al.	Entire Document

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	11	20120236133	A1	2012-09-20	Gallagher	Entire Document
	12	20130070046	A1	2013-03-21	Wolf et al.	Entire Document
	13	20130076853	A1	2013-03-28	Diao	Entire Document
	14	20130163659	A1	2013-06-27	Sites	Entire Document
	15	20140016871	A1	2014-01-16	Son et al.	Entire Document
	16	20140267584	A1	2014-09-18	ATZPADIN et al.	Entire Document
	17	20150077526	A1	2015-03-19	Kim et al.	Entire Document
	18	20150269737	A1	2015-09-24	LAM et al.	Entire Document
	19	20150339512	A1	2015-11-26	Son et al.	Entire Document
	20	20160125227	A1	2016-05-05	Soare et al.	Entire Document
	21	20160196465	A1	2016-07-07	Wu et al.	Entire Document

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	22	20170134720	A1	2017-05-11	Park et al.	Entire Document
	23	20170364149	A1	2017-12-21	Lu et al.	Entire Document
	24	20180035886	A1	2018-02-08	COURTEMANCHE et al.	Entire Document

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Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2]	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	2007109255	JP	A	2007-04-26	Agostino et al.	Entire Document	
	2	2011148366	WO	A1	2011-12-01	Wolf et al.	Entire Document	
	3	2016132148	WO	A1	2016-08-25	WANG et al.	Entire Document	

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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	EP-17736268.8 European Extended Search Report of European Patent Office dated July 12, 2019.	

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	2	GANIN et al., "DeepWarp: Photorealistic Image Resynthesis for Gaze Manipulation", 2016-07-25, XP055295123, Retrieved from Internet: URL: http://arxiv.org/pdf/1607.07215v2.pdf (retreived on 2018-01-10].	
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	4	International Preliminary Report on Patentability dated Spetember 26, 2017 in International Patent Application No. PCT/RU2016/000118.	
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	9	XIONG et al., "Supervised descent method and its applications to face alignment", In Computer Vision Pattern Recognition (CVPR), 2013 IEEE Conference, pgs. 532-539.	
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	11	YIP, "Face and Eye Rectification in Video Conference Using Artificial Neural Network", IEEE International Conference on Multimedia and Expo, 2005, pgs. 690-693.	

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

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	Art Unit	2618
	Examiner Name	PRINGLE-PARKER, JASON A.
	Attorney Docket Number	409001

EXAMINER SIGNATURE			
Examiner Signature	/JASON A PRINGLE-PARKER/	Date Considered	03/19/2020

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	Examiner Name	PRINGLE-PARKER, JASON A.
	Attorney Docket Number	409001

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).

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☐ 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	/Charles Yang/	Date (YYYY-MM-DD)	2020-03-05
Name/Print	Charles Yang	Registration Number	62059

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.**

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

Bibliographic Data

Application No: 16/057,566

Foreign Priority claimed: ○ Yes ◉ No

35 USC 119 (a-d) conditions met: ☐ Yes ☑ No ☐ Met After Allowance

Verified and Acknowledged: /JASON A PRINGLE-PARKER/ (Examiner's Signature) | (Initials)

Title: Adjusting a digital representation of a head region

FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
08/07/2018	345	2618	409001
RULE			

APPLICANTS

RealD Spark, LLC, Beverly Hills, CA,

INVENTORS

Eric Sommerlade Oxford, UNITED KINGDOM

Alexandros Neophytou Oxford, UNITED KINGDOM

CONTINUING DATA

This application has PRO of 62543587 08/10/2017

This application has PRO of 62542661 08/08/2017

FOREIGN APPLICATIONS

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08/24/2018

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RealD Spark, LLC
9777 Wilshire Blvd.
Suite 400
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UNITED STATES

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	3	9224248	B2	2015-12-29	Ye et al.	Entire Document
	4	9378574	B2	2016-06-28	Kim et al.	Entire Document
	5	9740282	B1	2017-08-22	McInerny	Entire Document
	6	9872007	B2	2018-01-16	Woodgate et al.	Entire Document
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	6	20070244606	A1	2007-10-18	Zhang et al.	Entire Document
	7	20110199460	A1	2011-08-18	Gallagher	Entire Document
	8	20120105486	A1	2012-05-03	Lankford et al.	Entire Document
	9	20120219180	A1	2012-08-30	Mehra	Entire Document
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	Filing Date	2018-08-07
	First Named Inventor	Eric Sommerlade
	Art Unit	2618
	Examiner Name	PRINGLE-PARKER, JASON A.
	Attorney Docket Number	409001

	22	20170134720	A1	2017-05-11	Park et al.	Entire Document
	23	20170364149	A1	2017-12-21	Lu et al.	Entire Document
	24	20180035886	A1	2018-02-08	COURTEMANCHE et al.	Entire Document

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Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2]	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	2007109255	JP	A	2007-04-26	Agostino et al.	Entire Document	
	2	2011148366	WO	A1	2011-12-01	Wolf et al.	Entire Document	
	3	2016132148	WO	A1	2016-08-25	WANG et al.	Entire Document	

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	1	EP-17736268.8 European Extended Search Report of European Patent Office dated July 12, 2019.	

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
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	2	GANIN et al., "DeepWarp: Photorealistic Image Resynthesis for Gaze Manipulation", 2016-07-25, XP055295123, Retrieved from Internet: URL: http://arxiv.org/pdf/1607.07215v2.pdf (retreived on 2018-01-10].	
	3	GIGER et al., "Gaze Correction with a Single Webcam", Proceedings of IEEE ICME 2014 (Chengdu, China, July 14-18, 2014).	
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	5	International Search Report and Written Opinion dated April 18, 2017 in International Patent Application No PCT/US17/12203.	
	6	International Search Report and Written Opinion dated August 25, 2016 in International Patent Application No. PCT/RU2016/000118.	
	7	REN et al., "Face alignment at 3000 fps via regressing local binary features", CVPR, pgs. 1685-1692, 2014.	
	8	SMITH et al., "Gaze locking: passive eye contact detection for human-object interaction. In Proceedings of the 26th annual ACM Symposium on User interface software and technology, pgs. 271-280, ACM 2013.	
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	11	YIP, "Face and Eye Rectification in Video Conference Using Artificial Neural Network", IEEE International Conference on Multimedia and Expo, 2005, pgs. 690-693.	

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16057566
	Filing Date	2018-08-07
	First Named Inventor	Eric Sommerlade
	Art Unit	2618
	Examiner Name	PRINGLE-PARKER, JASON A.
	Attorney Docket Number	409001

EXAMINER SIGNATURE			
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99)**		
	Application Number	16057566
	Filing Date	2018-08-07
	First Named Inventor	Eric Sommerlade
	Art Unit	2618
	Examiner Name	PRINGLE-PARKER, JASON A.
	Attorney Docket Number	409001

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).

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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	/Charles Yang/	Date (YYYY-MM-DD)	2020-03-05
Name/Print	Charles Yang	Registration Number	62059

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.**

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Bibliographic data: JP2007109255 (A) — 2007-04-26

WAVELET-BASED FACIAL MOTION CAPTURE FOR ANIMATING OBJECT IMPARTED WITH HUMAN APPEARANCE

Inventor(s): MAURER THOMAS; ELAGIN EGOR VALERIEVICH; AGOSTINO NOCERA LUCIANO PASQUA; STEFFENS JOHANNESS BERNHARD; NEVEN HARTMUT ± (MAURER THOMAS, ; ELAGIN EGOR VALERIEVICH, ; AGOSTINO NOCERA LUCIANO PASQUALE, ; STEFFENS JOHANNESS BERNHARD, ; NEVEN HARTMUT)

Applicant(s): EYEMATIC INTERFACES INC ± (EYEMATIC INTERFACES INC)

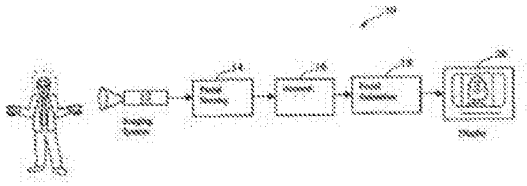
Classification: - international: ***G06K9/00; G06T7/20;*** *G06T17/40*
- cooperative: **G06K9/00228**; **G06K9/00248**; **G06K9/00362**; **G06K9/4619**; **G06K9/469**; **G06T7/246**; **G06T7/262**; G06T2207/20064

Application number: JP20060329956 20061206 Global Dossier

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Also published as: AT248409 (T) AU3639699 (A) BR9909611 (A) BR9909611 (B1) CA2327304 (A1) more

Abstract of JP2007109255 (A)



PROBLEM TO BE SOLVED: To track a natural property of a person without being accompanied by an unnatural element capable of disturbing or blocking the natural property of the person, in a device for detecting motion, a characteristic, and properties or the like of a face of the person, generating an image of an object imparted with human appearance on the basis of detection of the face, and animating it. ;SOLUTION: Image processing technology based on a bunch graph and a model graph efficiently expressing a characteristic of the image as a jet is used. The jet comprises a wavelet transform processed by a landmark location or a node of the image corresponding to the easily identifiable characteristic. The node is acquired and

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tracked, and the object imparted with the human appearance is animated according to the facial motion of the person. In the detection of the face, by finding the characteristic and the properties of the face of the person by use of jet similarity, the natural property of the person can be tracked without being accompanied by the unnatural element capable of disturbing or blocking the natural property of the person. ;COPYRIGHT: (C) 2007,JPO&INPIT

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審査請求 有　請求項の数 1　OL　（全 21 頁）

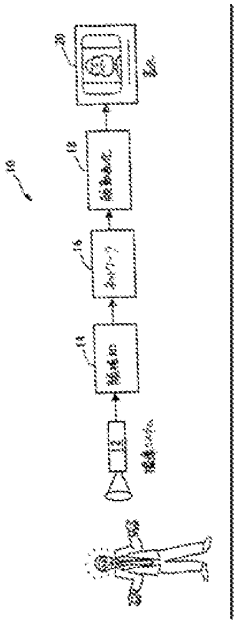
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最終頁に続く

(54)【発明の名称】人間の姿を与えたものを動画化するためのウェーブレットに基づく顔の動きの捕捉

(57)【要約】
【課題】人物の顔の動き、特徴、および特性などを検知し、顔の検知に基づいて、人間の姿を与えたものの画像を生成しかつ動画化するための装置において、人物の自然な特性を、その人物の自然な特性を妨害または阻止し得る不自然な要素を伴なわずに、追跡する。
【解決手段】画像の特徴をジェットとして効率的に表現するモデルグラフおよびバンチグラフに基づいた画像処理技術を用いる。ジェットは、容易に識別可能な特徴に対応する。画像のノードまたはランドマークロケーションで処理されたウェーブレット変換からなる。ノードを獲得し追跡して、人物の顔の動きに従い、人間の姿を与えたものを動画化する。また顔の検知では、ジェット類似度を用いて人物の顔の特徴および特性を求めることにより、人物の自然な特性を、その人物の自然な特性を妨害または阻止し得る不自然な要素を伴なわずに、追跡することができる。
【選択図】図１



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【特許請求の範囲】
【請求項1】
画像フレームのシーケンスに対する特徴検知のための方法であって、
ウェーブレット変換を用いて各画像フレームを変換し、変換された画像フレームを生成するためのステップと、
モデルグラフのノードを、前記変換された画像フレームのロケーションに初期化するためのステップとを含み、各ノードは特徴に特有のウェーブレットジェットに関連し、前記初期化するステップは、前記モデルグラフを前記変換された画像フレームを横切るように動かし、前記モデルグラフを前記変換された画像フレームを横切るように動かす際に求められた前記ノードのウェーブレットジェットと前記変換された画像フレームのロケーションとの間のジェット類似度が最大である前記変換された画像フレームのロケーションに、前記モデルグラフを配置することにより行なわれ、さらに、
画像フレーム間で前記モデルグラフの１以上のノードのロケーションを追跡するためのステップを含み、
前記方法がさらに、追跡されたノードのロケーションを、前記追跡されたノードのロケーションが画像フレーム間の予め定められた位置制約を超えてずれた場合に、再初期化するためのステップを含むことを特徴とする、特徴検知のための方法。

【発明の詳細な説明】
【技術分野】
【0001】
本発明は、動的な顔の特徴の検知に関し、より具体的には、顔の特徴をリアルタイムで発見、追跡、かつ分類して、人の姿を与えたもの（avatar、分身）を動画化するグラフィックスエンジンに入力する、視覚に基づく動き捕捉システムに関する。
【背景技術】
【0002】
仮想空間を人間の姿を与えたもので満たすことは、共有環境を経験できるようにするには魅力的な方法である。しかしながら、一般的に、既存の共有環境では、ユーザを具体化するすなわちユーザの表情またはジェスチャーをそのユーザの分身に与えユーザに似たものにするのに十分な質で顔の特徴は検知されていない。高品質で顔の特徴を検知することは非常に有利である。なぜなら、顔によるジェスチャーは、コミュニケーションの根本的手段であるからである。したがって、ユーザを具体化することによって、仮想空間の魅力は増大する。
【発明の開示】
【発明が解決しようとする課題】
【0003】
典型的に、顔の特徴を検知する既存の方法は、人物の顔に固定されるマーカを用いる。顔の動きを捕捉するためにマーカを使用することは煩わしいもので、一般的にはマーカの使用によって顔の動き捕捉の用途は映画の制作といったコストのかかる応用に限定されてきた。
【0004】
したがって、現在非常に必要なのは、好都合でかつ効率的な顔の特徴検知を実現する、視覚に基づく動き捕捉システムである。本発明はこの必要を満たす。
【課題を解決するための手段】
【0005】
本発明は、人物の顔の動き、特徴または特性を検知するための装置および関連の方法において実施される。顔の検知の結果を用いて、人間の姿を与えたもの（分身）の画像を動画化することができる。この分身装置は、モデルグラフおよびバンチグラフに基づく画像処理技術を使用する。このモデルグラフおよびバンチグラフは、画像の特徴を、容易に識別可能な特徴に対応する顔の画像のランドマークにおけるウェーブレット変換からなるジェットとして、効率的に表現する。この検知システムにより、ある人物の自然な特性を、

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その人物の自然な特性を妨害する不自然な要素を伴なわずに追跡することができる。
【0006】
特徴検知プロセスは、画像フレームのシーケンスに対して働き、ウェーブレット変換を用いて各画像フレームを変換し、変換された画像フレームを生成する。変換された画像フレームへの、モデルグラフのウェーブレットジェットに関連するノードロケーションの初期化は、モデルグラフを変換された画像フレームを横切るように動かし、モデルグラフを、ノードロケーションのウェーブレットジェットと変換された画像フレームとの間のジェット類似度が最大である、変換された画像フレームにおけるあるロケーションに配置することによって行なわれる。モデルグラフの１以上のノードロケーションのロケーションを画像フレーム間で追跡する。追跡されたノードは、そのノードの位置が画像フレーム間の予め定められた位置制約を超えてずれた場合に、再初期化される。
【0007】
本発明のある実施例において、顔の特徴の発見は、頭モデルを個別化するための弾性バンチグラフマッチングに基づき得る。また、顔の画像の解析のためのモデルグラフは、人間の顔の目立つ特徴に関連する複数のロケーションノード（たとえば１８）を含み得る。
【0008】
本発明の他の特徴および利点は、好ましい実施例についての以下の記載を、添付の図面と関連づけて検討することにより明らかになるはずであり、この図面は例として本発明の原理を示している。
【発明を実施するための最良の形態】
【0009】
本発明は、人物の顔の動き、特徴、および特性などを検知し、その顔検知に基づいて、人間の姿を与えたもの（分身）の画像を生成しかつ動画化するための装置および関連の方法において実施される。この分身装置は、画像の特徴をジェットとして効率的に表現するモデルグラフおよびバンチグラフに基づく画像処理技術を利用する。このジェットはウェーブレット変換からなり、容易に識別可能な特徴に対応する画像のノードまたはランドマークロケーションにおいて処理される。ノードを獲得して追跡し、人物の顔の動きに従って、人間の姿を与えたものの画像を動画化する。また、顔の検知では、ジェット類似度を用いて人物の顔の特徴および特性を判断するので、人物の自然な特性を、その人物の自然な特性を妨害し得る不自然な要素を伴なわずに、追跡することができる。
【0010】
図１に示すように、本発明の分身動画化システム１０は、撮像システム１２と、顔検知プロセス１４と、データ通信ネットワーク１６と、顔動画化プロセス１８と、分身ディスプレイ２０とを含む。撮像システムは、ある人物のライブビデオ画像信号を獲得しデジタル化することによって、画像フレームに組織されるデジタル化されたビデオデータのストリームを生成する。デジタル化されたビデオ画像データは、顔検知プロセスに与えられ、このプロセスは、各フレームにおける、その人物の顔および対応する顔の特徴の場所を求める。顔検知プロセスはまた、フレームからフレームへと顔の特徴の位置および特性を追跡する。追跡情報をネットワークを介して１以上の遠隔場所に送り、この遠隔場所においてその情報を受信し、グラフィックスエンジンを用いて分身ディスプレイに動画化された顔の画像を生成することができる。動画化された顔の画像は、その人物の写真のように写実的なモデル、漫画のキャラクター、またはユーザに全く無関係の顔に基づき得る。
【0011】
撮像システム１２および顔検知プロセス１４を図２および３においてさらに詳細に示す。撮像システムは、ビデオ画像フレームのストリームを発生するデジタルビデオカメラ２２を用いて人物の画像を捕捉する。ビデオ画像フレームは、処理のためにビデオランダムアクセスメモリ（ＶＲＡＭ）２４に転送される。Matrox（登録商標）から入手可能なMatrox Meteor IIは、申し分ない撮像システムであり、これは、従来のＣＣＤカメラによって生成されたデジタル化画像を発生し、この画像をリアルタイムでフレームレート３０Ｈｚでメモリに転送する。画像フレームは、ＶＲＡＭおよびランダムアクセスメモリＲＡＭ３

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０に結合された中央処理装置（ＣＰＵ）２８を備える画像プロセッサ２６によって処理される。ＲＡＭは、プログラムコードおよびデータを記憶し、顔検知および分身動画化プロセスを実現する。

【0012】

顔特徴プロセスは、デジタル化された画像に対して働き、人物の顔の特徴を発見し（ブロック３２）、その特徴を追跡し（ブロック３４）、必要に応じて特徴追跡を再初期化する。顔の特徴を分類してもよい（ブロック３６）。顔特徴プロセスは、顔の特徴の位置および分類に関連するデータを生成し、これが、顔動画化プロセスとのインターフェイスに与えられる（ブロック３８）。

【0013】

顔の特徴の場所は、図４に示す弾性グラフマッチングを用いて求めることができる。この弾性グラフマッチング技術では、捕捉された画像（ブロック４０）を、図５を参照して以下でさらに詳細に説明するウェーブレット変換を用いて、ガボール空間に変換する（ブロック４２）。変換された画像（ブロック４４）は、当初の画像の各画素につき、ウェーブレット成分を表わす４０の複素値によって表現される。次に、図７を参照して以下できらに詳細に説明するモデルグラフのハードコピーを、変換された画像の上の、変化するモデルノード位置に位置決めし、最適類似度の位置を発見する（ブロック４６）。最適類似度の探索は、モデルグラフを画像の左上隅に位置決めし、ノードにあるジェットを抽出し、画像グラフとモデルグラフとの間の類似度を求めることによって行なうことができる。この探索は、モデルグラフを、画像の左上隅から始めて左から右へとスライドさせることによって続けられる（ブロック４８）。顔のおおよその位置がわかると（ブロック５０）、ノードを個別に動かして弾性グラフ歪みを導入する（ブロック５２）。うまくマッチングする場所を求めるために、位相の影響を受けない類似度関数を用いる（ブロック５４）。次に、位相の影響を受ける類似度関数を用いて、正確にジェットの場所を求める。その理由は、位相がジェットの小さな変位の影響を大きくうけるからである。位相の影響を受けない類似度関数および位相の影響を受ける類似度関数については、図５－８を参照して以下で説明する。なお、図４では当初の画像に関するグラフが示されているが、モデルグラフの移動およびマッチングは、実際には変換された画像に対して行なわれる。

【0014】

ウェーブレット変換について図５を参照して説明する。当初の画像をガボールウェーブレットを用いて処理すると畳込みの結果が生じる。ガボールに基づくウェーブレットは、ガウスエンベロープにより変調された２次元の複合波フィールドからなる。

【0015】

【数1】

$$\psi_{\vec{k}}(x) = \frac{k^2}{\sigma^2} e^{-x^2 \frac{k^2}{2\sigma^2}} \left\{ e^{i\vec{k}\vec{x}} - e^{\frac{-\sigma^2}{2}} \right\} \qquad (1)$$

【0016】

ウェーブレットは、ガウス窓により制限される、波数ベクトルｋ→（記号→は本来ｋの上に示されるものである。以下の表記も同様。）の平面波であり、波長に対するその大きさは、σによりパラメータ化される。括弧内の項はＤＣ成分を除去する。波数ベクトルｋの振幅は以下のようにして選択できる。式中νは所望の空間解像度に関連する。

【0017】

【数2】

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$$k_\nu = 2^{-\frac{\nu+2}{2}}\pi, \nu = 1, 2, \ldots \qquad (2)$$

画像位置 $\vec{x}$ を中心とするウェーブレットを用いてグレーレベル分布 $I(\vec{x})$ の画像からウェーブレット成分 J_k を抽出する。

$$J_k(\vec{x}) = \int d\vec{x}' I(\vec{x}') \Psi_k(\vec{x} - \vec{x}') \qquad (3)$$

【0018】
典型的には、波数ベクトルｋ→の空間を、解像度レベルが５（２分の１オクターブずつ異なる）および各解像度レベルでの配向が８の離散階層構造において（例として図８参照）サンプリングすることにより、サンプリングされた画像ポイント各々に対し４０の複素値を生成する。（実成分および虚成分は平面波の正弦および余弦相を指す。）ｋ一空間におけるサンプルは、インデックスｊ＝１、…、４０で指定され、１つの画像ポイントを中心とするすべてのウェーブレット成分は、図６に示すジェット６０と呼ばれるベクトルとみなされる。各ジェットは、ｘ→を囲む領域の局所的な特徴を記述する。サンプリングの際の密度が十分であれば、画像を、サンプリングされた周波数によりカバーされる帯域内のジェットから再構成できる。このように、あるジェットの各成分は、画像のポイント（ｘ、ｙ）で抽出されたガボールウェーブレットのフィルタ応答である。

【0019】
図６に示す６２で示した画像グラフを用いて物体の外観を記述する（このコンテクストでは顔）。この番号で示されたグラフのノード６４は、物体上のポイントを指し、ジェット６０として示される。グラフのエッジ６６は、ノード間の距離ベクトルで示される。ノードおよびエッジはグラフトポロジーを定める。トポロジーが等しいグラフを比較することができる。２つのジェットの絶対成分の正規化ドット積が、ジェット類似度を定める。この値はコンラストの変化と無関係である。２つのグラフ間の類似度を計算するために、グラフ間の対応するジェットの類似度に対して和を取り入れる。

【0020】
画像において人間の顔を発見するために具体的に指定されるモデルグラフ６８を図７に示す。グラフにおいて数字がつけられたノードは以下のロケーションを有する。

【0021】
０　右の瞳
１　左の瞳
２　鼻の上端
３　右眉の右隅
４　右眉の左隅
５　左眉の右隅
６　左眉の左隅
７　右の鼻孔
８　鼻尖
９　左の鼻孔
１０　口の右隅
１１　上唇の中心
１２　口の左隅
１３　下唇の中心
１４　右耳の下部
１５　右耳の上部
１６　左耳の上部

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１７　左耳の下部
顔を表わすために、バンチグラフ７０（図６）と呼ばれるデータ構造を用いる。これは上記のグラフと似ているが、各ノードに対しジェットを１つだけ設ける代わりに、ジェットのバンチ（束）全体７２（バンチジェット）を各ノードに設ける。各ジェットは異なる顔の画像から得られる。バンチグラフを形成するために、顔の画像のコレクション（バンチグラフギャラリー）を、顔の規定された位置のノードロケーションでマークする。この規定された位置はランドマークと呼ばれる。バンチグラフと画像とのマッチングの際、画像から抽出されたジェットを、バンチグラフに添付された対応するバンチにおけるすべてのジェットと比較し、最もよくマッチングしているもの１つを選択する。このマッチングプロセスは、弾性バンチグラフマッチングと呼ばれる。バンチグラフは、慎重に選択したギャラリーを用いて構成されると、局所的性質が大きく異なる多岐にわたる顔、たとえば、男性および女性の顔のサンプルならびに年齢または人種の異なる人々のサンプルをカバーする。

【0022】
再び、画像における顔を発見するために、グラフが最もよくマッチングしている場所が見つかるまで、グラフを移動させ、スケーリングし、歪ませる（バンチジェット内で最も適合するジェットは、ノードの現在の位置で画像から抽出されたジェットに最も類似する）。顔の特徴は顔ごとに異なるため、グラフはこのタスクに対してより一般的に作成される。たとえば、各ノードには、１０から１００の個々の顔から取り入れた、対応するランドマークのジェットが割当てられる。

【0023】
異なるまたは相補的でさえある２つのタスクに対して異なる２つのジェット類似度関数が用いられる。ジェットＪ一の成分が振幅および位相ϕ_jを用いた形式で書かれる場合、２つのジェットＪ→およびＪ’一の類似度に対する一方の形式は、以下のような、振幅ベクトルの正規化されたスカラ積である。

【0024】
【数3】

$$S(\vec{J},\vec{J}') = \frac{\sum a_j a'_j}{\sqrt{\sum a_j^2 \sum a'^2_j}} \qquad (4)$$

他方の類似度関数は以下の形式である。

$$S(\vec{J},\vec{J}') = \frac{\sum a_j a'_j \cos(\phi_j - \phi'_j - \vec{d}\vec{k}_j)}{\sqrt{\sum a_j^2 \sum a'^2_j}} \qquad (5)$$

【0025】
この関数は、２つのジェットが指す画像ポイント間の相対移動ベクトルを含む。グラフマッチング中に２つのジェットを比較するとき、これらの類似度をｄに関して最大化し、ジェット位置の正確な判断を行なう。双方の類似度関数を用いるが、最初にグラフのマッチングを行なうときには位相の影響を受けない方（これは相対的位置とともに滑らかに変化する）が好まれることが多く、ジェットを正確に位置決めするときには位相の影響を受ける方が好まれることが多い。

【0026】
顔の特徴の位置を発見した後、顔の特徴を、図９に示すように連続フレームにわたって追跡する。本発明の追跡技術により、ある特徴またはノードの追跡に失敗したかどうかを検出しそのノードに対する追跡プロセスを再初期化する追跡修正方法を用いることによって、長いフレームシーケンスにわたって強力な追跡を行なうことができる。

【0027】

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画像シーケンスの画像Ｉ＿ｎにおける１つのノードの位置Ｘ＿ｎは、上記のランドマーク発見方法（ブロック８０）を用いて画像Ｉ＿ｎでランドマークを発見する、または、追跡プロセスを用いて画像Ｉ＿（ｎ－１）からＩ＿ｎへとノードを追跡することによりわかる。次にこのノードを、いくつかの技術のうち１つによって、画像Ｉ＿（ｎ＋１）における対応する位置Ｘ＿（ｎ＋１）まで追跡する（ブロック８２）。以下で説明する追跡法により、有利に高速な動きに対処することができる。

【0028】

第１の追跡技術は線形動き予測を含む。新規の画像Ｉ＿（ｎ＋１）における対応するノード位置Ｘ＿（ｎ＋１）に対する探索は、動き予測子により発生した位置で開始される。速度が一定であると仮定して、先行する２つのフレーム間でのノードの変位を表わすディスパリティベクトル（Ｘ＿ｎ－Ｘ＿（ｎ－１））を計算する。ディスパリティまたは変位ベクトルＤ＿ｎを位置Ｘ＿ｎに加算して、ノード位置Ｘ＿（ｎ＋１）を予測することができる。この線形動きモデルは、一定速度の動きに対処するのに特に好都合である。線形動きモデルはまた、追跡されている物体の加速度と比較してフレームレートが高い場合に優れた追跡をもたらす。しかしながら、フレームレートが画像シーケンスにおける物体の加速度と比較して低すぎれば、線形動きモデルの性能は低い。動きモデルがこういった条件下で物体を追跡するのは困難であるため、フレームレートのより高いカメラを用いることが推奨される。

【0029】

線形動きモデルが発生する推定動きベクトルＤ＿ｎが大きすぎると、動き予測における誤差の累積につながり得る。したがって、線形予測を減衰定数ｆ＿Ｄを用いて減衰することができる。結果として得られる、予測された動きベクトルは、Ｄ＿ｎ＝ｆ＿Ｄ＊（Ｘ＿ｎ－Ｘ＿（ｎ－１））である。適切な減衰定数は０．９である。先行するフレームＩ＿（ｎ－１）がない場合、たとえば、ランドマーク発見直後のフレームに対し、予測される動きベクトルは０と等しくなるように設定される（Ｄ＿ｎ＝０）。

【0030】

１次元に適用される、ガウス画像ピラミッドに基づく追跡技術は図１０に示される。当初の画像解像度を用いる代わりに、画像を２から４倍にダウンサンプリングして画像のガウスピラミッドを作成する。４レベルの画像ピラミッドは、結果として、最も粗いレベルにおいて３画素のみとして表わされている最も精細な当初の解像度レベルに対し２４画素の距離をもたらす。ピラミッドのいずれかのレベルでジェットを計算および比較することができる。

【0031】

一般的に、ガウス画像ピラミッドにおけるノードの追跡は、最初に最も粗いレベルで行ない次に最も精細なレベルに移る。ジェットは、上記のように減衰された線形動き予測Ｘ＿（ｎ＋１）＝（Ｘ＿ｎ＋Ｄ＿ｎ）を用いて、位置Ｘ＿（ｎ＋１）の実際の画像フレームＩ＿（ｎ＋１）の最も粗いガウスレベルで抽出され、先行する画像フレームの最も粗いガウスレベルで計算した対応するジェットと比較される。これらの２つのジェットから、ディスパリティを求める、すなわちＸ＿（ｎ＋１）から、先行するフレームからのジェットに最もよく対応する位置までを指し示す２次元ベクトルを求める。この新しい位置がＸ＿（ｎ＋１）に割当てられる。このディスパリティ計算については、以下できらに詳細に説明する。最も粗いガウスレベルの位置Ｘ＿（ｎ＋１）に対応する、実際の画像（２＊Ｘ＿（ｎ＋１）である）の次に精細なガウスレベルの位置が、この次に精細なレベルのディスパリティ計算についての開始点である。この点で抽出されたジェットは、先行する画像フレームの同じガウスレベルについて計算された対応するジェットと比較される。このプロセスは、最も精細な解像度レベルに達するまで、または、先行する画像の位置に対応するノードの位置を求めるのに特定されたガウスレベルに達するまで、すべてのガウスレベルに対して繰返される。

【0032】

ガウス画像ピラミッドの代表的な２つのレベルが図１０に示されており、粗い方のレベ

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ル９４は上であり、精細な方のレベル９６は下である。各ジェットは２つの周波数レベルに対するフィルタ応答を有すると仮定される。粗い方のガウスレベルの位置Ｘ＿（ｎ＋１）＝Ｘ＿ｎ＋Ｄ＿ｎで始めて、最低周波数ジェット係数のみを用いた第１のディスパリティ移動により位置２に至る。双方の周波数レベルのすべてのジェット係数を用いた第２のディスパリティ移動により位置３に至り、これはこのガウスレベルの最終位置である。精細な方のガウスレベルの位置１は、座標が２倍の粗い方のレベルの位置３に対応する。ディスパリティ移動シーケンスは繰返され、最も精細なガウスレベルの位置３が、追跡されたランドマークの最終位置である。追跡をより正確にするために、ガウスおよび周波数レベルの数を増やしてもよい。

【0033】

実際の画像フレームにおいて追跡されたノードの新規の位置を求めた後、すべのガウスレベルにおけるジェットをこの位置で計算する。追跡されたノードを表わす、先行するフレームに対して計算されたジェットの記憶されたアレイを、現在のフレームに対して計算されたジェットの新規のアレイと置き換える。

【0034】

ガウス画像ピラミッドを用いることには２つの主要な利点がある。第１に、粗い方のレベルにおける画素に関しノードの移動が当初の画像におけるものよりも遥かに小さく、これによって、大きな画像領域において徹底的に探索を行なう代わりに局所的な移動のみを行なうことによって追跡が可能になる。第２に、ジェット成分の計算が低周波数に対して非常に速い。なぜなら、この計算は、当初の解像度の画像の大きなカーネルウィンドウに対してではなく、ダウンサンプリングされた画像の小さなカーネルウィンドウを用いて行なわれるからである。

【0035】

なお、対応レベルは動的に選択してもよい。たとえば、顔の特徴の追跡の場合、対応レベルを顔の実際の大きさに依存して選択してもよい。ガウス画像ピラミッドの大きさも、追跡プロセスを通して変更できる。すなわち、この大きさを動きが速くなったときに大きくし動きが遅くなったときに小さくできる。典型的には、最も粗いガウスレベルの最大ノード移動は４画素に制限される。なお、動き予測は最も粗いレベルで行なわれることが多い。

【0036】

同じガウスレベルの所与の２つのジェット間の移動ベクトル（ディスパリティベクトル）の計算について次に説明する。連続する２つのフレーム間の変位を計算するために用いるある方法は、本来、D. J. FleetおよびA. D. Jepson, Computation of component image velocity from local phase information, International Journal of Computer Vision, volume 5, issue 1, pages 77-104, 1990、ならびに、W. M. TheimerおよびH. A. Mallot, Phase-based binocular vergence control and depth reconstruction using active vision, CVGIP: Image Understanding, volume 60, issue 3, pages 343-358, November 1994に基づき、ステレオ画像におけるディスパリティ推定に対して開発されたものである。

【0037】

複合フィルタ応答の位相の強い変化を用いてサブピクセル精度で変位を明確に計算する（Wiskott, L., "Labeled Graphs and Dynamic Link Matching for Face Recognition and Scene Analysis", Verlag Harri Deutsch, Thun-Frankfurt
am Main, Reihe Physik 53 (PhD thesis, 1995)）、振幅a_jおよび位相jに関しj番目のガボールフィルタへの応答Ｊを書くことにより、類似度関数を以下のように定めることができる。

【0038】

【数4】

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$$S(J, J', d) = \frac{\sum_j a_j a'_j \cos(\phi_j - \phi_{j'} - d \cdot k_j)}{\sqrt{\sum_j a_j^2 \sum_{j'} a'^2_{j'}}} \qquad (6)$$

【0039】
ＪおよびＪ′を位置ＸおよびＸ′＝Ｘ＋ｄの２つのジェットとすると、変位ｄは、ｄに関する類似度Ｓを最大化することによって発見でき、k_jはJ_jを発生するフィルタと関連する波数ベクトルである。ｄの推定は、小さな変位、すなわちガボールジェットの大きな重なりのみに対して正確であるため、大きな移動ベクトルは第１の推定のみとして扱われ、このプロセスは以下の態様で繰返される。最初に、最も周波数レベルの低いフィルタ応答のみを用いて第１の推定ｄ＿１が生まれる。次に、この推定を実行し、ジェットＪをジェットＪ′の位置Ｘ′により近い位置Ｘ＿１＝Ｘ＋ｄ＿１で再計算する。次に、２つの最も低い周波数レベルを変位ｄ＿２の推定のために用い、ジェットＪを位置Ｘ＿２＝Ｘ＿１＋ｄ＿２で再計算する。これは、用いた最大周波数レベルに達するまで反復され、２つの開始ジェットＪおよびＪ′間の最終ディスパリティｄが、ｄ＝ｄ＿１＋ｄ＿２＋…として与えられる。このようにして、最低周波数のカーネルの波長の半分まで変位を計算することができる（先のWiskott、1995参照）。
【0040】
変位は浮動小数点数を用いて求めているが、ジェットを（整数）画素位置のみで抽出してもよい（すなわち畳込みによって計算してもよい）。その結果、システム的な丸め誤差が生まれる。このサブピクセル誤差Δｄを補償するために、複合ガボールフィルタ応答の位相を以下に従いシフトする必要がある。
【0041】
【数5】

$$\Delta\phi_j = \Delta d \cdot k_j \qquad (7)$$

【0042】
こうすれば、ジェットは、あたかも正しいサブピクセル位置で抽出されたかのように見えるであろう。このように、ガボールジェットを、さらなる丸め誤差を考慮せずに、サブピクセル精度で追跡できる。なお、ガボールジェットは画像処理において実質的な利点をもたらす。その理由は、サブピクセル精度の問題は他のほとんどの画像処理方法において対処がより困難なためである。
【0043】
追跡誤差は、信頼度または類似度の値が予め定められたしきい値よりも小さいかどうかを判断することによって検出できる（図９のブロック８４）。類似度（または信頼度）の値Ｓを計算して、２つの画像フレームにおける２つの画像領域がいかにうまく対応しているかを、連続する画像フレーム間のノードの変位の計算と同時に、示すことができる。典型的には、信頼度の値が１に近いことは、対応度の高いことを示す。信頼度の値が１に近くなければ、画像において対応するポイントが発見されていないか（たとえばフレームレートが動いている物体の速度と比較して低すぎるため）、または、この画像領域があるフレームから次のフレームへとあまりにも大幅に変化しているため対応性をうまく定めることができないかである（たとえば瞼を追跡するノードに対し瞼が閉じられる）。信頼度の値があるしきい値よりも低いノードはスイッチオフされる。
【0044】
何らかの幾何学的制約が侵害されたときにも追跡誤差が検出される（ブロック８６）。同時に多くのノードが追跡される場合、ノードの幾何学的構成が一致しているかどうかについて検査される。このような幾何学的制約はかなり緩やかでよい。たとえば、顔の特徴

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を追跡するとき鼻は目と口との間になければならないといったことである。代わりに、こういった幾何学的制約はかなり厳しいものでもよい。たとえば、追跡される顔の正確な形状情報を含むモデルといったものである。この中間の精度に対しては、制約は平面モデルに基づくものである。平面モデルでは、顔グラフのノードは平面にあると仮定される。正面図で始まる画像シーケンスについては、追跡されるノード位置を、アフィン変換により実際のフレームに変換される正面グラフの対応するノード位置と比較することができる。最適アフィン変換の６つのパラメータが、ノード位置における最小二乗誤差を最小にすることによって発見される。追跡されたノード位置と変換されたノード位置との間のずれがしきい値と比較される。しきい値よりもずれの大きいノードはスイッチオフされる。アフィン変換のパラメータを用いて、姿勢および相対的なスケール（開始グラフと比較したもの）を同時に求めることができる（ブロック８８）。このように、この大まかな平面モデルによって、追跡誤差が予め定められたしきい値よりも大きくなることが確実になくなる。

【0045】

追跡されたノードが追跡誤差のためにスイッチオフされた場合、ノードを、異なる姿勢を含むバンチグラフを有利に用いて正しい位置で再び活性化し（ブロック９０）、修正された位置から追跡を続行することができる（ブロック９２）。追跡されたノードがスイッチオフされた後、システムは、姿勢に固有のバンチグラフが存在する予め規定された姿勢に達するまで待ってもよい。それ以外の場合は、正面のバンチグラフのみが記憶されているならば、システムは、正面の姿勢に達するまで待って追跡誤差を修正しなければならない。記憶されたジェットのバンチを適合位置を囲む画像領域と比較してもよい（たとえば平面モデルからのもの）。これは追跡と同じ態様で作用するが、異なる点は、先行する画像フレームのジェットとの比較の代わりに、比較は例のバンチのジェットすべてについて繰返され最も似ているものが取込まれることである。顔の特徴はわかっているので、たとえば、実際の姿勢、スケールおよび大まかな位置までもわかっているので、グラフマッチングまたは画像における徹底的な探索および／または姿勢空間は不要であり、ノード追跡修正をリアルタイムで行なうことができる。

【0046】

追跡訂正のために、多くの異なる姿勢およびスケールに対するバンチグラフは不要である。なぜなら、画像面における回転およびスケールは、局所的画像領域またはバンチグラフのジェットの変換を図１１に示すように行なうことにより、考慮されているからである。正面の姿勢に加え、深さにおける回転に対してのみバンチグラフを作成する必要がある。

【0047】

再初期化プロセスの速度を、画像シーケンス中は追跡される人物のアイデンティティが同じであるという事実を利用して、高めることができる。したがって、最初の学習セッションでは、人物の最初のシーケンスに、正面の顔の表情の全レパートリーを表わしている人物を与える。この最初のシーケンスを、異なる多くの人物に関する知識を含む大きな一般化されたバンチグラフに基づき上述の追跡および訂正方法を用いて、精度高く追跡することができる。このプロセスをオフラインで行ない、個人別にされた新たなバンチグラフを生成することができる。次に、個人別にされたバンチグラフを用いて、この人物をリアルタイムで高速レートで追跡できる。なぜならば、個人別にされたバンチグラフは一般化された大きなバンチグラフよりも遥かに小さいからである。

【0048】

再初期化プロセスの速度を、部分バンチグラフ再初期化を利用して高めることもできる。部分バンチグラフは、全バンチグラフのノードのサブセットのみを含む。このサブセットの大きさは１つのノードぐらいでしかない。

【0049】

姿勢推定バンチグラフは、画像面において定められる２次元バンチグラフの一族を利用する。１つの族内の異なるグラフは、顔の、異なる姿勢および／またはスケールを説明す

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る。ランドマーク発見プロセスは、画像における頭の姿勢または大きさを求めるために、その族からの各バンチグラフを入力画像とマッチングさせようとする。こうした姿勢推定手順の一例が図１２に示される。この姿勢推定の第１ステップは、通常のランドマーク発見のものと等しい。画像（ブロック９８）は、グラフ類似度関数を用いるために、変換される（ブロック１００および１０２）。次に、１つだけではなく、３つのバンチグラフの族を用いる。第１のバンチグラフは正面の姿勢の顔のみを含み（上記の正面図と等しい）、他の２つのバンチグラフは４分の１だけ回転させた顔を含む（一方が左への回転を表わし、他方が右への回転を表わす）。先のように、グラフ各々に対する初期位置は左上隅にあり、グラフの位置は画像においてスキャンされ、ランドマーク発見後最も高い類似度を戻す位置およびグラフが選択される（ブロック１０４－１１４）。

【0050】

各グラフに対する最初のマッチングの後、最終位置の類似度が比較される（ブロック１１６）。画像において与えられた姿勢に最もよく対応しているグラフは類似度が最も高い。図１２において、左に回転させたグラフは、類似度によって示されるように最もよく適合している（ブロック１１８）。像における顔の解像度および回転の角度に応じて、正しいグラフおよび他の姿勢に対するグラフの類似度は、変化し、グラフを規定した２つの姿勢間のおよそ中間に顔があるときに、非常に近くなる。より多くの姿勢に対してバンチグラフを作成することにより、姿勢推定手順がより精細になり、これにより、他の方向（たとえば上または下）への頭の回転およびハンドル回転のより多くの角度が識別される。

【0051】

カメラから任意の距離にある顔を確実に発見するために、同様の方策を用いて、各々がスケールの異なる２または３の異なるバンチグラフを用いてもよい。画像における顔は、最高のものを顔の画像に戻すバンチグラフと同じスケールを有すると仮定される。

【0052】

上記の技術に関連する３次元（３Ｄ）ランドマーク発見技術を用いて、異なる姿勢に適合させた複数のバンチグラフを用いることもできる。しかしながら、この３次元方策は３次元空間で規定されるバンチグラフ１つのみを用いる。３次元グラフのジオメトリは、平均的な顔または頭のジオメトリを反映する。回転度数の異なる数人の人物の顔の画像からジェットを抽出することにより、３次元バンチグラフを作成する。これは、２次元方策と似ている。次に各ジェットを３つの回転角度でパラメータ化する。２次元方策のように、ノードは顔の画の基準点に位置する。次に、３次元グラフの突起をマッチングプロセスで用いる。３次元方策におけるある重要な一般化は、各ノードに、異なる姿勢に適合するバンチジェットのパラメータ化された族を設けることである。第２の一般化は、グラフが画像面での変換のみではなく３次元空間でユークリッド変換されることである。

【0053】

グラフマッチングプロセスは、粗から精への方策として定めることができる。ここでは初めにノードおよびカーネルの少ないグラフを用い、次に後続のステップではより密度の高いグラフを利用する。粗から精への方策は、顔のある領域における特徴ポイントの高精度の局所化が所望される場合に特に適している。このように、階層的方策を採用することによって、計算上の手間を省く。ここでは、最初に粗い解像度についてランドマーク発見を行ない、次に、適合したグラフをより高い解像度で検査して、ある領域をより精細に解析する。

【0054】

さらに、計算上の作業負荷を、マルチプロセッサマシンで簡単に分割できる。こうすれば一旦粗い領域が発見されると、少数の子プロセスが並列に、各々が画像全体のうちそれ自身の部分に対して作業を開始する。子プロセスの最後に、これらプロセスはそれらが位置する特徴座標をマスタプロセスに送り、マスタプロセスは適切にこれらをスケーリングおよび組合せて当初の画像に適合するようにし、こうして計算の総時間が大幅に短縮する。

【0055】

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図１３に示すように、ノードに対応する顔の特徴を分類して、たとえば瞬きや口の開きといった不適切な追跡誤差の表示に対応することができる。顔の特徴に対応する、バンチグラフにおける異なるジェットに、たとえば目が開いている／閉じている、口が開いている／閉じているなどの、ラベルを添付する。このラベルを、現在の画像と比較して最も類似している、バンチグラフにおける対応するジェットとともに、コピーする。追跡誤差が検出されたかどうかにかかわらず、ラベル追跡を連続してモニタする。このようにして、以下について、分類ノードが追跡されたノードに添付される。

【0056】

目が開いている／閉じている。

口が開いている／閉じている。

【0057】

舌が見えているまたは見えていない。

紙の種類の分類。

【0058】

皺の検出（たとえば額の皺）。

このように、追跡により２つの情報源を利用できる。一方の情報源は特徴の場所すなわちノード位置に基づき、他方の情報源は特徴分類に基づく。特徴分類情報は、テクスチャに一層基づいており、局所的画像領域を１組の記憶された例と比較することにより、ノード位置のみに基づく特徴分類情報よりも、低い解像度および追跡精度で機能し得る。

【0059】

本発明の顔検知は、図１４に示すように、静的および動的な、人間の姿を与えたものの、作成および動画化に適用できる。この人間の姿を与えたものは、一般的な顔のモデルに基づく、または、ある人物に固有の顔のモデルに基づく。追跡および顔の表情の認識を利用して、その人物の特徴を有するようにこの人間の姿を与えたものを具体化できる。

【0060】

一般的な顔のモデルを、代表的な数の個人に適合させ、写実的な動画化を行ない、広範囲にまたがる顔の特徴および／または表情を与えることができる。一般的なモデルは以下の技術によって得ることができる。

【0061】

１．モノカメラシステムを用いて（T. Akimoto他、１９９３）、低価格のテレイマージョンシステムにおいて用いるために、実物に似た、人間の姿を与えたものを作成する。サジタル平面および頭頂面から見た、個人の横顔情報を併合して、人間の姿を与えたものを得る。

【0062】

２．ステレオカメラシステムは、カメラを十分に校正した場合（カメラパラメータは校正プロセスを通して計算される）、正確な３次元測定を行なうことができる。次に、個々の顔のモデルは、一般的な顔のモデルを、得られた３次元データに適合させることによって得ることができる。ステレオアルゴリズムは非テクスチャ領域に対する正確な情報を与えないので、活性テクスチャ光の投射を利用する。

【0063】

３．個々の顔に対してマーカを用いる、特徴に基づくステレオ技術によって、マーカの正確な３次元位置を計算する。次に３次元情報を用いて一般的なモデルに適合させる。

【0064】

４．センサまたは位置発見装置が、測定される各平面の点に対して動かされる、３次元デジタイザ。

【0065】

５．パターンが投影され、結果として得られるビデオストリームを処理して３次元測定値を抽出するアクティブ構成光。

【0066】

６．正確な顔測定値をもたらす、レーザに基づいた表面スキャン装置（Cyberware, Inc

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が開発するもののようなもの）。

【0067】

７．以前の技術の組合せ

こうした異なる技術はユーザにとって等しく好都合ではない。１回のプロセスで個人の測定値を得ることができるものもあれば（顔は測定期間中所望の姿勢をとっている）。一方で、サンプルの収集が必要であり使用するのに面倒なものもある。

【0068】

特定の人物に対する一般的な３次元頭モデルを、正面および側面を示す２つの顔の画像を用いて生成できる。顔の検知により、３次元頭モデルを効率的かつ強力に生成できる。

【0069】

顔の輪郭の抽出は、人物の目、鼻、口および頬の局所化とともに行なわれる。図１４に示すように、この特徴局所情報は、弾性バンチグラフ技術を階層的マッチングとともに用いて、自動的に顔の特徴を抽出することにより得ることができる。次に、特徴場所情報を組合せ（T. AkimotoおよびY. Suenaga, Automatic Creation of 3D Facial Models, IEEE Computer Graphics & Applications, Pages 16-22, September 1993参照）、人物の頭の３次元モデルを生成する。一般的な３次元頭モデルを適合させて、そのプロポーションが画像の測定値と関連するようにする。最後に、側面および正面の画像を組合せ、人間の姿を与えたものに対しよりよいテクスチャモデルを得る、すなわち、正面図を用いてモデルの正面をテクスチャマッピングし、側面図をモデルの側面に対して用いる。顔の検知によりこの技術が向上する。なぜなら抽出された特徴をラベルづけし（既知のポイントは横顔において定められる）、２つの画像が同時に取込まれないようにするからである。

【0070】

人間の姿を与えたものの画像は、以下の一般的な技術によって動画化できる（F.I.ParkeおよびK.Waters, Computer Facial Animation, A K Peters, Ltd., Wellesley, Massachusetts, 1996）。

【0071】

１．キーフレーミングおよび幾何内挿。多数の重要な姿勢および表情を規定する。次に幾何内挿をキーフレーム間で用いて動画化を行なう。このようなシステムは、性能に基づく（または性能により駆動される）モデルと呼ばれることが多い。

【0072】

２．直接パラメータ化。これは表情および姿勢を１組のパラメータに直接マッピングし次にこれを用いてモデルを駆動する。

【0073】

３．幾何学的変形を用いて筋肉動作をシミュレートする擬似筋肉モデル。

４．筋肉および皮膚を物理的モデルを用いてモデル化する、筋肉に基づくモデル。

【0074】

５．２次元および３次元モーフィング。これは、ビデオストリームにおける画像間で２次元モーフィングを用い、２次元動画を生成する。１組のランドマークを識別しこれを用いてシーケンスの２つの画像間のワープを行なう。このような技術は３次元に拡張できる（F.F.Pighin, J.Hecker, D.Lischinski, R.Szeliski,D.H.Salesin, Synthesizing Realistic Facial Expression from Photographs, SIGGRAPH 98 Conference Proceedings, pages 75-84, July 1998参照）。

【0075】

６．制御ポイントおよび有限要素モデルといった他の方策。

これらの技術に対し、顔検知は、顔の特徴の自動抽出および特徴化によって、動画化プロセスを向上させる。抽出された特徴を用いて、キーフレーミングおよび内挿モデルの場合は表情を内挿し、または、直接パラメータ化モデルまたは擬似筋肉または筋肉モデルの場合はパラメータを選択できる。２次元および３次元モーフィングの場合は、顔検知を用いて、自動的に顔の特徴を選択し、幾何学的変換を行なうのに適切な情報を与える。

【0076】

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顔の特徴の追跡および分類を利用した、人間の姿を与えたものの動画化の例は、図１５に関連付けて示される。訓練相の間、個人は、一連の予め定められた顔の表情をするようにされる（ブロック１２０）。検知を用いて特徴を追跡する（ブロック１２２）。予め定められた場所で、ジェットおよび画像パッチを種々の表情に対して抽出する（ブロック１２４）。顔の特徴を囲む画像パッチは、これらの特徴から抽出したジェット１２６とともに集められる。これらのジェットを後で用いて、顔の特徴１２８を分類またはタグづけする。これは、これらのジェットを用いて、個人別のバンチグラフを生成し、上記のような分類法を適用することによって、行なわれる。

【0077】

図１６に示すように、人間の姿を与えたものを動画化するために、このシステムは、すべての画像パッチ１２８とともに、顔全体１３０（「顔フレーム」）の画像から画像パッチにおいて示された部分をマイナスしたものを、遠隔場所に送る（ブロック１３２および１３４）。動画化エンジンのためのソフトウェアも送る必要がある。次に、検知システムは、ユーザの顔を観察して、顔の検知を適用してどの画像パッチが現在の顔の表情に最も似ているかを判断する（ブロック１３６および１３８）。画像タグは遠隔場所に送られ（ブロック１４０）、動画化エンジンが正しい画像パッチを用いて顔１４２を組立てることができるようにする。

【0078】

画像パッチをスムーズに画像フレームに適合させるために、ガウスぼかしを用いることができる。写実的にするためには、局所画像モーフィングが必要である。なぜなら、動画は、画像の連続が検知によって与えられた通りに現れるという意味において、不連続かもしれないからである。モーフィングは、画像空間において対応するポイントの線形内挿を用いて実現される。中間画像を作成するために、以下の等式を用いて線形内挿を適用する。

【0079】

$$P_i = (2-i)P_1 + (i-1)P_2 \qquad (7)$$

$$I_i = (2-i)I_1 + (i-1)I_2 \qquad (8)$$

式中、P_1およびP_2は画像I_1およびI_2において対応するポイントであり、I_iはｉ番目に内挿された画像で、$1 \leq i \leq 2$である。なお、プロセス効率のために、画像内挿を、予め計算したP_iおよびI_iに対するハッシュ表を用いて実現できる。用いるポイントの数および精度、それらの正確度、ならびに内挿された顔のモデルが、一般的に、結果として得られる画像の品質を決定する。

【0080】

このように、遠隔ディスプレイにおいて再構成された顔は、学習ステップにおいて検出された表情に対応する画像の部分を集めることによって作成できる。したがって、こうして人間の姿を与えたものは、動画化を命令する人物に対応する特徴を示している。したがって、初期化時、１組のクロッピングされた画像は、追跡された顔の各特徴、および、結果として得られる、各特徴が除去された後の画像としての「顔コンテナ」に対応する。動画化が開始され、前述のように、顔の検知を用いて、送られる特定のタグを生成する。送られたタグと関連する画像部分を選択することによりデコードが生じる。たとえば、「笑っている口」というタグ１４６（図１６）でラベルづけられた口の画像である。

【0081】

上記のような動的テクスチャ生成を、図１７に示すようなボリュームモーフィングの従来技術と統合した場合に、より進んだレベルで、人間の姿を与えたものを動画化できる。ボリュームモーフィングを行なうために、ノード位置のロケーションを用いてメッシュ１５０の制御ポイントを駆動する。次に、タグを用いて動的に生成されたテクスチャ１５２をメッシュにマッピングし、実物に似た顔の画像１５４を生成する。検知されたノード位置をメッシュの制御ポイントのドライバとして用いる代わりに、タグを用いて局所的モーフィングターゲットを選択する。モーフィングターゲットは、サンプルジェットを収集した対象の、顔の異なる表情およびジェスチャに対して求められた、局所的メッシュ構成で

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ある。局所的メッシュジオメトリはステレオ視覚技術によって求めることができる。モーフィングターゲットの使用はさらに、以下の関連団体によって開発されている。（J.R.Kent, W.E.Carlson, R.E.Parent, Shape Transformation for Polyhedral Objects, SIGGRAPH 92 Conference Proceeding, volume 26, pages 47-54, August 1992, Pighin et al, 1998参照）。

【0082】

視覚に基づき人間の姿を与えたものを動画化することに役立つ拡張は、図１８に示すように正しい唇の動きを合成するために顔の検知を音声解析と統合することである。リップシンク技術は特に、音声の結果として現われる唇の動きを、人物の姿を与えたものにマッピングするのに役立つ。これはまた、視覚に基づく唇の追跡に失敗した場合のバックアップとしても役立つ。

【0083】

上記は本発明の好ましい実施例を開示しているが、当業者であれば本発明の範囲から逸脱することなく好ましい実施例を種々に変形できることが理解される。本発明は前掲の特許請求の範囲によってのみ規定される。

【図面の簡単な説明】

【0084】

【図1】本発明に従う、人間の姿を与えたものを動画化するシステムおよびプロセスのブロック図である。

【図2】図１の人間の姿を与えたものを動画化するシステムおよびプロセスのための、本発明に従う顔の特徴検知装置およびプロセスのブロック図である。

【図3】図２の顔の特徴検知装置を実現するためのビデオ画像プロセッサのブロック図である。

【図4】図２の顔の特徴検知装置およびシステムのランドマーク発見技術を示すためのフロー図に写真を添付したものである。

【図5】本発明に従う、ガボールウェーブレットを用いた顔の画像の処理を示す一連の画像である。

【図6】本発明に従う、図５のウェーブレット処理技術を用いた、ジェット、画像グラフおよびバンチグラフの構成を示す、一連のグラフである。

【図7】顔の画像を処理するための、本発明に従うモデルグラフの図である。

【図8】顔の特徴の場所を求めるためのウェーブレット処理の使用を示す２つの図を含む。

【図9】図４のランドマーク発見技術により発見されるランドマークを追跡するための追跡技術を示すフロー図である。

【図10】１次元でのランドマーク追跡を示すためのガウス画像ピラミッド技術の図である。

【図11】２つの顔の一連の画像に、５０の一連の画像フレームにわたる顔の特徴の追跡を示した姿勢の角度対フレーム数のグラフを添付したものである。

【図12】図２の顔の特徴検知装置およびシステムの姿勢推定技術を示すフロー図に写真を添付したものである。

【図13】粗から精へのランドマーク発見技術を示すための、顔を抽出された目および口領域とともに示す概略図である。

【図14】図６の弾性バンチグラフ技術を用いた横顔および顔の特徴の抽出を示す写真である。

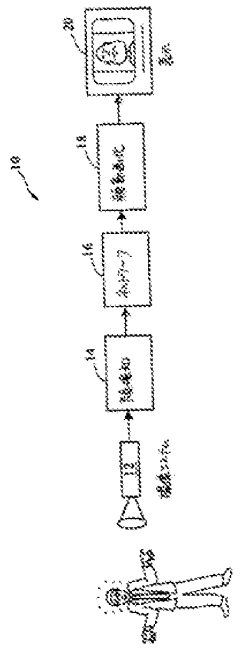
【図15】本発明に従う、タグづけされ個別化されたバンチグラフの生成を示すフロー図とともに、人間の姿を与えたものの動画化のための、人物の種々の表情を含む対応の画像パッチのギャラリーを示したものである。

【図16】遠隔場所に送られる画像パッチを用いて人間の姿を与えたものを動画化するための技術を示すフロー図であり、この画像パッチは、人物の現在の顔の表情に関連した顔の検知に基づき、送られたタグに基づいて、遠隔場所で選択される。

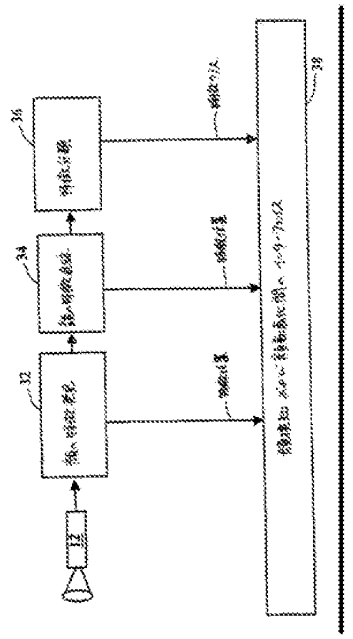
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【図17】顔の特徴の位置およびタグに基づき、動的テクスチャ生成と統合されたボリュームモーフィングを用いて生成された、３次元の顔の画像を与えることを示す、フロー図である。
【図18】本発明に従う、人間の姿を与えたものを動画化するシステムのブロック図であり、人間の姿を与えたものの動画化のためのオーディオ解析を含む。
【符号の説明】
【0085】
１０　分身動画化システム。

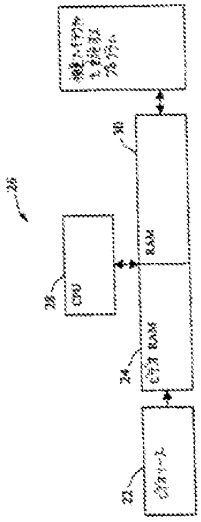
【図1】



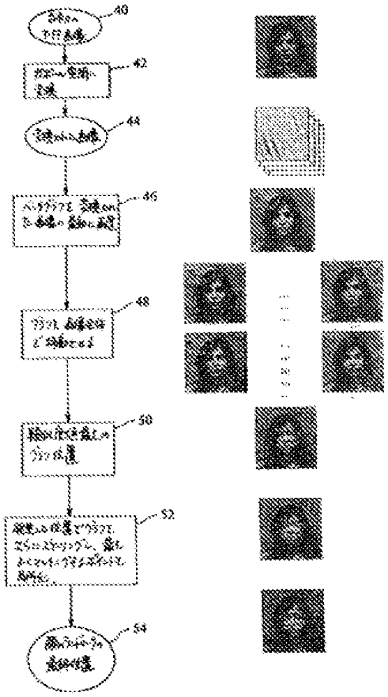
【図2】



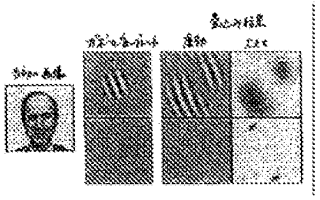
【図３】



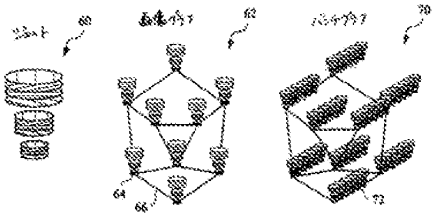
【図４】



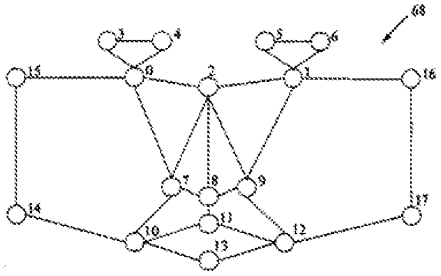
【図５】



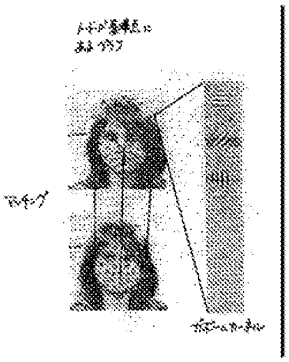
【図６】



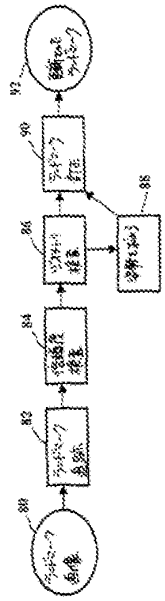
【図７】



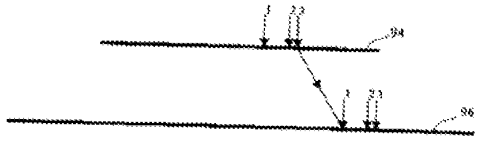
【図８】



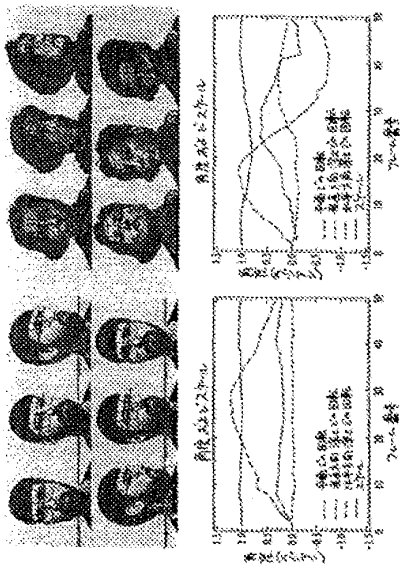
【図9】



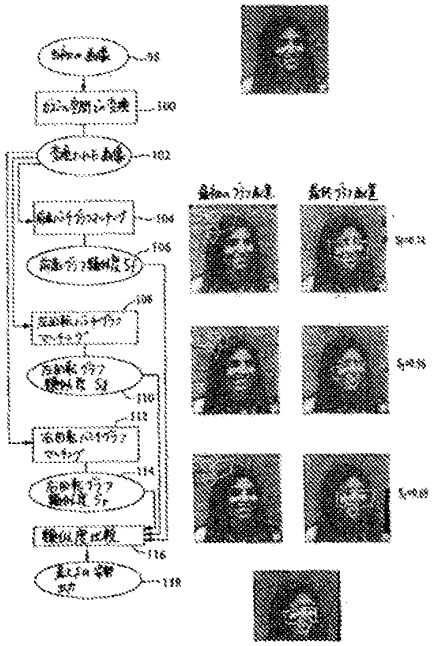
【図10】



【図11】

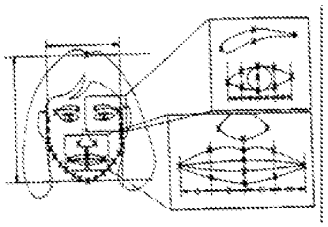


【図12】

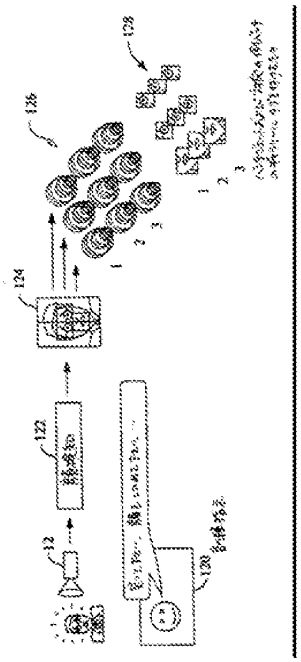


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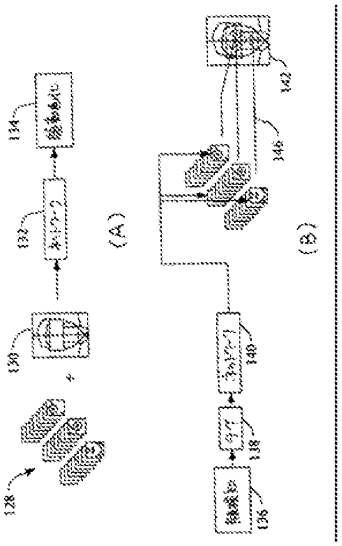
【図13】



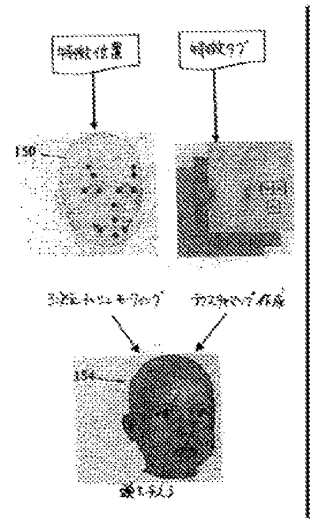
【図15】



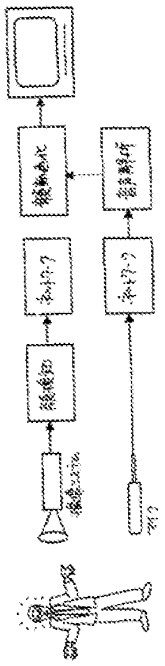
【図16】



【図17】



【図18】



【図14】



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5L096 AA06　CA04　FA22　FA69　HA02　HA05　JA03

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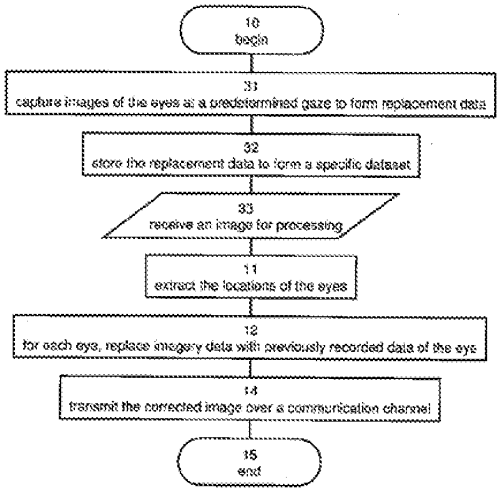


FIG. 3

(57) Abstract: A method of correcting gaze offset in an image of at least one individual having eyes is disclosed. The method comprises: processing the image to extract location of at least one eye over the image, processing the image to replace imagery data associated with each location of each eye with replacement data thereby providing a corrected image, and transmitting the corrected image to a display device. The replacement data are preferably previously-recorded imagery data which respectively correspond to the same eye but a different gaze.

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METHOD AND SYSTEM FOR CORRECTING GAZE OFFSET

RELATED APPLICATION

This application claims the benefit of priority from U.S. Patent Application No. 61/348,269, filed May 26, 2010, the contents of which are incorporated by reference as if fully set forth herein.

FIELD AND BACKGROUND OF THE INVENTION

The present invention, in some embodiments thereof, relates to image processing and, more particularly, but not exclusively, to a method and system for processing an image to correct gaze offset.

Videoconferencing systems hold the promise of allowing a natural interpersonal communication at a range. Recent advances in video quality and the adaptation of large high definition screens are contributing to a more impressive user experience.

Along with gestures and facial expression, gaze is one of the most important aspects of person's non-verbal behavior, and many socio-psychological studies have been attested to the importance of the gaze direction and visual contact as communicative signals. In the case of conventional videoconference systems, the arrangement of camera, monitor and user causes an angular error between the gaze direction towards the monitor and the camera optical axis. As a result, when the remote party is looking straight into the image of the local party, the gazes, as perceived by the two parties, are not collinear. For example, when camera is located on top of the screen, the effect is interpreted as looking down.

Several solutions have been proposed to the problem of offset gaze in videoconferencing. One such solution employs a beam splitter between camera and monitor. A partially transparent mirror is fitted in front of the monitor in such a way that the viewer can see the monitor image through the mirror. By means of this mirror, the camera captures the viewer from the direction of the monitor, permitting recording and reproduction over one axis.

Some techniques reproduce the image of the other party by a video projector on a projection screen. The camera can be located behind the projection screen and the

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party's image can be captured through the screen by means of a window provided with a light valve or a partially transparent projection screen.

Another technique employs view synthesis from multiple cameras. In one such technique, dynamic programming based disparity estimation is used to generate a middle view from two cameras that were positioned on the left and right sides of the screen [A. Criminisi, J. Shotton, A. Blake, and P. H. S. Torr. Gaze manipulation for one-to-one teleconferencing. In ICCV, 2003].

In an additional technique, the images of participants are rendered digitally in a virtual three-dimensional space, and a head-pose orientation and eye-gaze direction are digitally corrected as internal mathematical computations without the need for a display device. The digitally corrected data are transmitted to a display screen so that a particular participant's image in the three-dimensional space appears to other participants viewing the screen as if the particular participant was looking at them screen [see, *e.g.*, Gemmell *et al.*, "Gaze awareness for video-conferencing: A software approach," IEEE MultiMedia, 2000, and U.S. Patent No. 6,806,898].

In another technique, a gaze deviation value is determined and used for calculating a corresponding point of an input image corresponding to a particular position in a corrected image. A pixel value at the corresponding point is calculated using the input image from the camera. The gaze corrected image is transmitted by using the calculated pixel value as the pixel value of the particular position of the corrected image [U.S. Patent No. 6,677,980].

Also known is a region filling technique in which the pupils of the other party in the image plane are segmented and displaced in the image plane, wherein areas which become free as a result of this displacement are filled-in using the color of the eyeballs [U.S. Patent No. 5,499,303].

Additional background art includes U.S. Patent Nos. 6,433,759 and 6,771,303.

SUMMARY OF THE INVENTION

According to an aspect of some embodiments of the present invention there is provided a method of correcting gaze offset in an image of at least one individual having eyes. The method comprises: processing the image to extract location of at least one eye over the image, processing the image to replace imagery data associated with each

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location of each eye with replacement data thereby providing a corrected image, and transmitting the corrected image to a display device. The replacement data is preferably previously-recorded imagery data which respectively correspond to the same eye but a different gaze.

According to some embodiments of the invention the method comprises, prior to the extraction of the locations, capturing at least one image of each of the at least one individual at one or more predetermined gazes, thereby providing the previously-recorded data.

According to some embodiments of the invention the method comprises processing the previously-recorded data so as to compute eye parameters wherein the replacing is based on the computed parameters.

According to some embodiments of the invention the computation of the parameters is bootstrapped using a non-specific database of eye images.

According to some embodiments of the invention the method comprises applying a morphological transformation to the previously-recorded data according to the parameters.

According to some embodiments of the invention the invention the method comprises varying the parameters so as to optimize a predetermined objective function describing matching between the replacement data and images in the non-specific database.

According to some embodiments of the invention the method comprises varying the parameters so as to optimize a predetermined objective function describing matching between the replacement data and the imagery data associated with the location of the eye.

According to some embodiments of the invention the method comprises, for each eye, determining whether an eyelid of the eye is close or open, wherein the imagery data is replaced with the replacement data only if the eyelid is open.

According to some embodiments of the invention the method comprises, for each eye, determining a characteristic gaze direction of the eye, wherein the imagery data is replaced with the replacement data only if the gaze direction is other than a predetermined gaze direction.

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According to some embodiments of the invention the method comprises, processing the image to replace imagery data associated with each location of each eye with additional replacement data to provide at least one additional corrected image such that each corrected image is characterized by a different gaze, and transmitting each corrected image to a different display device.

According to some embodiments of the invention the method comprises for each eye, determining a characteristic gaze direction of the eye, wherein the at least one additional corrected image is generated responsively to the determined characteristic gaze direction.

According to an aspect of some embodiments of the present invention there is provided a computer software product, comprising a computer-readable medium in which program instructions are stored. The instructions, when read by a processer, cause the processer to process the image so as to extract locations of at least one eye over the image, to provide a corrected image by replacing imagery data associated with each location of each eye with replacement data and to transmit the corrected image to a display device. The replacement data are preferably previously-recorded imagery data respectively corresponding to the same eye but a different gaze.

According to an aspect of some embodiments of the present invention there is provided an imaging system. The imaging system comprises: (a) a camera for capturing an image of at least one individual having eyes; and (b) a processer configured for: processing the image so as to extract locations of at least one eye over the image, processing the image to replace imagery data associated with each location of each eye with replacement data, thereby providing a corrected image, and transmitting the corrected image to a display device. The replacement data are preferably being previously-recorded imagery data respectively corresponding to the same eye but a different gaze

According to some embodiments of the invention the previously-recorded imagery data are processed by the processor so as to compute eye parameters wherein the imagery data are replaced based on the computed parameters.

According to some embodiments of the invention the computation of the parameters is bootstrapped using an annotated non-specific database of eye images.

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According to some embodiments of the invention the the previously-recorded data are transformed by the processor using a morphological transformation according to the parameters.

According to some embodiments of the invention the parameters are varied by the processor so as to optimize a predetermined objective function describing matching between the replaced data and the replacement data.

According to some embodiments of the invention the image is processed by the processor to determine whether an eyelid of the eye is close or open, and wherein the imagery data is replaced with the replacement data only if the eyelid is open.

According to some embodiments of the invention the image is processed by the processor to determine a characteristic gaze direction of the eye wherein the imagery data is replaced with the replacement data only if the characteristic gaze direction is other than a predetermined gaze direction.

According to some embodiments of the invention the image is processed by the processor to replace imagery data associated with each location of each eye with additional replacement data to provide at least one additional corrected image, such that each corrected image is characterized by a different gaze, and transmitting each corrected image to a different display device.

According to some embodiments of the invention the image is processed by the processor to determine a characteristic gaze direction of the eye, wherein the at least one additional corrected image is generated responsively to the determined characteristic gaze direction.

According to some embodiments of the invention the extraction of the locations comprises, for each eye: detecting eye corners, defining a region-of-interest based on the corners and scaling the region-of-interest to predetermined dimension.

According to some embodiments of the invention the previously-recorded imagery data is stored in a computer-accessible specific database of imagery data, and wherein the replacement of the imagery data comprises searching over the specific database for the previously-recorded imagery data.

According to some embodiments of the invention the search comprises comparing imagery data of the image with imagery data entries in the specific database,

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determining a similarity level responsively to the comparison, and selecting the previously-recorded imagery data based on the similarity level.

According to some embodiments of the invention the image is a frame of a video stream.

According to some embodiments of the invention the replacement data are selected from a specific database according to an optimization procedure which comprises a first objective function for reducing differences between the replacement data and replacement data of a previous frame, and a second objective function for reducing differences between the replacement data and replacement data of a frame immediately following an eyelid opening of the respective eye.

Unless otherwise defined, all technical and/or scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the invention pertains. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of embodiments of the invention, exemplary methods and/or materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and are not intended to be necessarily limiting.

Implementation of the method and/or system of embodiments of the invention can involve performing or completing selected tasks manually, automatically, or a combination thereof. Moreover, according to actual instrumentation and equipment of embodiments of the method and/or system of the invention, several selected tasks could be implemented by hardware, by software or by firmware or by a combination thereof using an operating system.

For example, hardware for performing selected tasks according to embodiments of the invention could be implemented as a chip or a circuit. As software, selected tasks according to embodiments of the invention could be implemented as a plurality of software instructions being executed by a computer using any suitable operating system. In an exemplary embodiment of the invention, one or more tasks according to exemplary embodiments of method and/or system as described herein are performed by a data processor, such as a computing platform for executing a plurality of instructions. Optionally, the data processor includes a volatile memory for storing instructions and/or data and/or a non-volatile storage, for example, a magnetic hard-disk and/or removable

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media, for storing instructions and/or data. Optionally, a network connection is provided as well. A display and/or a user input device such as a keyboard or mouse are optionally provided as well.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments of the invention are herein described, by way of example only, with reference to the accompanying drawings and images. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of embodiments of the invention. In this regard, the description taken with the drawings makes apparent to those skilled in the art how embodiments of the invention may be practiced.

In the drawings:

FIG. 1 is a flowchart diagram of a method suitable for correcting gaze offset in an image of one or more individuals, according to various exemplary embodiments of the present invention;

FIGs. 2A-D are schematic illustrations of imagery data representing an offset gaze (FIGs. 2A and 2C) and replacement imagery data representing a corrected gaze (FIGs. 2B and 2D), according to various exemplary embodiments of the present invention;

FIGs. 2E-G are schematic illustrations of embodiments of the invention in which gaze correction is used for multilateral conferencing;

FIG. 3 is a flowchart diagram of a method suitable for correcting gaze offset in an optional embodiment of the invention in which the method also captures the replacement data;

FIG. 4 is a flowchart diagram of a method suitable for correcting gaze offset in embodiments of the invention in which the method comprises one or more additional optional operations;

FIG. 5 is a schematic illustration of a representative eye model, according to some embodiments of the present invention;

FIG. 6 is a flowchart diagram illustrating a procedure suitable for extracting the locations of an eye an image, according to some embodiments of the present invention;

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FIG. 7 is a flowchart diagram illustrating a procedure suitable for constructing an annotated specific database, according to some embodiments of the present invention;

FIG. 8 is a schematic illustration of an imaging system 80, according to various exemplary embodiments of the present invention;

FIGs. 9A-D shows four images of two individuals captured during experiments performed according to some embodiments of the present invention;

FIGs. 10A-D show samples of successful (FIGs. 10A-C) and unsuccessful (FIG. 10D) facial feature points detection obtained by eye corner localization, according to some embodiments of the present invention;

FIGs. 11A-F show initially fitted model (red) and refined model obtained by a search procedure (green) as obtained in experiments performed according to some embodiments of the present invention;

FIGs. 12A-D show the effect of combined optimization procedure, according to various exemplary embodiments of the present invention;

FIGs. 13A-D demonstrates an eye replacement procedure employed in experiments performed according to some embodiments of the present invention; and

FIG. 14 shows several frames from some of the video sequences processed in experiments performed according to some embodiments of the present invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS OF THE INVENTION

The present invention, in some embodiments thereof, relates to image processing and, more particularly, but not exclusively, to a method and system for processing an image to correct gaze offset.

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not necessarily limited in its application to the details of construction and the arrangement of the components and/or methods set forth in the following description and/or illustrated in the drawings and/or the Examples. The invention is capable of other embodiments or of being practiced or carried out in various ways.

FIGS. 1, 3 and 4 are flowchart diagrams of a method suitable for correcting gaze offset in an image of one or more individuals, according to various exemplary embodiments of the present invention.

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Computer programs implementing the method of this invention can commonly be distributed to users on a distribution medium such as, but not limited to, a floppy disk, a CD-ROM, a flash memory device and a portable hard drive. From the distribution medium, the computer programs can be copied to a hard disk or a similar intermediate storage medium. The computer programs can be run by loading the computer instructions either from their distribution medium or their intermediate storage medium into the execution memory of the computer, configuring the computer to act in accordance with the method of this invention. All these operations are well-known to those skilled in the art of computer systems.

The method of the present embodiments can be embodied in many forms. For example, it can be embodied in on a tangible medium such as a computer for performing the method steps. It can be embodied on a computer readable medium, comprising computer readable instructions for carrying out the method operations. In can also be embodied in electronic device having digital computer capabilities arranged to run the computer program on the tangible medium or execute the instruction on a computer readable medium.

It is to be understood that, unless otherwise defined, the operations described hereinbelow can be executed either contemporaneously or sequentially in many combinations or orders of execution. Specifically, the ordering of the flowchart diagrams is not to be considered as limiting. For example, two or more operations, appearing in the following description or in the flowchart diagrams in a particular order, can be executed in a different order (*e.g.*, a reverse order) or substantially contemporaneously. Additionally, several operations described below are optional and may not be executed.

The image is in the form of imagery data arranged gridwise in a plurality of picture-elements (*e.g.*, pixels, group of pixels, *etc.*).

The term "pixel" is sometimes abbreviated herein to indicate a picture-element. However, this is not intended to limit the meaning of the term "picture-element" which refers to a unit of the composition of an image.

References to an "image" herein are, *inter alia*, references to values at picture-elements treated collectively as an array. Thus, the term "image" as used herein also encompasses a mathematical object which does not necessarily correspond to a physical

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object. The original and processed images certainly do correspond to physical objects which are the scene from which the imaging data are acquired. The scene preferably includes one or more faces of individuals. In any event, the scene includes the eyes of the individuals.

In various exemplary embodiments of the invention the method of the present embodiments analyzes a stream of imaging data. The stream can be in the form of a series of images or a series of batches of images captured at a rate which is selected so as to provide sufficient information to allow spatial as well as time-dependent analysis. For example, the images can be acquired by a video camera. A single image in a stream of images such as a video stream is referred to as a frame.

The picture-elements of the images are associated with intensity values preferably, but not necessarily, at different colors.

Ideally, the input to the method is the amount of light as a function of the wavelength of the light at each point of a scene. This ideal input is rarely attainable in practical systems. Therefore, the scope of the present embodiments includes the processing of a sampled version of the scene. Specifically, the input to the method of the present embodiments is digital signals resolvable to discrete intensity values at each pixel over the grid. Thus, the grid samples the scene, and the discrete intensity values sample the amount of light. The update rate of the images in the stream provides an additional sampling in the time domain.

Each pixel in the image can be associated with a single intensity value, in which case the image is a grayscale image. Alternatively and preferably, each pixel is associated with three or more intensity values sampling the amount of light at three or more different color channels (*e.g.*, red, green and blue) in which case the image is a color image. Also contemplated are images in which each pixel is associated with a mantissa for each color channels and a common exponent (*e.g.*, the so-called RGBE format). Such images are known as "high dynamic range" images.

The method of the present embodiments corrects a gaze offset in an image using previously-recorded imagery data which correspond to other image or images. Herein, the image in which the gaze offset is to be corrected is referred to as the "image **100**," and the image corresponding to the previously-recorded imagery data is referred to as "image **50**." Oftentimes, for clarity of presentation, the terms "currently processed

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image" or "original image" will be used instead of "image **100**," and "replacement image" will be used instead of "image **50**."

Referring now to FIG. 1, the method begins at **10** and continues to **11** at which image **100** is processed to extract locations of one or more of the eyes over image **100**. The locations of the eyes can be extracted using any known image processing technique for automatic extraction of features from an image. A preferred technique for extracting the locations of the eyes according to some embodiments of the present invention is described hereinunder with reference to FIG. 6.

The method proceeds to **12** at which image **100** is processed to replace imagery data associated with each location of each eye with replacement data. The replacement data includes previously-recorded imagery data respectively corresponding to the same eye of the same individual but at a different gaze. In various exemplary embodiments of the invention the gaze characterizing the replacement data is a forward gaze, while the gaze characterizing the replaced data is offset with respect to the forward gaze.

The situation is illustrated in FIGS. 2A-D. FIG. 2A illustrates a front view of an eye **20** at a particular gaze. In the schematic illustration of the FIG. 2A the gaze is directed downward. The gaze direction is defined as the optical axis of the eye, namely a straight line connecting the retina's macula and the optical center of the cornea. The gaze direction is better shown in FIG. 2C which illustrates a side view of eye **20**. As shown, gaze direction **22** is directed downward at an angle α, relative to the horizontal direction. FIGS. 2B and 2D illustrate a front view (FIG. 2B) and a side view (FIG. 2D) of the same eye **20** at a gaze direction **24**, which is different from gaze direction **22**. In the illustrations of FIGS. 2B and 2D the gaze is directed forwardly along the horizontal direction. Thus, FIG. 2A (or FIG. 2C) represents the imagery data of the original image (image **100**) and FIG. 2B (or FIG. 2D) represents the respective replacement data. The image corresponding to the replacement data is designated **50** in FIGS. 2B and 2D.

Typically, image **100** includes a front view of the eyes, but the use of the method of the present embodiments for non-frontal views (*e.g.*, side view images) is not excluded from the scope of the present invention. It is to be understood that although FIGS. 2A-D illustrate a situation in which a downward gaze is replaced with a forward gaze, this need not necessarily be the case, since the original image may includes a gaze directed to another direction (*e.g.*, upward or to the sides). Furthermore, for some

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application it may be desired to have replacement data that correspond to a non-forward gaze. In various exemplary embodiments of the invention the gaze in the replacement data is substantially collinear with the optical axis of the imaging device that captures the eyes.

Typically, the replacement data are stored on a computer readable medium as a computer-accessible specific database of imagery data, and the method accesses the database for obtaining the replacement data. The database is "specific" in the sense that it includes images (or imagery data representing images) of the eyes of the same individual(s) that appear in the currently processed image (image **100**).

The data in the specific database is preferably in a digital form. Optionally and preferably, the specific database includes data pertaining to several images of each eye, and the method searches the specific database for replacement data that best matches the eyes in image **100**. Once the respective imagery data in image **100** is replaced with the replacement data, a corrected image is formed.

The term "corrected image" refers to an image in which the gaze of at least one eye in the image differs from the gaze of the same eye at the time of image capture.

The replacement of the data may optionally include one or more of the following operations: artificial enlargement of the eyes (*e.g.*, by a factor of 5-15%), adjustment of image illumination and application of a processes known as "feathering" particularly to the border of the replacement image. A preferred procedure for replacing the data in the original image with the replacement data is provided in the Examples section that follows. Optionally, two or more corrected images, each characterized by a different gaze direction, are formed. This embodiment is particularly useful, for example, for multilateral videoconferencing as further detailed hereinafter.

The method continues to **14** at which the corrected image is transmitted to a display device. The transmission is typically over a communication network to a remote location in which a remote display device receives the corrected image and displays it. When more than one corrected image is formed, each corrected image can be transmitted to a different display device.

The method ends at **15**.

Before providing a further detailed description of the system and method for correcting gaze offset, as delineated hereinabove and in accordance with the present

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embodiments, attention will be given to the advantages and potential applications offered thereby.

The system and method of the present embodiments are particularly useful in videoconferencing wherein the gaze of a given participant in the videoconference is corrected according to some embodiments of the present invention so as to provide the other participants with a natural view of the given participant. The system and method can be used in bilateral as well as multilateral videoconferencing.

For bilateral videoconferencing, the system and method preferably correct the gaze of the local participant such that the remote participant receives a view of the local participant as if he or she were looking into the camera, namely by correcting the gaze to a direction that is collinear with the optical axis of the camera.

For multilateral videoconferencing, the system and method preferably provides more than one gaze corrected images of the local participant. The situation is better explained with reference to FIGS. 2E-G. Consider a videoconferencing with three participants P1, P2 and P3. In FIG. 2E, participant P1 is local (seen from the back) and participants P2 and P2 are situated at remote locations. Images of P1 and P2 are transmitted to one or more display devices which are viewed by P1. FIG. 2E is similar to FIG. 2E except that P2 is local (seen from the back) and is viewing images of P2 and P3 which are situated at remote locations. FIG. 2F is also similar to FIG. 2E except that P3 is local and is viewing images of remote participants P1 and P2.

Referring to FIG. 2E, suppose that P1 is looking at P2 along gaze direction **22**. In this case, the system and method according to some embodiments of the present invention generate two gaze corrected images of P1. In the first corrected image, P1 is seen as if he or she were looking into the camera. This corrected image is transmitted to P2's location, as illustrated in FIG. 2F where the first corrected gaze of P1 is indicated by arrow **24a**. In the second corrected image, P1 is seen as if he or she were looking leftward. This corrected image is transmitted to P3, as illustrated in FIG. 2G, where the second corrected gaze of P1 is indicated by arrow **24b**. As shown in FIG. 2G, P1 is seen to P3 as if he or she were looking in the direction of P2, thus creating an illusion of a face to face meeting.

The method and system of the present embodiments can also produces images of a virtual conference room and transmit them to the display devices of the participants.

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The virtual conference room can include images of participants and optionally also three-dimensional models of computer graphics representing, for example, a table and the inside of the conference room. Preferably, when each participant is arranged at its respective position in the virtual conference room, each participant sees the virtual conference room from a location at which the participant is arranged. Accordingly, the image of the virtual conference room which is viewed by each participant on its display is different among the different conference displays.

The method and system of the present embodiments can be used for correcting images of one of the participants, *e.g.*, locally via a data processor which can be located anywhere but is typically located at the respective participant's location, or they can be employed for correcting images of more than one participant, preferably all the participants via a central data processor.

When the method and system are employed for correcting images of more than one of the participants, non-corrected images as well as specific databases can be transmitted to a central location to allow the method and/or system generating the corrected images of two or more (*e.g.*, all) participants at the central location, and distribute them among the conference display devices. The central location can be a location which is remote with respect to all participants, or it can be the location of one of the participants (and remote with respect to all other participants).

FIG. 3 illustrates the method in an optional embodiment of the invention in which the method also captures the replacement data. In this embodiment, the method begins at **10** and continues to **31** at which one or more images of each of the individuals are captured at a one or more predetermined gazes, for example, a forward gaze, a sideward gaze and a gaze having a gaze direction which is substantially collinear with the optical axis of the imaging device that captures the eyes. The images of the eyes captured at **31** are used as replacement data.

The method optionally and preferably proceeds to **32** at which the captured replacement data is stored in a computer readable medium so as to form a computer-accessible specific database. A preferred procedure for constructing a computer-accessible specific database according to some embodiments of the present invention is provided hereinunder with reference to FIG. 7. At **33** the method receives image **100**. From **33** the method continues **11**, **12**, **14** and **15** as further detailed hereinabove.

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FIG. 4 illustrates the method in embodiments of the invention in which one or more additional optional operations are employed.

The method begins at **10** and optionally and preferably continues to **31** at which one or more images of each of the individuals are captured at one or more predetermined gazes to form replacement data, and **32** at which the replacement data is stored to form a specific database as further detailed hereinabove. Optionally, the imagery data recorded at **31** is processed so as to compute eye parameters characterizing the eyes represented by the data. The eye parameters are preferably also stored in the specific database such as to form an annotated specific database, wherein each image in the database is annotated by a respective set of parameters.

The eye parameters can be computed according to a predetermined eye model. Representative examples of eye parameters suitable for the present embodiments include, but are not limited to, the location of the center of the eye relative to one of the corners of the eye, the location of a corner of the eye relative to another corner of the eye, orientation of the eye, width of the eye, height of the eye above a line connecting the corners of the eye, height of the eye below the line connecting the corners of the eye, parameters defining one or more curved sections (*e.g.*, parabola, hyperbola, ellipsis) conjointly modeling the boundary of the eye, the radius of the iris, *etc.*

A representative non-limiting example of an eye model suitable for the present embodiments is illustrated in FIG. 5. A rectangle system of coordinate is defined over an image **50** which includes eye **20**, such that the axes x and y of the system are parallel to the image gridlines (not shown) and the origin O(0, 0) is defined at one of the corners of the eye (the leftmost corner in the present example). The antipodal corner (the rightmost corner in the present example) is marked A, and the straight line segment connecting the two corners is referred to hereinbelow as the OA line segment. The eye model defines the shape of the imaged eye in terms of six parameters: the center (X_C, Y_C) of the eye (middle point of OA), the width w of the eye (length of OA), a first height h_1 measured perpendicularly to and above OA, a second height h_2 measured perpendicularly to and below OA, and an angle θ describing the orientation of OA (measured anticlockwise relative to the x direction in the present example).

Also contemplated is the use of one or more of the eye model parameters described in the literature [see, for example, Yuille *et al.* "Feature extraction from faces

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using deformable templates," International Journal of Computer Vision, 8:2, 99-111 (1992), and Tian *et al.*, "Dual-state parametric eye tracking," in Automatic Face and Gesture Recognition, pages 110-115(2000), the contents of which are hereby incorporated by reference].

The characterization of the replacement data using the eye model parameters can serve for comparing the respective data in the currently processed image (image **100**) with the replacement data (*e.g.*, the eyes in the specific database).

At **33** the method receives image **100** for processing and at **11** the method extracts the locations of the eyes over image **100** as described above and further detailed hereinunder with reference to FIG. 6. The method optionally continues to decision **42** at which the method determines whether or not the eyelid **26** of eye **20** is close or open. In other words, at **42** the method attempts to determine whether or not the individual(s) in image **100** is in a blink state. The determination can be based on the results of extraction **11**. For example, the method can determine that the eyelid is close when the method fails to identify the eye in image **100** (*i.e.*, when the extraction of eye's location fails) and that the eyelid is open when the eye is identified (*i.e.*, when the extraction of eye's location is successful).

If the eyelid is close, the method loops back to **33**, waits to receive another image for processing (*e.g.*, the successive frame of the video stream) and continues thereafter to **11**. If the eyelid is open, the method optionally continues to decision **44** at which the method determines a characteristic gaze direction of the eye and decides, based on the characteristic gaze, whether or not there is a gaze offset. A gaze offset is defined as a gaze having a direction other than a predetermined gaze direction. Preferably the predetermined gaze direction is collinear with the optical axis of the imaging device that captured image **100**.

If the method identifies that the gaze is generally at the predetermined gaze direction (*i.e.*, there is no gaze offset) the method loops back to **33**, waits to receive another image for processing (*e.g.*, the successive frame of the video stream) and continues thereafter to **11**. If the method determines that the gaze direction substantially deviates from the predetermined gaze direction (for example, deviation of more than 5°) a gaze offset is identified and the method optionally continues to **45**.

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The gaze direction can be determined by any technique known in the art. In some embodiments of the present invention, a machine-learning procedure is used. The machine-learning procedure can be trained, preferably prior to the execution of the method, on a collection of training images each being annotated with a gaze direction, to provide a trained gaze direction classifier. Once trained, the gaze direction classifier can be applied to the previously-recorded data (image **50**) to thereby extract the gaze direction characterizing image **50**. Since image **50** corresponds to the desired gaze direction, the gaze direction as obtained by the classifier from image **50** can be used as the predetermined gaze direction for the purpose of decision **44**.

In embodiments in which a specific database is employed, the classifier is preferably applied to all images in the specific database to obtain a range of gaze directions characterizing the database. In operation, the classifier is applied to image **100** (or some region-of-interest thereof) to obtain the gaze direction of image **100**. If the gaze direction of image **100** is not within the ranged characterizing the specific database, the method determines that there is a gaze offset. Otherwise, the method determines that there is no gaze offset.

At **45** the eye parameters of image **100** are computed. In embodiments in which the replacement data (image **50**) is processed to compute eye parameters, the computations of parameters for the currently processed image (image **100**) are preferably according to the same eye model that is used for computing the parameters for image **50**. For example, when a six-parameter eye model (*e.g.*, the model illustrated in FIG. 5) is used for characterizing image **50**, the same six-parameter eye model is used for characterizing the eyes in image **100**.

The parameters as computed at **45** can also be used for determining whether or not the eyelid is open. In these embodiments, **45** is executed before decision **42** and the decision at **42** is by imposing a predetermined set of criteria to the computed parameters. For example, when the parameters includes one or more height parameters measured perpendicularly to the straight line connecting the corners of the eyes (*e.g.*, the aforementioned heights h_1 and h_2) the method can determine that the eyelid is close when the value of each of the height parameters is below a predetermined threshold or when the sum of two or more height parameters is below a predetermined threshold. A suitable threshold for this embodiment of the invention is about 5 pixels or about 4

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pixels or about 3 pixels or about 2 pixels. In some embodiments of the present invention the method determines that the eyelid is close when both h_1 and h_2 are less than 2 pixels.

The method optionally continues to **46** at which the computer-accessible specific database is searched for replacement data that matches the eyes in image **100**. Typically, such search includes comparison between the imagery data of image **100** with imagery data entries in the database and determination of a similarity level responsively to the comparison. The replacement data can then be selected based on the calculated similarity level. Typically, the data with highest similarity level is selected.

Any type of similarity measure can be employed for calculating the similarity level during the comparison. In some embodiments of the present invention normalized cross correlation is used.

The comparison can also be done in terms of the computed eye model parameters, wherein the eye model parameters as computed for image **100** are compared with the eye parameters as computed for image **50**. In these embodiments, the search over the specific database is performed in a multidimensional space spanned by the eye-model parameters. For example, when an n-parameter eye model is employed, the search is conducted in an n-dimensional space.

The method optionally continues to **47** at which a morphological transformation is applied to the replacement data according to the eye model parameters. This transformation is preferably executed so as to rescale image **50** to fit the eye in image **100**. The transformation can include any of: translation, rotation, stretching and shrinking. For example, when the six-parameter eye model of FIG. 5 is used (both for image **50** and image **100**), the center can be shifted by the differences in the respective X_C and Y_C values, the width w can be scaled by the ratio of the respective w values, the regions above and below the OA line segment can be stretched or shrunk in accordance with the respective h_1 and h_2 values, and the entire replacement eye image can be rotated by the difference in the respective θ values. The transformation can also be part of the search over the database. Specifically, the transformation can be applied to each candidate eye in the database and the comparison can be made between the morphologically transformed candidate eye and the eye of the currently processed image.

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When image **100** is a frame of a video stream, the search for best matching eyes in the database can also be based on the results of previous searches. For example, the replacement data of the previous frame can be used as the initial guess for a candidate in the current frame. This initial guess can be refined, preferably by conducting a further search in the database, so as to obtain a better match. The search can include a combined optimization procedure which comprises a first objective function for reducing differences between the replacement data and replacement data of the previous frame and a second objective function for reducing differences between the replacement data and replacement data of a frame immediately following an eyelid opening. The present inventors discovered that such combined optimization procedure reduces drift over time and accumulation of tracking errors. This embodiment is particularly useful for preventing the eye to gradually shrink. For the first and second objective functions, any statistical moment can be used, such as, but not limited to, sum of squared differences.

The method optionally continues to **48** at which the parameters of the eye in image **50** (the replacement data) are varied so as to optimize a predetermined objective function (*e.g.*, normalized cross correlation) describing matching between the eye in image **100** and the eye in image **50**. The method continues to **49** at which, imagery data associated with each location of each eye is replaced with the matched, and optionally varied, replacement data, to provide a corrected image.

Optionally, more than one corrected image is formed, where each corrected image is characterized by a different gaze. The gaze of each corrected image can be selected responsively to the gaze as determined (*e.g.*, using the trained classifier) for the original image. For example, when the method is employed for multilateral videoconferencing, the gaze of the original image can be analyzed to determine to which of the participants on the local display eyes **20** are directed. Then, for each of the displayed participants, a corrected image with a different gaze is formed, e.g., a corrected image with a forward gaze for the looked-at participant, and a corrected image with a sideward gaze to the other participants, as explained hereinabove and exemplified in FIGS. 2E-G.

The method continues to **14** at which the corrected image or images is transmitted to a display device or display devices, as further detailed hereinabove.

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The method ends at **15**.

Reference is now made to FIG. 6 which is a flowchart diagram illustrating a procedure suitable for extracting the locations of an eye an image, according to some embodiments of the present invention. The procedure is particularly useful for extracting the locations of the eyes in image **100** or image **50**. Thus, the procedure can be used for executing operation **11** of the embodiments described with reference to FIGS. 1, 3 and 4.

The procedure begins at **60** and continues to **61** at which the corners of the eye (see points O and A in FIG. 5) are detected. This can be done using any image processing technique known in the art. In some embodiments of the present invention the procedure employs the technique disclosed in Everingham *et al.*, "Hello! My name is... Buffy' - automatic naming of characters in TV video," In BMVC, 2006, the contents of which are hereby incorporated by reference, or some variant thereof.

The procedure continues to **62** at which a region-of-interest is defined using the two detected corners. In various exemplary embodiments of the invention a rectangular region-of-interest is defined. For example, the region-of-interest can be a rectangle whose width approximately equals or slightly above the distance w between the two corners (see FIG. 5) and height is less than the w. In experiments performed by the present inventors a rectangular region-of-interest having dimensions of $1.2w \times 0.6w$ was used. The region-of-interest was defined such that the OA line segment (see FIG. 5) passed through the center of the rectangle parallel to its longest dimension. Other shapes, dimensions, and relative locations of the region-of-interest are not excluded from the scope of the present invention.

The procedure continues to **63** at which the region-of-interest is scaled to predetermined dimensions. In the experiments performed by the present inventors, the rectangular region-of-interest was scaled to an image of 120×80 pixels. Other scaling schemes are not excluded from the scope of the present invention.

The procedure ends at **64**.

Reference is now made to FIG. 7 which is a flowchart diagram illustrating a procedure suitable for constructing a specific database, according to some embodiments of the present invention. The procedure can be used for executing operations **31** and **32** of the embodiments described with reference to FIGS. 3 and 4.

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The procedure begins at **70** and continues to **71** at which a set of images are captured for at least one individual at one or more predetermined gazes. The gaze(s) can be a forward gaze, a sideward gaze, a gaze having a gaze direction which is substantially collinear with the optical axis of the imaging device that captures individual(s) *etc*. The following operations are preferably performed for each image in the set.

The procedure continues to **72** at which the location of each eye is extracted from the respective image of the set. This is preferably executed by means of the procedure described above with reference to FIG. 6. Thus, eye corners are detected and region-of-interests are defined and scaled as further detailed hereinabove.

The procedure then continues to **73** at which the respective image is processed so as to extract image features pertaining to the eyes in the image. The image features can be extracted in more than one. For example, in some embodiments, a Scale-Invariant Feature Transform (SIFT) representation is employed. This representation is known in the art and is found, *e.g.*, in U.S. Patent No. US Patent 6,711,293, the contents of which are hereby incorporated by reference.

While the embodiments below are described with a particular emphasis to the SIFT representation, it is to be understood that more detailed reference to SIFT is not to be interpreted as limiting the scope of the invention in any way, and that other representations, including, without limitation, gray values in the region-of-interest, are not excluded. Also contemplated are combinations of representations for better accuracy.

The SIFT descriptors can be computed over a dense grid for the scaled region-of-interest. In experiments performed by the present inventors, a 6×4 grid was employed, but other grid densities are not excluded from the scope of the present invention. Once all the SIFT descriptors are computed, they are preferably concatenated into a vector.

At **74** the extracted features (*e.g.*, the vector of SIFT descriptors) are fed to a machine learning algorithm for computing approximated eye parameters according to a predetermined eye model, such as the aforementioned six-parameter model or any eye model known in the art. In various exemplary embodiments of the invention the computation of approximated eye parameters is bootstrapped by means of an annotated non-specific database of imagery data. The database is "non-specific" in the sense that it includes images (or imagery data representing images) of eyes of several individuals

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which are not necessarily the individual(s) which are imaged at **71**. Preferably, the non-specific database includes images (or imagery data representing images) of eyes of at least one or at least two or at least three or at least four or at least five individuals other than the individuals that appear in the set of images. The non-specific database is "annotated" in the sense that each image in the non-specific database is associated with a set of eye-parameters that define, preferably uniquely, the eye in that image. In experiments performed by the present inventors, a non-specific annotated database of approximately 200 images of 14 different individuals was used, but other sizes of non-specific database are not excluded from the scope of the present invention.

Let *i* be some image captured at **71**. The machine learning algorithm accesses the annotated non-specific database and compares the features (as extracted at **73**) of image *i* to features in the images of the non-specific database. Based on this comparison, the machine learning algorithm computes the approximated eye parameters of image *i*. In various exemplary embodiments of the invention the procedure selects from the non-specific database an image *j* which best matches image *i*.

Any type of machine learning algorithm can be used. Preferably, the machine learning algorithm features supervised learning. Representative examples of machine learning algorithm suitable for the present embodiments include, without limitation, support vector machine (SVM) regression, nearest neighbor classifier and the like. These types of machine learning algorithms are known in the art and are found, *e.g.*, in U.S. Patent Nos. 6,892,193 and 6,134,344 and U.S. Published Application No. 20080187213, the contents of which are hereby incorporated by reference.

The procedure then continues to **76** at which the parameters are varied so as to optimize a predetermined objective function (*e.g.*, normalized cross correlation) describing matching between the respective image of the set (captured at **71**) and the images in the non-specific database. In various exemplary embodiments of the invention the objective function describes matching between image *i* of the set and image *j* of the non-specific database. This operation is preferably preceded by a morphological transformation **75** selected so as to rescale image *j* to fit image *i*. The morphological transformation is preferably applied according to the eye model parameters, as further detailed hereinabove.

The procedure ends at **77**.

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Reference is now made to FIG. 8 which is a schematic illustration of an imaging system **80**, according to various exemplary embodiments of the present invention. System **80** comprises a camera **82** for capturing an image of at least one individual **84** having eyes **20**, and a processer **86** configured for processing the image so as to extract locations of the eyes over the image and replace imagery data associated with each location of each eye with replacement data as further detailed hereinabove. Processor **86** can also be configured for transmitting the corrected image to a remote display device (not shown). System **80** can also include a local display device or monitor **90** for presenting individual **84** with a view of an image of another individual (not shown) at a remote location. In one application of system **80**, camera **82** captures an image or a stream of images of individual **84** while he or she is looking into monitor **90**. Since individual **84** is looking into monitor **90** and not camera **82**, there is a gaze offset in the captured image or images. Processor **86** corrects the gaze offset and transmits the corrected image(s) to one or more remote display devices. In the corrected image(s), individual **84** is seen as if he or she were looking into camera **82** (*e.g.*, at a forward gaze), or as if he or she were looking at another participant. In some embodiments of the present invention, system **80** constructs a computer-accessible specific database of replacement imagery data. In these embodiments, camera **82** captures a set of images and processor **86** processes these images for constructing the specific database, as further detailed hereinabove.

Processor **86** can be supplemented by a computer software product, which comprises a computer-readable medium **88** in which program instructions are stored. The instructions, when read by processer **86**, cause the processer to process the image and transmit the corrected image to a display device. The program instructions can also cause processer **86** to construct the specific database, as further detailed hereinabove.

As used herein the term "about" refers to ± 10 %.

The word "exemplary" is used herein to mean "serving as an example, instance or illustration." Any embodiment described as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments and/or to exclude the incorporation of features from other embodiments.

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The word "optionally" is used herein to mean "is provided in some embodiments and not provided in other embodiments." Any particular embodiment of the invention may include a plurality of "optional" features unless such features conflict.

The terms "comprises", "comprising", "includes", "including", "having" and their conjugates mean "including but not limited to".

The term "consisting of" means "including and limited to".

The term "consisting essentially of" means that the composition, method or structure may include additional ingredients, steps and/or parts, but only if the additional ingredients, steps and/or parts do not materially alter the basic and novel characteristics of the claimed composition, method or structure.

As used herein, the singular form "a", "an" and "the" include plural references unless the context clearly dictates otherwise. For example, the term "a compound" or "at least one compound" may include a plurality of compounds, including mixtures thereof.

Throughout this application, various embodiments of this invention may be presented in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the invention. Accordingly, the description of a range should be considered to have specifically disclosed all the possible subranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed subranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

Whenever a numerical range is indicated herein, it is meant to include any cited numeral (fractional or integral) within the indicated range. The phrases "ranging/ranges between" a first indicate number and a second indicate number and "ranging/ranges from" a first indicate number "to" a second indicate number are used herein interchangeably and are meant to include the first and second indicated numbers and all the fractional and integral numerals therebetween.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination

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in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination or as suitable in any other described embodiment of the invention. Certain features described in the context of various embodiments are not to be considered essential features of those embodiments, unless the embodiment is inoperative without those elements.

Various embodiments and aspects of the present invention as delineated hereinabove and as claimed in the claims section below find experimental support in the following examples.

EXAMPLES

Reference is now made to the following examples, which together with the above descriptions illustrate some embodiments of the invention in a non limiting fashion.

Prototype System for Videoconferencing

A prototype system for correcting gaze offset was constructed according to some embodiments of the present invention. In experiments performed using the system, the system successfully replaced the eyes of a person in a video stream with eyes that look straight ahead. Eyes were captured at an initial training stage. During the videoconferencing session, the system found and tracked the eyes. In every frame, the eyes captured during training were accurately pasted to create an illusion of straight-looking gaze.

FIGS. 9A-D shows four images of two individuals captured during the experiments. FIGS. 9A and 9D are control images in which the respective individual was captured at a forward gaze, and FIGS. 9B and 9C are images which were corrected by the prototype system and in accordance with preferred embodiments of the present invention. Surprisingly, the resulting effect of replacing the eyes alone looked natural.

The prototype system included an eye detector for receiving an image of a face and returning an accurate position of the eye. Once eye location was detected, it was replaced with an image of the same eye but with a proper gaze direction. To achieve this goal the system learned a regression function that mapped face images to eye model

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parameters, using a non-specific database of annotated images. This stage was followed with a refinement stage.

The experiments included three stages, as follows. In a first stage, referred to as "offline training", a rough eye pose estimation was learned from the annotated non-specific database. This database was a general database, unrelated to the any particular videoconferencing session. A second stage was executed at the beginning of the video conferencing session where the users were requested to look straight at the camera. This allowed the system to construct a specific database of direct gaze images. In a third stage the system detected the location of the eye in the current frame, found the most similar image in the specific database and replaced it. The eye model that was used in the experiments included six parameters, as depicted in FIG. 5 above.

In the offline training stage, the direct gaze models were learned based on previous annotated examples. These examples were stored in a non-specific database that was used to bootstrap the runtime system. It consisted of a separate set of 14 individuals for whom videos were captured and manually annotated in accordance with the six-parameter model.

In the second stage, the specific database was constructed. Given images of a new person looking directly into the camera, the closest eye in the non-specific database was retrieved and then served as an initial guess as to the eye parameters in the new image. These parameters were then adapted to provide a more accurate estimation.

In the third stage, the parameters of the eyes in the video were estimated by matching the image to the eyes of the person when looking straight. The illumination was corrected, and a replacement was performed.

Following is a more detailed description of the experiments.

Training

Given a video of a person looking directly into the camera, the eye parameters were found by the system. This was done for each frame independently, thereby collecting pairs of straight looking eyes of that person. The localization of the corners of the eyes was achieved using the method of Everingham *et al.*, *supra*, which describes the geometric distribution of facial features as a tree-structured mixture of Gaussians [P. F. Felzenszwalb and D. P. Huttenlocher, "Pictorial structures for object recognition, "

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IJCV, 2005] and captures appearance by Haar-wavelet like features [P. Viola and M. Jones, "Robust real-time face detection," In CVPR, volume 2, page 747, 2001].

Once the corners of the eyes were localized, a rectangular region-of-interest which approximately captures the eye regions was constructed for each eye. Let w be the distance between the two corners of the eye (see FIG. 5). The rectangle of each eye was a combination of a strip of width $h_1 = 0.3w$ above the line segment OA (see FIG. 5) and of a strip of width $h_2 = 0.3w$ below this line. Each region-of-interest was scaled to an image of 120×80 pixels. Then, SIFT descriptors were computed at 24 evenly spaced points in the stretched image.

FIGS. 10A-C show samples of successful facial feature points detection obtained by eye corner localization. The region-of-interest around the eyes are marked by a black rectangle. FIG. 10D shows an example of a failure case in detection. For such cases, the last model of an open eye was used to initialize the eye model search process.

From the non-specific database of manually annotated eyes, the left and right eyes with the closest appearance descriptor were selected. This yielded an approximate model. In Leave-One-Person-Out experiments conducted on the non-specific database it was found that their average absolute error is about 3 pixels for the center of the eye, and about 6 pixels in the width of the eye.

Tables 1 and 2 below present the regression results for the left and right eyes, respectively. The values in Tables 1 and 2 correspond to mean ± standard deviation. Two representations are compared in the tables: the SIFT representation and the vector of gray values in the eye rectangle resized to 120 pixels times 80 pixels. Also compared are two machine learning algorithms: SVM Regression and Nearest Neighbor. As shown, SIFT obtained preferable performance, especially for the Nearest Neighbor classifier.

Table 1

parameter	gray values		SIFT	
	NN	SVM	NN	SVM
X_C	4.26 ± 3.62	3.08 ± 2.3	3.02 ± 2.47	3.08 ± 2.3
Y_C	4.3 ± 2.96	3.84 ± 2.92	2.73 ± 1.8	3.23 ± 2.72
w	7.83 ± 6.16	6.86 ± 6.51	6.95 ± 6.52	6.47 ± 6.79

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h_1	3.79 ± 2.25	3.35 ± 2.28	3.58 ± 3.04	3.35 ± 2.28
h_2	3.22 ± 2.73	2.93 ± 2.51	2.45 ± 1.72	2.68 ± 2.56
θ	0.10 ± 0.06	0.08 ± 0.04	0.08 ± 0.06	0.07 ± 0.05

Table 2

parameter	gray values		SIFT	
	NN	SVM	NN	SVM
X_C	3.69 ± 2.99	7.49 ± 4.66	3.76 ± 3.06	5.72 ± 4.42
Y_C	3.62 ± 2.89	3.01 ± 2.62	2.84 ± 2.01	2.91 ± 2.54
w	8.03 ± 6.26	6.13 ± 4.7	5.24 ± 4.48	5.81 ± 4.89
h_1	3.28 ± 2.77	2.94 ± 2.4	2.35 ± 1.89	2.89 ± 2.37
h_2	2.4 ± 1.88	2.05 ± 1.71	2.28 ± 2.04	2.05 ± 1.71
θ	0.07 ± 0.05	0.06 ± 0.05	0.076 ± 0.05	0.06 ± 0.05

This initial model was then refined by performing a local search in the space of the 6 parameters. The search was conducted in a range of twice the average error in each parameter, and in a coarse to fine manner.

For each set of candidate parameter values, the closest eye in the non-specific database was translated, rotated and stretched in accordance with the difference in parameters. The center was shifted by the different in X_C and Y_C, the width was scaled by the ratio of the w values, the regions above and below the line connecting the two corners were stretched in accordance with h_1 and h_2 respectively, and the database eye image was rotated by the difference in the θ values between the database image and the candidate parameter value.

As a matching score, the normalized cross correlation measure between the warped database eye and the eye in the new directly looking frame was used. The region-of-interest for this comparison was the region of the eye, slightly enlarged, and not a rectangular frame.

A threshold was used to determine cases in which the search for eye parameters failed to produce good database to image matches. Typically, the process successfully produced one pair of eyes for 80 % of the frames in the training video.

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Table 3 below summarizes the mean (± standard deviation) error in pixels for each parameter of the eye model after the refinement stage. The errors were estimated in a leave-one-out fashion on the non-specific database.

Table 3

Parameter	Left eye	Right eye
X_C	2.04 ±1.80	1.75±1.52
Y_C	1.86 ±1.72	1.60±2.02
w	6.66 ± 5.03	4.29 ± 3.70
h_1	3.68 ±3.42	2.54±1.93
h_2	2.22 ±1.95	2.20±1.83
θ	0.08 ±0.06	0.06±0.04

Runtime

During runtime, the system replaced frames whenever the eyelid was open. During blinks, no replacement was done. Immediately after a blink, the system is reinitialized and started similarly to the first frame in the video steam. Remarkably, the lack of intervention during blink frames did not seem to reduce the quality of the resulting video.

In the first frame (or first frame after a blink), the best matching set of eyes were searched for. This was done by using the normalized correlation measurements to compare the learned eye models to an eye shaped region-of-interest situated between the corners of the eyes and at a width of $0.7w$. Notice that SIFT descriptors were not used at runtime, since the goal was to find eyes that were similar in appearance, so as to prevent or at least reduce artifacts during replacement.

Once the closest direct looking pair of eyes was found, they where morphed in order to better fit the new frame. This was done by searching in the six dimensional parameter space, similarly to the search performed during training. The search performed during runtime for all frames other than the first frame after a blink included calculation of sum of squared differences (SSD). Note that this is unlike the training phase and the first frame after a blink where the normalized cross correlation matching score was used.

FIGS. 11A-F show initially fitted model (red) and refined model obtained by the search procedure (green). During the specific database construction, the initial guess

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was the nearest neighbor (for each eye separately) in the SIFT feature space from among the training examples of the non-specific database (FIG. 11A). In the first frame of the videoconferencing session, the initial guess for each eye was the highest correlated example in the specific database (FIG. 11B). In the tracking phase, the initial guess was the eye-model of the previous frame (FIG. 11C). FIG. 1D depicts the two eyes (from two different individuals) from the non-specific database that were used as an initial guess for the eye model of FIG. 11A. The initial models for FIG. 11B were taken from FIG. 11E which shows an entry of the specific database. The initial model for FIG. 11C was taken from the previous video frame shown in FIG. 11F.

The eye parameters were estimated for every frame in the video stream. Given a new frame, the eye parameters of the previous frame serve as an initial guess, and a search was once again conducted as a refinement process. The matching score was composed of two components. One component considered the sum of squared differences (SSD) between the eye in the current frame and the eye in the previous frame, where the latter was warped to the new frame in accordance with the difference in the eye parameters. Another component considered the SSD between the current eye and the warped eye from the first frame.

SSD was used since illumination changes between consecutive frames were expected to be small and since it was convenient to combine multiple SSD scores. The combined cost term minimized drift over time, and reduced accumulation of small tracking errors. A noticeable example would be for the eye to gradually shrink, as shown in FIGS. 12A-D. FIGS. 12A and 12C show result of eye replacement after tracking the eye model while only considering the previous frame, and FIGS. 12B and 12D show result of eye replacement after tracking the eye model while considering both the previous frame and the first frame. As shown, the eye tends to shrinks without the first frame consideration.

In cases in which the search process performed during tracking failed, a blink was declared, and the system entered a blink mode. While in this mode, the eye parameters were not adapt, and no eye replacement took place. During every blink frame; tracking based on the last detected eye model was attempted. Once this tracking was successful for both eyes for at least 2 consecutive frames, the blink state was terminated.

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The first frame after the blink mode was treated as if it was the first frame of the video sequence. This allowed the system to move to a more suitable set of eyes. In cases in which the eye corner detector failed, the last model of an open eye was used to initialize the eye model search process. Although the pair of replacement eyes used between two successive blinks did not change, this effect was unnoticeable.

The eye replacement was done by pasting the warped set of model eyes onto the eye location in the image. The warping was done in order to adjust the parameters of the model eyes to the parameters of the actual eyes in the video frame. In order to eliminate artifacts, several optional operations were taken.

In one such optional operation, the eyes were enlarged by a factor of 10 % in the vertical direction. This compensated for underestimation of the height of the eye due to the change in gaze between the model eyes and the actual eyes. In addition, this operation ensured that there were no residue pixels from the original eye.

Another such optional operation was adjustment of image illumination. To this end, a low pass quotient image was applied [T. Riklin-Raviv and A. Shashua, "The quotient image: Class based recognition and synthesis under varying illumination conditions," In CVPR, 1999; Liu *et al.*, "Expressive expression mapping with ratio images," In SIGGRAPH, 2001; and Wang *et al.*, "Face relighting from a single image under arbitrary unknown lighting conditions," PAMI, 31(11):1968--1984, 2009; Bitouk *et al.*, "Face swapping: automatically replacing faces in photographs," In SIGGRAPH, 2008]. For both the original pixels to be replaced and the new eye to be pasted, the illumination was estimated by fitting a third order polynomial to the image data [R. Basri and D. Jacobs, "Lambertian reflectance and linear subspaces," PAMI, 25(2):218--233, Feb 2003]

Denote the Red value of pixel (x, y) in the original video frame as $I_R^{(1)}(x,y)$, and the values in the pasted eye image as $I_R^{(2)}(x,y)$. Let $\hat{I}_R^{(1)}(x,y)$ and $\hat{I}_R^{(2)}(x,y)$ be the corresponding values of the fitted low-order polynomial:

$$\hat{I}_R^{(1)}(x,y) = \sum_{i=0}^{3} \sum_{j=0}^{3-i} \beta_{R,ij}^{(1)} x^i y^j$$

$$\hat{I}_R^{(2)}(x,y) = \sum_{i=0}^{3} \sum_{j=0}^{3-i} \beta_{R,ij}^{(2)} x^i y^j$$

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The fitting was done to each of the three channels R, G and B separately using a least square system of equations (10 unknown βs per image per channel).

Using quotient image re-illumination, the new image values were given by:

$$I_R^{(1)}(x,y) = I_R^{(2)}(x,y)\frac{\hat{I}_R^{(1)}(x,y)}{\hat{I}_R^{(2)}(x,y)}.$$

An additional optional operation included a feathering technique in which on a strip of about 10 pixels surrounding the replaced region, blending with linear weights was performed between the old image and the pasted eye.

FIGS. 13A-D demonstrates the eye replacement procedure and the optional operations. FIG. 13A shows the original image of the eye to be replaced. FIG. 13B shows eye replacement without the quotient image re-illumination stage. As shown, the highlight on the left eye lid of the subject is not consistent with the input image. FIG. 13C shows eye replacement with the quotient image but without feathering. As shown, the highlight was removed, but additional edges were created around the right eye. FIG. 13D shows eye replacement with both quotient image and feathering. As shown, the illumination was corrected and the spurious edges were suppressed by feathering.

Results

The system was tested on a number of sequences. All sequences were captured at 1280 × 1024 pixels at 25 frames per second. The non-specific database consisted of about 200 images of 14 individuals with manually annotated eye models. At the beginning of the videoconferencing session, each user was asked to look straight at the camera for a couple of seconds. These frames were used to construct the specific database that was used for the remaining of the session of each individual.

FIG. 14 shows several frames from some of the video sequences that were processed. In each image pair of FIG. 14, the left image is the original image and the right image is the modified image. The top right pair of images and the left pair of images of the fifth row show cases in which the system automatically detected a blink and did not modify the image.

The prototype system of the present embodiments also maintained a high level of temporal consistency with no flickering. In other words, the eye did not change its size from frame to frame.

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Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.

All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention. To the extent that section headings are used, they should not be construed as necessarily limiting.

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WHAT IS CLAIMED IS:

1. A method of correcting gaze offset in an image of at least one individual having eyes, comprising:

processing the image so as to extract location of at least one eye over the image;

processing the image to replace imagery data associated with each location of each eye with replacement data, said replacement data being previously-recorded imagery data which respectively correspond to the same eye but a different gaze, thereby providing a corrected image; and

transmitting said corrected image to a display device.

2. The method of claim 1, further comprising, prior to said extraction of said locations, capturing at least one image of each of the at least one individual at one or more predetermined gazes, thereby providing said previously-recorded data.

3. The method according to any of claims 1 and 2, further comprising processing said previously-recorded data so as to compute eye parameters wherein said replacing is based on said computed parameters.

4. The method of claim 3, wherein said computation of said parameters is bootstrapped using a non-specific database of eye images.

5. The method according to any of claims 3 and 4, further comprising applying a morphological transformation to said previously-recorded data according to said parameters.

6. The method according to claim 4, further comprising varying said parameters so as to optimize a predetermined objective function describing matching between said replacement data and images in said non-specific database.

7. The method according to any of claims 3-6, further comprising varying said parameters so as to optimize a predetermined objective function describing

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matching between said replacement data and said imagery data associated with said location of said eye.

8. The method according to any of claims 1-6, further comprising, for each eye, determining whether an eyelid of said eye is close or open, wherein said imagery data is replaced with said replacement data only if said eyelid is open.

9. The method according to any of claims 1-8, further comprising, for each eye, determining a characteristic gaze direction of said eye, wherein said imagery data is replaced with said replacement data only if said gaze direction is other than a predetermined gaze direction.

10. The method according to any of claims 1-9, further comprising, processing the image to replace imagery data associated with each location of each eye with additional replacement data to provide at least one additional corrected image such that each corrected image is characterized by a different gaze, and transmitting each corrected image to a different display device.

11. The method according to claim 10, further comprising for each eye, determining a characteristic gaze direction of said eye, wherein said at least one additional corrected image is generated responsively to said determined characteristic gaze direction.

12. A computer software product, comprising a computer-readable medium in which program instructions are stored, which instructions, when read by a processer, cause the processer to process the image so as to extract locations of at least one eye over the image, to provide a corrected image by replacing imagery data associated with each location of each eye with replacement data being previously-recorded imagery data respectively corresponding to the same eye but a different gaze, and to transmit said corrected image to a display device.

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13. An imaging system, comprising:

(a) a camera for capturing an image of at least one individual having eyes; and

(b) a processer configured for:

processing the image so as to extract locations of at least one eye over the image,

processing the image to replace imagery data associated with each location of each eye with replacement data being previously-recorded imagery data respectively corresponding to the same eye but a different gaze, thereby providing a corrected image; and

transmitting said corrected image to a display device.

14. The computer software product or system of claim 13, wherein said previously-recorded imagery data are processed by the processor so as to compute eye parameters wherein said imagery data are replaced based on said computed parameters.

15. The computer software product or system of claim 14, wherein said computation of said parameters is bootstrapped using an annotated non-specific database of eye images.

16. The computer software product or system according to any of claims 14 and 15, wherein said previously-recorded data are transformed by said processor using a morphological transformation according to said parameters.

17. The computer software product or system according to any of claims 14-16, wherein said parameters are varied by said processor so as to optimize a predetermined objective function describing matching between said replaced data and said replacement data.

18. The computer software product or system according to any of claims 12-17, wherein the image is processed by said processor to determine whether an eyelid of said eye is close or open, and wherein said imagery data is replaced with said replacement data only if said eyelid is open.

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19. The computer software product or system according to any of claims 12-18, wherein the image is processed by said processor to determine a characteristic gaze direction of said eye wherein said imagery data is replaced with said replacement data only if said characteristic gaze direction is other than a predetermined gaze direction.

20. The computer software product or system according to any of claims 12-19, wherein the image is processed by said processor to replace imagery data associated with each location of each eye with additional replacement data to provide at least one additional corrected image, such that each corrected image is characterized by a different gaze, and transmitting each corrected image to a different display device.

21. The computer software product or system according to claim 20, wherein the image is processed by said processor to determine a characteristic gaze direction of said eye, wherein said at least one additional corrected image is generated responsively to said determined characteristic gaze direction.

22. The method, computer software product or system according to any of claims 1-19, wherein said extraction of said locations comprises, for each eye: detecting eye corners, defining a region-of-interest based on said corners and scaling said region-of-interest to predetermined dimension.

23. The method, computer software product or system according to any of claims 1-22, wherein said previously-recorded imagery data is stored in a computer-accessible specific database of imagery data, and wherein said replacement of said imagery data comprises searching over said specific database for said previously-recorded imagery data.

24. The method, computer software product or system of claim 23, wherein said searching comprises comparing imagery data of the image with imagery data entries in said specific database, determining a similarity level responsively to said comparison, and selecting said previously-recorded imagery data based on said similarity level.

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25. The method, computer software product or system according to any of claims 1-6, wherein said image is a frame of a video stream.

26. The method, computer software product or system of claim 25, wherein said replacement data are selected from a specific database according to an optimization procedure which comprises a first objective function for reducing differences between said replacement data and replacement data of a previous frame, and a second objective function for reducing differences between said replacement data and replacement data of a frame immediately following an eyelid opening of the respective eye.

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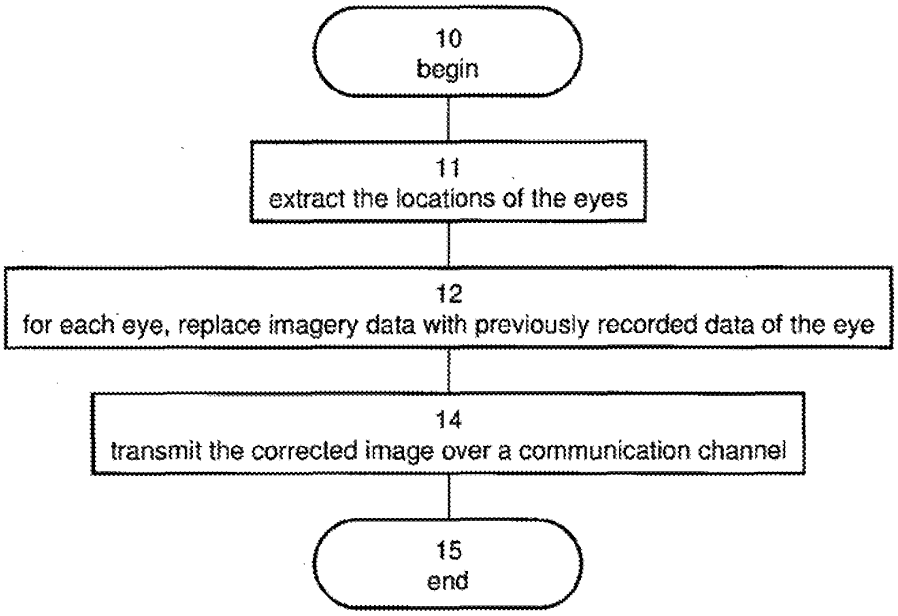


FIG. 1

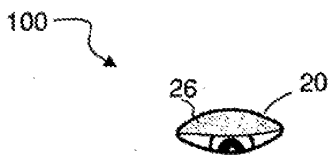


FIG. 2A

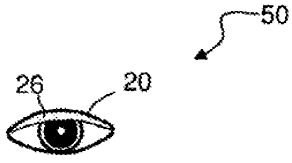


FIG. 2B

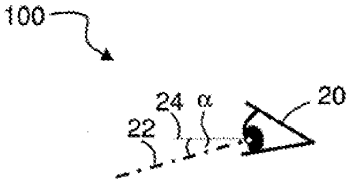


FIG. 2C

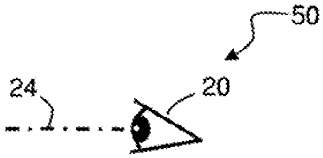


FIG. 2D

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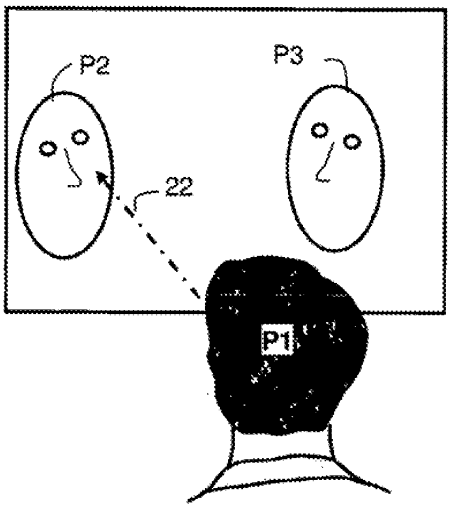


FIG. 2E

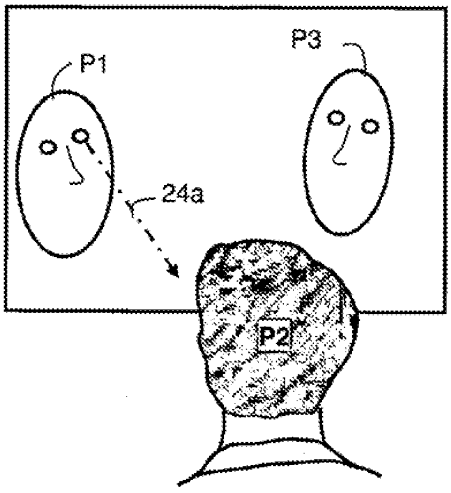


FIG. 2F

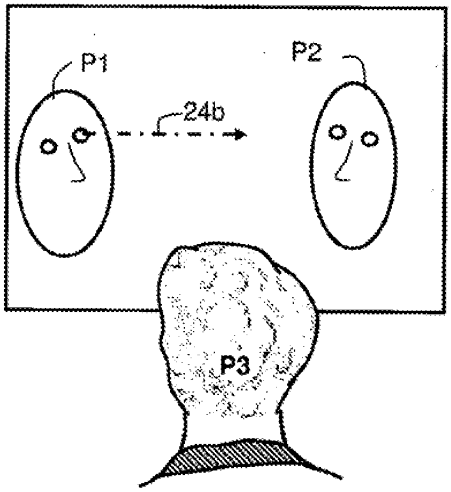


FIG. 2G

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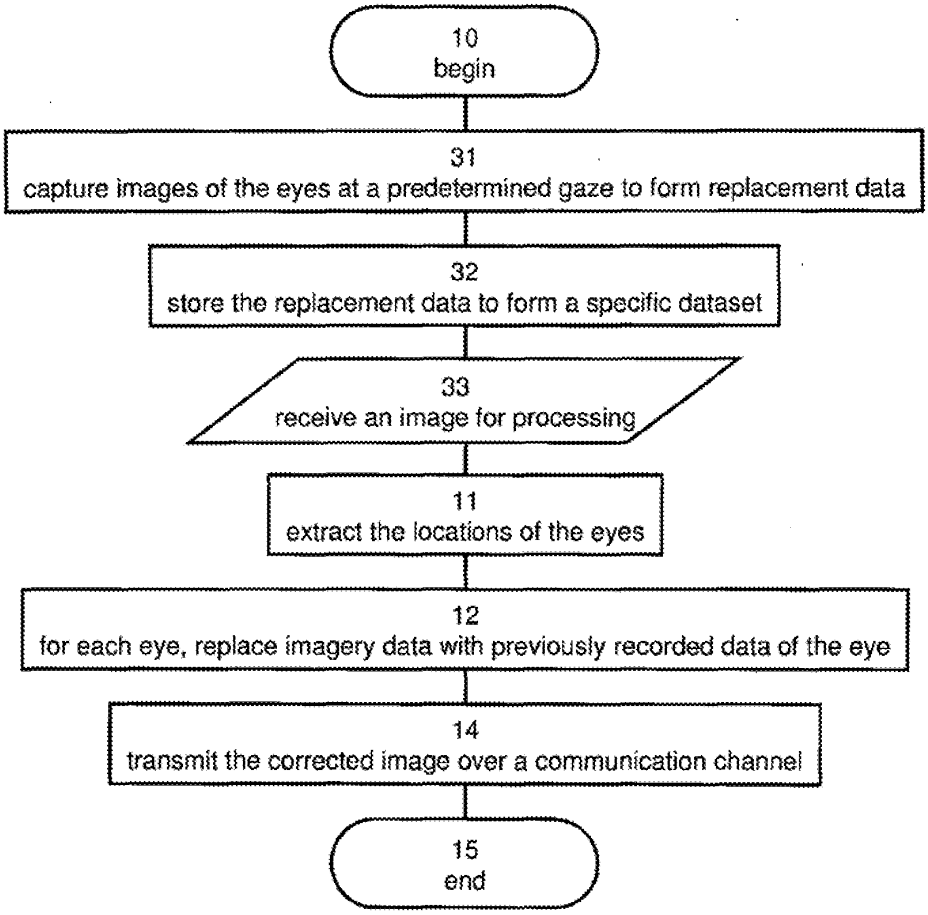


FIG. 3

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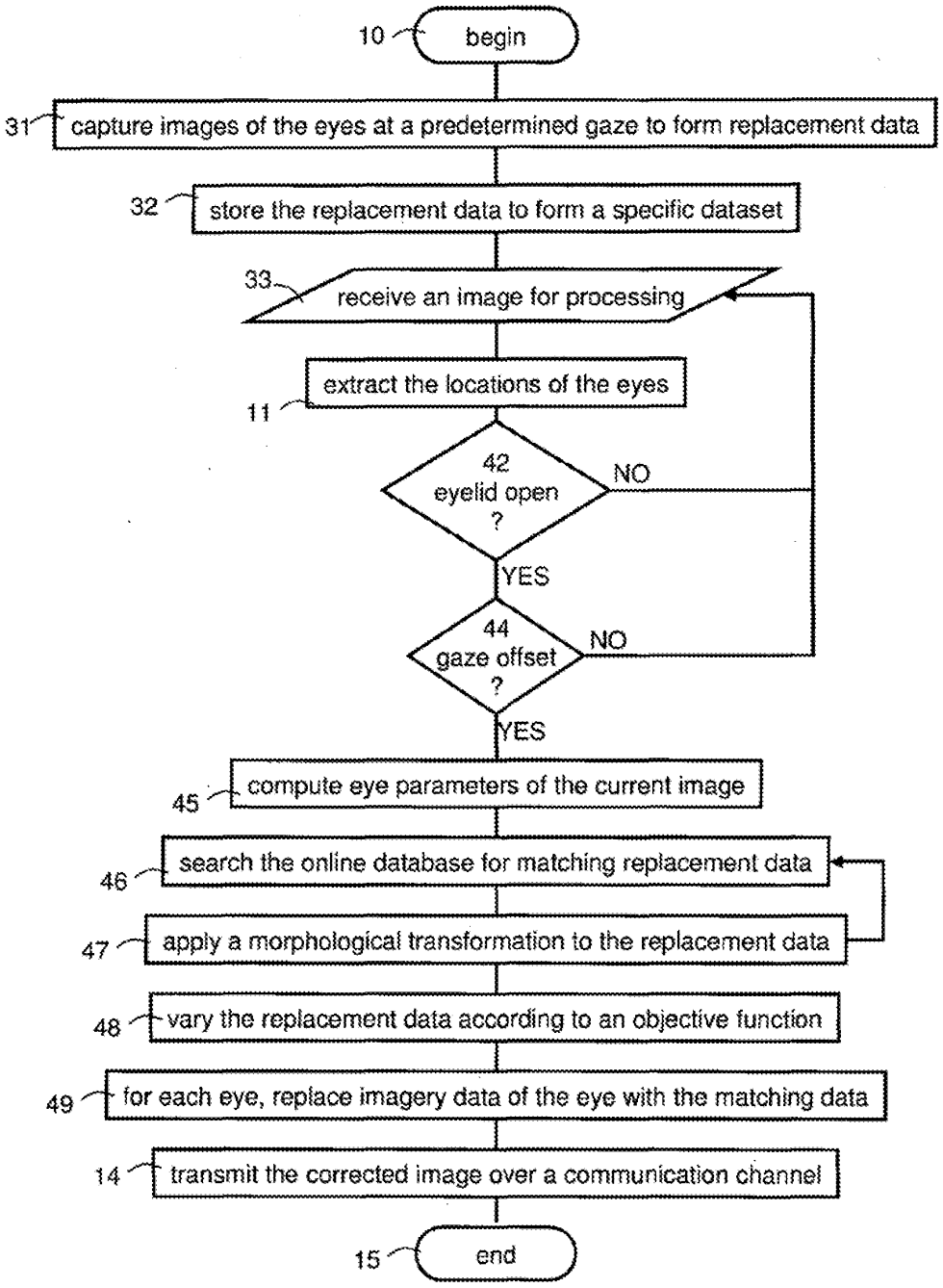


FIG. 4

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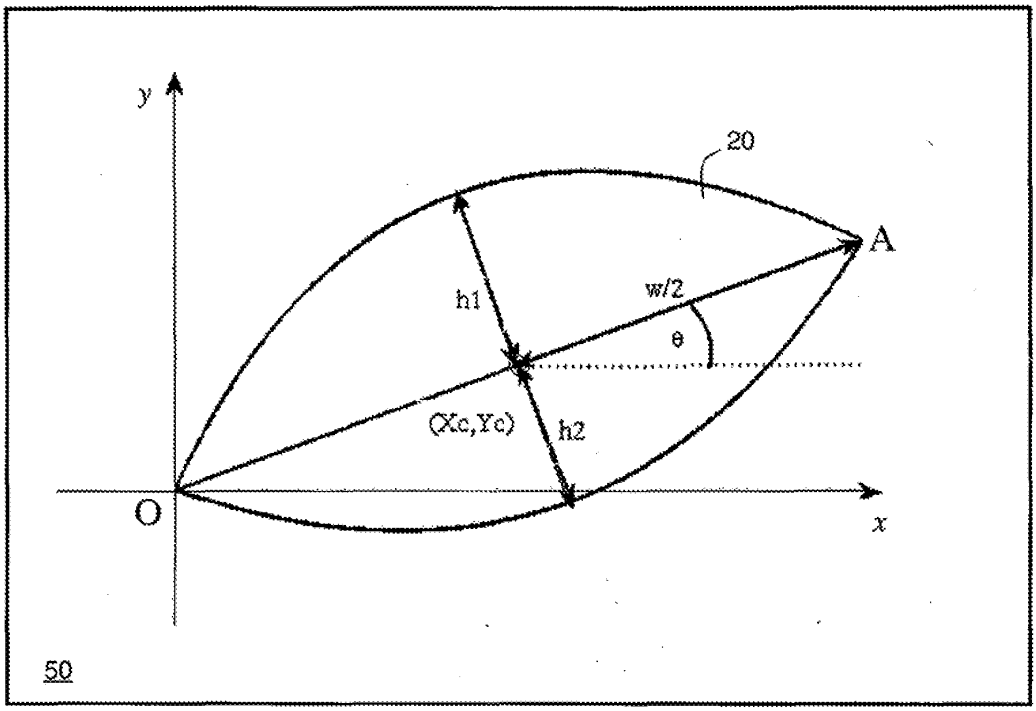
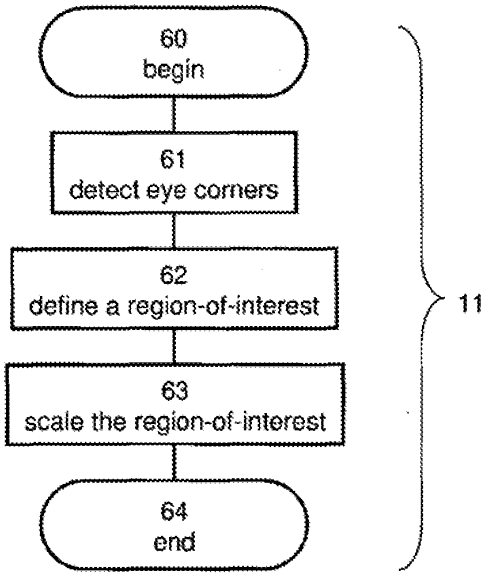


FIG. 5

FIG. 6



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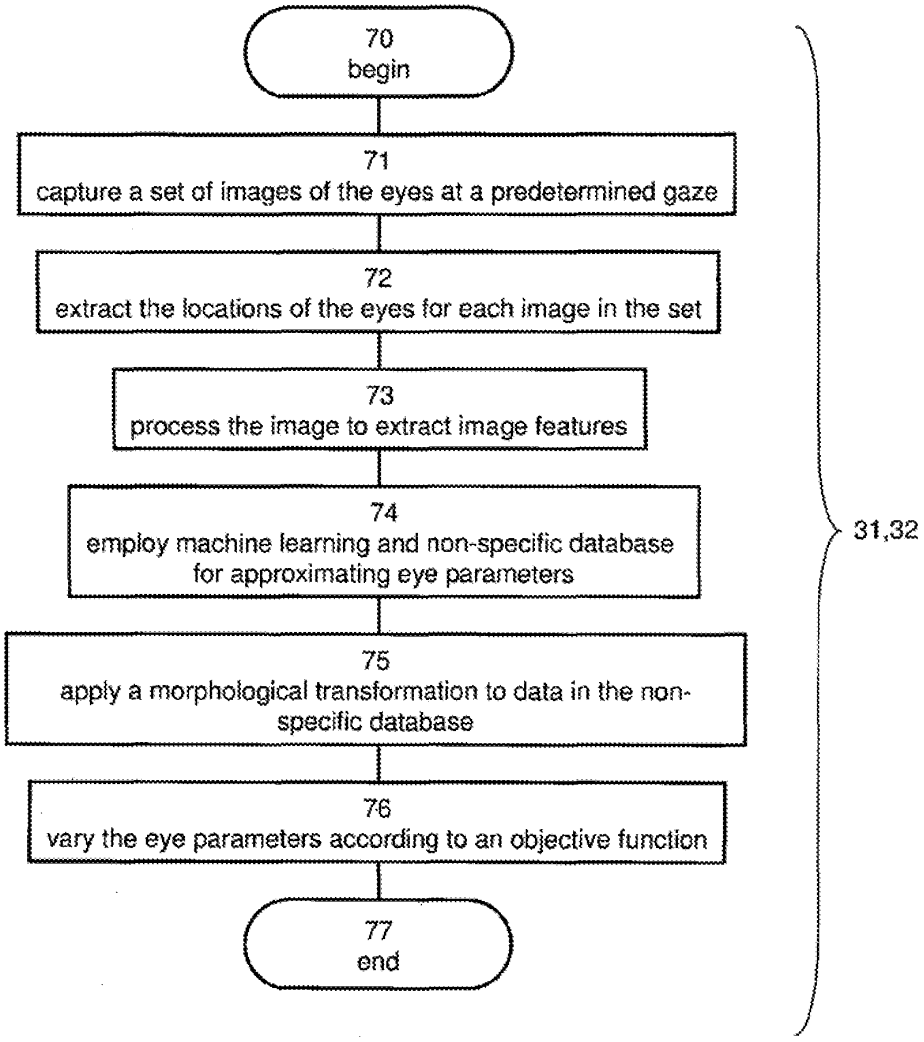

70
begin
71
capture a set of images of the eyes at a predetermined gaze
72
extract the locations of the eyes for each image in the set
73
process the image to extract image features
74
employ machine learning and non-specific database for approximating eye parameters
75
apply a morphological transformation to data in the non-specific database
76
vary the eye parameters according to an objective function
77
end
31,32

FIG. 7

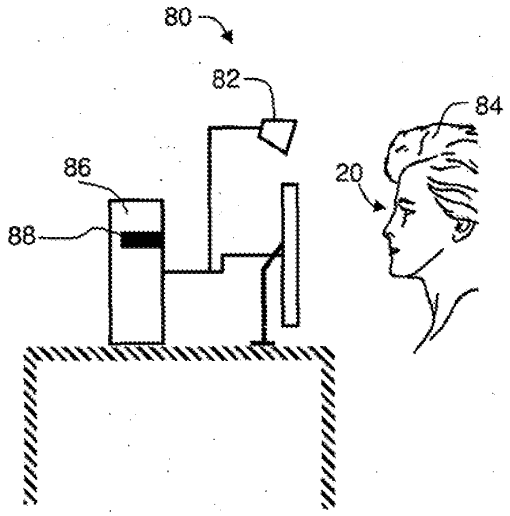


FIG. 8

FIG. 9A





FIG. 9B

FIG. 9C





FIG. 9D

FIG. 10A



FIG. 10B





FIG. 10C



FIG. 10D

FIG. 11A



FIG. 11B



FIG. 11C





FIG. 11D



FIG. 11E



FIG. 11F

FIG. 12A

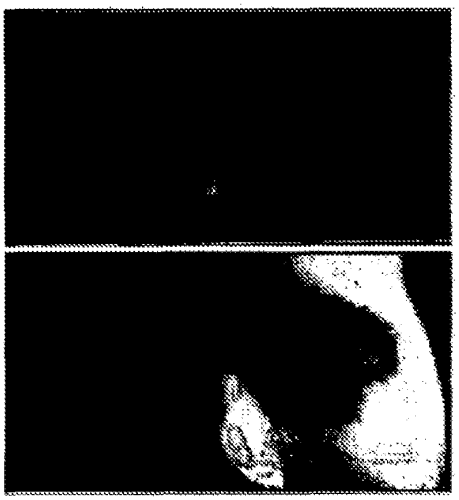


FIG. 12B

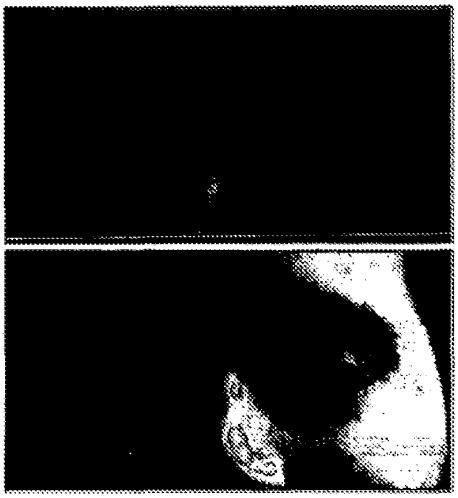


FIG. 12C

FIG. 12D

FIG. 13A

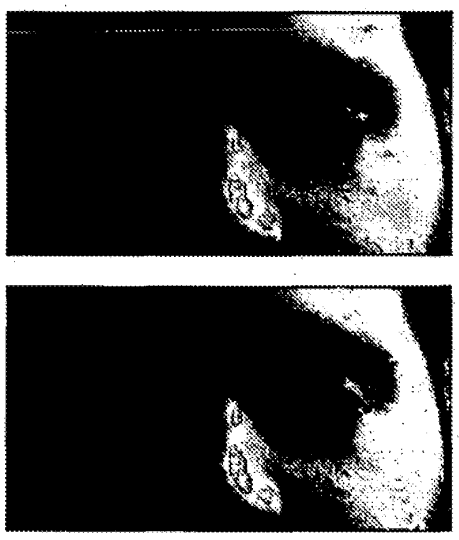


FIG. 13B

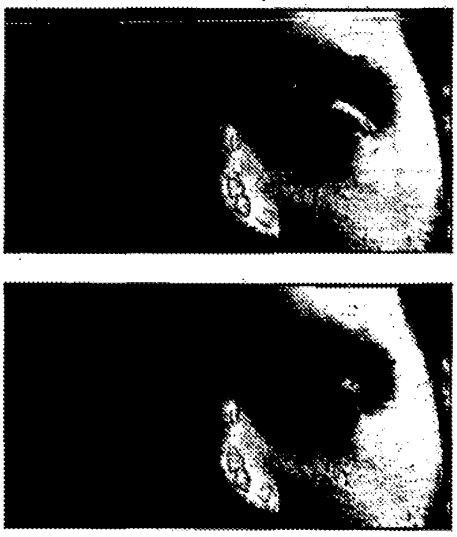


FIG. 13C

FIG. 13D

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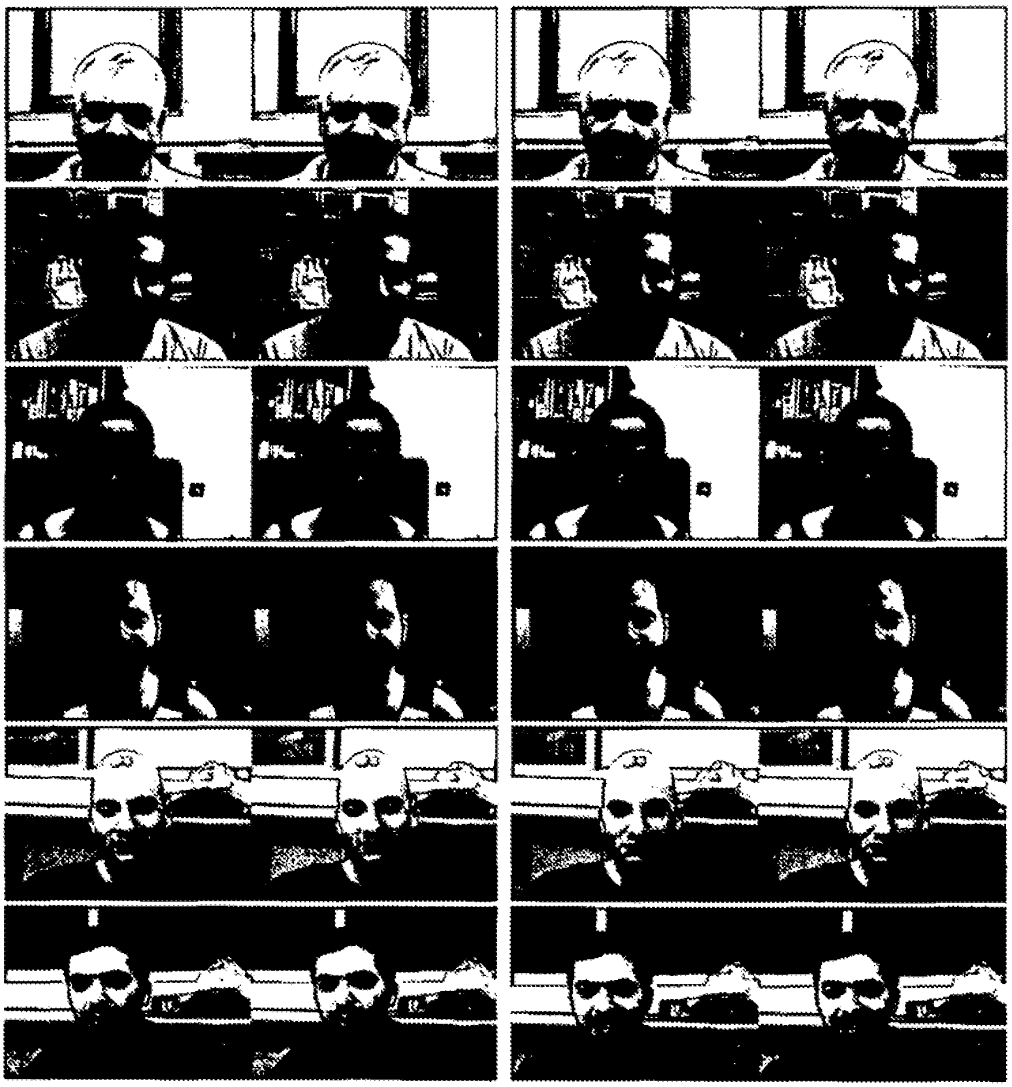


FIG. 14

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IL2011/000334

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N7/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06K G06T H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/079816 A1 (QVARFORDT PERNILLA [US] ET AL) 26 March 2009 (2009-03-26) paragraph [0024] - paragraph [0044]	1-26
X,P	WO 2011/030263 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; VAN BREE KARL CATHARINA [NL]; BEL) 17 March 2011 (2011-03-17) page 2, line 3 - line 32	1-26

☐ Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
1 September 2011	09/09/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Sonius, Michiel

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IL2011/000334

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009079816 A1	26-03-2009	JP 2009077380 A	09-04-2009
WO 2011030263 A1	17-03-2011	NONE	

Form PCT/ISA/210 (patent family annex) (April 2005)

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International Bureau

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(25) Filing Language: English

(26) Publication Language: English

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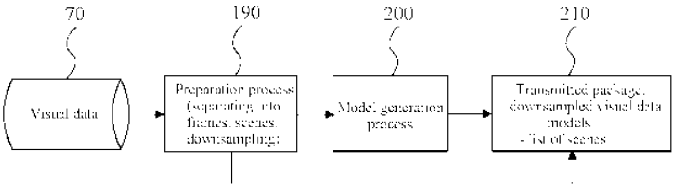
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Fig. 5



(57) Abstract: A method for developing an enhancement model for low-quality visual data, the method comprising the steps of receiving one or more sections of higher-quality visual data; and training a hierarchical algorithm. The hierarchical algorithm is operable to increase the quality of one or more sections of lower-quality visual data so as to substantially reproduce the one or more sections of higher-quality visual data. The hierarchical algorithm is then outputted.

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MACHINE LEARNING FOR VISUAL PROCESSING

Field of the Invention

The present invention relates to methods for generating hierarchical algorithms using machine learning techniques to enable high quality reconstruction of lower-quality visual data.

Background

Background - Increase in quality of video and display technology

Developments in display technology have led to significant improvements in the resolution able to be displayed on display hardware, such as on televisions, on computer monitors and using video projectors. For example, television screens that are able to display "High Definition" or "HD" resolution content (typically having a resolution of 1920 x 1080 pixels) have been broadly adopted by consumers. More recently, television screens able to display Ultra High Definition or "Ultra HD" resolution content (typically having a resolution over 3840 x 2160 pixels) are starting to become more widespread.

In contrast, HD resolution video content is only now becoming commonplace and most legacy content is only available at either Digital Versatile Disc Video (or "DVD-Video") resolution (typically having a resolution of 720 x 586 pixels or 720 x 480 pixels) or Standard Definition or "SD" resolution (where the video content only has a resolution of 640 x 480 pixels). Some broadcast channels are limited to SD resolutions. Video-streaming services can be restricted to operating at DVD-Video or SD resolutions, to reduce transmission problems where consumers have limitations on available transmission bandwidth or because of a lack of legacy content at higher resolutions.

As a result, there can be a lack of sufficiently high-resolution video content for display on HD and Ultra HD television screens, for both current video content as well as for legacy video content and video streaming services. Also, over time mobile devices such as mobile 'phones and tablet computers with increasingly larger and higher-resolution screens are being produced and adopted by users. Further, current video content, being output at HD resolutions, is already at a significantly lower resolution than can be displayed by the latest consumer displays operating at, for example, Ultra HD

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resolutions. To provide sufficiently immersive virtual reality (or "VR") experiences, display technology needs to be sufficiently high resolution even for smaller screen sizes.

The user experience of having to display content that has significantly lower resolution than the user's default screen/display resolution is not optimal.

Background - Growth in data transmission and network limitations

The amount of visual data being communicated over data networks such as the Internet has grown dramatically over time and there is increasing consumer demand for high-resolution, high quality, high fidelity visual data content, such as video streaming including, for example, video at HD and Ultra HD resolution. As a result, there are substantial challenges in meeting this growing consumer demand and high performance video compression is required to enable efficient use of existing network infrastructure and capacity.

Video data already makes up a significant fraction of all data traffic communicated over the Internet, and mobile video (i.e. video transmitted to and from mobile devices over wireless data networks such as UTMS/CDMA) is predicted to increase 13-fold between 2014 and 2019, accounting for 72 percent of total mobile data traffic by the end of that forecast period. As a result, there are substantial challenges in meeting this growing consumer demand and more efficient visual data transmission is required to enable efficient use of existing network infrastructure and capacity.

To stream video to consumers using available streaming data bandwidth, media content providers can down-sample or transcode the video content for transmission over a network at one or a variety of bitrates so that the resolution of the video can be appropriate for the bitrate available over each connection or to each device and correspondingly the amount of data transferred over the network can be better matched to the available reliable data rates. For example, a significant proportion of current consumer Internet connections are not able to reliably support continuous streaming of video at an Ultra HD resolution, so video needs to be streamed at a lower quality or lower resolution to avoid buffering delays.

Further, where a consumer wishes to broadcast or transmit video content, the uplink speeds of consumer Internet connections are typically a fraction of the download speeds and thus only lower quality or lower resolution video can typically be transmitted. In addition, the data transfer speeds of typical consumer wireless networks are another potential bottleneck when streaming video data for video at resolutions higher than HD

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resolutions or virtual reality data and content to/from contemporary virtual reality devices. A problem with reducing the resolution of a video when transmitting it over a network is that the reduced resolution video may not be at the desired playback resolution, but in some cases there is either not sufficient bandwidth or the bandwidth available is not reliable during peak times for transmission of a video at a high resolution.

Alternatively, even without reducing the original video resolution, the original video may have a lower resolution than desired for playback and so may appear at a suboptimal quality when displayed on higher-resolution screens.

Background – Video Compression Techniques

Existing commonly used video compression techniques, such as H.264 and VP8, as well as proposed techniques, such as H.265, HEVC and VP9, all generally use similar approaches and families of compression techniques. These compression techniques make a trade-off between the quality and the bit-rate of video data streams when providing inter-frame and intra-frame compression, but the amount of compression possible is largely dependent on the image resolution of each frame and the complexity of the image sequences.

To illustrate the relationship between bitrate and resolution among other factors, it is possible to use an empirically-derived formula to show how the bitrate of a video encoded with, for example the H.264 compression technique, relates to the resolution of that video:

$$\text{bitrate} \propto Q \times w \times h \times f \times m$$

where Q is the quality constant, w is the width of a video, h is the height of a video, f is the frame-rate of a video and m is the motion rank, where $m \in \{1, \ldots, 4\}$ and a higher m is used for fast-changing hard-to-predict content.

The above formula illustrates the direct relationship between the bitrate and the quality constant Q. A typical value, for example, that could be selected for Q would be 0.07 based on published empirical data, but a significant amount of research is directed to optimising a value for Q.

The above formula also illustrates the direct relationship between the bitrate and the complexity of the image sequences, i.e. variable m. The aforementioned existing video codecs focus on spatial and temporal compression techniques. The newer

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proposed video compression techniques, such as H.265, HEVC and VP9, seek to improve upon the motion prediction and intra-frame compression of previous techniques, i.e. optimising a value for m.

The above formula further illustrates a direct relationship between the bitrate and the resolution of the video, i.e. variables w and h. In order to reduce the resolution of video, several techniques exist to downscale the resolution of video data to reduce the bitrate.

As a result of the disadvantages of current compression approaches, existing network infrastructure and video streaming mechanisms are becoming increasingly inadequate to deliver large volumes of high quality video content to meet ever-growing consumer demands for this type of content. This can be of particular relevance in certain circumstances, for example in relation to live broadcasts, where bandwidth is often limited, and extensive processing and video compression cannot take place at the location of the live broadcast without a significant delay due to inadequate computing resources being available at the location.

Background – Video Upscaling Techniques

To reproduce a video at a higher resolution than that at which it has been transmitted (e.g. by a streaming service or broadcaster) or provided (e.g. on DVD or via a video download provider), various "upscaling" techniques exist to increase the resolution of video data/signals, which enhance image quality when starting from a lower resolution image or video and which produce an image or video of a higher resolution.

Referring to Figure 14, a conventional upscaling technique 1400 will now be described.

Received video data 1410 is provided into a decoder system and is, for example, a lower-resolution video encoded in a standard video format, such as an SD resolution video. This video format can be a variety of known video codecs, for example such as H.264 or VP8, but can be any video data that the system is able to decode into component frames of video.

The system then separates a first section of the video data 1410 into single frames at step 1420, i.e. into a sequence of images at the full SD resolution of the video data 1410. For some video codecs, this will involve "uncompressing" or restoring the video data as, for example, common video compression techniques remove redundant (non-changing) features from sequential frames.

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An upscaling technique 1430 is then used on one or more of the frames or sections of frames, to increase the resolution of the areas upon which it is used. The higher resolution frames are then optionally processed at step 1440 into a format suitable for output as a video. The video, being composed of higher resolution frames, will be in the form of a higher resolution video 1450 than the original video file.

For example, a basic upscaling technique that makes little attempt to enhance the quality of the video is known as nearest-neighbour interpolation. This technique simply increases the resolution of received video data by representing an original pixel of the transmitted video as multiple pixels or a "block" of pixels. The resulting effect is that the video appears pixelated and in blocks.

Other less basic upscaling techniques use the existing video data to estimate unknown intermediate pixels between known pixel values in order to increase the resolution with a less noticeable loss in quality, these techniques generally known by the term interpolation, these techniques typically factoring into account a weighted average of known pixels in the vicinity of each unknown intermediate pixel or fit to a curve or line to surrounding values and interpolate to the mid-point along the curve or line (e.g. bicubic or bilinear interpolation). Typically, such upscaling techniques determine values for the additional pixels required to create a higher resolution image by averaging neighbouring pixels, which creates a blurring effect or other visual artefacts such as "ringing" artefacts. Most upscaling techniques use interpolation-based techniques to produce higher-resolution versions of received video data. Various methods of interpolation are possible and well documented in the prior art in relation to video or image enhancement.

Various methods of interpolation are possible and well documented in the prior art in relation to video or image enhancement. There are many problems with conventional upscaling techniques. Upscaling techniques that reduce jagged edges tend to introduce more blur to an up-scaled video, for example, while upscaling techniques that reduce "halos" or "ringing" artefacts tend to make an up-scaled video less sharp. Further, conventional upscaling techniques are not content-aware or adaptive. Fundamentally, conventional upscaling techniques are limited by the Nyquist-Shannon sampling theorem.

As a result of the disadvantages of current upscaling techniques, the quality of video data that has been "up-scaled" to a higher resolution than that at which it is stored or transmitted can be inadequate or non-optimal for its intended function.

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Background – Super Resolution Techniques For Enhancing Images

Super resolution techniques are techniques that can be described as recovering new high-resolution information that is not explicitly present in low-resolution images.

Super resolution techniques have been developed for many different applications, such as for satellite and for aerial imaging and medical image analysis for example. These applications start with low-resolution images where the higher-resolution image is not available or is possibly unknowable, and by using super resolution techniques it is possible to make substantial enhancements to the resolution of such low-resolution images.

Super resolution techniques allow for the creation of one or more high-resolution images, typically from one or more low-resolution images. Typically, super resolution is applied to a set or series of low-resolution images of the same scene and the technique attempts to reconstruct a higher-resolution image of the same scene from these images.

Super resolution techniques fall predominantly into one of two main fields; optical super resolution techniques and geometrical super resolution techniques. Optical super resolution techniques allow an image to exceed the diffraction limit originally placed on it, while geometrical super resolution techniques increase the resolution from digital imaging sensors. In the field of image resolution enhancement, geometrical super resolution seems to be the predominant technique.

Further, super resolution approaches are usually split into learning- or example-based approaches and interpolation-based (multi-frame) approaches. Example based super resolution techniques are generally accepted to be a superior technique to enhance image quality.

One specific super resolution technique is termed multi-exposure image noise reduction. This technique takes the average of many exposures in order to remove unwanted noise from an image and increase the resolution.

Another super resolution technique employed is sub-pixel image localisation, which involves calculating the 'centre of gravity' of the distribution of light over several adjacent pixels and correcting blurring accordingly. However, this technique relies on the assumption that all light in the image came from the same source, which is not always a correct assumption.

Background – Machine Learning Techniques

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Machine learning is the field of study where a computer or computers learn to perform classes of tasks using the feedback generated from the experience or data gathered that the machine learning process acquires during computer performance of those tasks.

Typically, machine learning can be broadly classed as supervised and unsupervised approaches, although there are particular approaches such as reinforcement learning and semi-supervised learning which have special rules, techniques and/or approaches.

Supervised machine learning is concerned with a computer learning one or more rules or functions to map between example inputs and desired outputs as predetermined by an operator or programmer, usually where a data set containing the inputs is labelled.

Unsupervised learning is concerned with determining a structure for input data, for example when performing pattern recognition, and typically uses unlabelled data sets.

Reinforcement learning is concerned with enabling a computer or computers to interact with a dynamic environment, for example when playing a game or driving a vehicle.

Various hybrids of these categories are possible, such as "semi-supervised" machine learning where a training data set has only been partially labelled.

For unsupervised machine learning, there is a range of possible applications such as, for example, the application of computer vision techniques to image processing or video enhancement. Unsupervised machine learning is typically applied to solve problems where an unknown data structure might be present in the data. As the data is unlabelled, the machine learning process is required to operate to identify implicit relationships between the data for example by deriving a clustering metric based on internally derived information. For example, an unsupervised learning technique can be used to reduce the dimensionality of a data set and attempt to identify and model relationships between clusters in the data set, and can for example generate measures of cluster membership or identify hubs or nodes in or between clusters (for example using a technique referred to as weighted correlation network analysis, which can be applied to high-dimensional data sets, or using k-means clustering to cluster data by a measure of the Euclidean distance between each datum).

Semi-supervised learning is typically applied to solve problems where there is a partially labelled data set, for example where only a subset of the data is labelled. Semi-supervised machine learning makes use of externally provided labels and objective

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functions as well as any implicit data relationships.

When initially configuring a machine learning system, particularly when using a supervised machine learning approach, the machine learning algorithm can be provided with some training data or a set of training examples, in which each example is typically a pair of an input signal/vector and a desired output value, label (or classification) or signal. The machine learning algorithm analyses the training data and produces a generalised function that can be used with unseen data sets to produce desired output values or signals for the unseen input vectors/signals. The user needs to decide what type of data is to be used as the training data, and to prepare a representative real-world set of data. The user must however take care to ensure that the training data contains enough information to accurately predict desired output values without providing too many features (which can result in too many dimensions being considered by the machine learning process during training, and could also mean that the machine learning process does not converge to good solutions for all or specific examples). The user must also determine the desired structure of the learned or generalised function, for example whether to use support vector machines or decision trees.

The use of unsupervised or semi-supervised machine learning approaches are sometimes used when labelled data is not readily available, or where the system generates new labelled data from unknown data given some initial seed labels.

Current training approaches for most machine learning algorithms can take significant periods of time, which delays the utility of machine learning approaches and also prevents the use of machine learning techniques in a wider field of potential application.

Background – Machine Learning & Image Super Resolution

To improve the effectiveness of some super resolution techniques, it is possible to incorporate machine learning, otherwise termed a "learned approach", into the image super resolution techniques described above.

For example, one machine learning approach that can be used for image enhancement, using dictionary representations for images, is a technique generally referred to as dictionary learning. This approach has shown effectiveness in low-level vision tasks like image restoration.

When using dictionary learning, the representation of a signal is given as a linear combination of functions drawn from a collection of atoms referred to as a dictionary. For

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example, a given signal y can be represented as:

$$y = \alpha_1 x_1 + \alpha_2 x_2 + \cdots + \alpha_n x_n$$

where $x_1, \ldots, x_n$ are the atoms of a dictionary of size n and $\alpha_1, \ldots \alpha_n$ are coefficients such that $\|\alpha\|_0 < \lambda$, where λ is the sparsity constraint, for example where $\lambda = 3$ no more than three coefficients can be non-zero. The atoms have the same dimensionality as the signal y so, while it is possible to have an atom x_i that is identical to y, a dictionary of simple atoms can usually be used to reconstruct a wide range of different signals.

In theory, at least k orthogonal atoms are required to fully reconstruct signals in k-dimensional space. In practice, however, improved results are achieved through using an over-complete dictionary where there are $n > k$ atoms and these atoms do not have to be orthogonal to one another.

A complete dictionary means that the number of dictionary atoms is the same as the dimensionality of the image patches and that the dictionary atoms are linearly independent (i.e. all orthogonal to each other and can represent the entire, or complete, dimensional space), so where 16 x 16 atoms represent 16 x 16 image patches, the dictionary is complete if it has 16 x 16 = 256 atoms. If more atoms than this are present in the dictionary, then the dictionary becomes over-complete.

An example of an over-complete dictionary is shown in Figure 1, where a 16 x 16 pixel patch is represented by a linear combination of 16 x 16 dictionary atoms 5 that is drawn from the collection of atoms that is the dictionary 1. It is noted that the atoms are not selected locally within the dictionary, but instead are chosen as the linear combination that best approximates the signal patch for a maximum number of atoms allowed and irrespective of their location within the dictionary. Without a constraint that the atoms must be orthogonal to one another, larger dictionaries than the signal space that the dictionary is intended to represent are created.

Over-complete dictionaries are used because they provide better reconstructions, but at the cost of needing to store and transmit all of the new dictionaries and representations created during the dictionary learning process. In comparison with a predetermined library of representations, a significantly increased amount of data is created as a result of dictionary learning because it generates a data set significantly larger than the basis set in a predetermined library of representations and the atoms are not all orthogonal to one another.

In dictionary learning, where sufficient representations are not available in an

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existing library of representations (or there is no library available), machine learning techniques are employed to tailor dictionary atoms such that they can adapt to the image features and obtain more accurate representations. Each new representation is then transferred along with the video data to enable the representation to be used when recreating the video for viewing.

The transform domain can be a dictionary of image atoms, which can be learnt through a training process known as dictionary learning that tries to discover the correspondence between low-resolution and high-resolution sections of images (or "patches"). Dictionary learning uses a set of linear representations to represent an image and, where an over-complete dictionary is used, a plurality of linear representations can be used to represent each image patch to increase the accuracy of the representation.

When using dictionary learning based super resolution techniques, there is a need for two dictionaries: one for the low-resolution image and a separate dictionary for the high-resolution image. To combine super resolution techniques with dictionary learning, reconstruction models are created to enhance the image based on mapping the coefficients of the low-resolution dictionary to coefficients in the high-resolution dictionary. Various papers describe this, including "On Single Image Scale-Up Using Sparse-Representations" by R. Zeyde et al and published in 2010, "Image super-resolution via sparse representation" by J. Yang and published in 2010, and "Coupled Dictionary Training for Image Super-Resolution" by J. Yang et al and published in 2012, which are incorporated by reference.

A disadvantage of using dictionary learning based super resolution techniques on low-resolution images to attempt to recreate the high-resolution image is the need for two dictionaries, one for the low-resolution image and a separate dictionary for the high-resolution image. It is possible to have a single combined dictionary, but in essence there is always in practice an explicit modelling for each resolution to enable representations to be matched between the two resolutions of image.

A further disadvantage of using dictionary learning, however, especially when used with an over-complete dictionary, is the amount of data that needs to be transferred along with the low-resolution image in order to recreate a high-resolution image from the low-resolution image.

Another disadvantage of dictionary learning approaches is that these tend to use a local patch averaging approach in the final step of reconstruction of a higher-resolution image from a lower-resolution image, which can result in unintentional smoothing in the reconstructed image.

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Another further disadvantage of dictionary learning approaches is that it is very slow and can have high memory requirements, depending on the size of the dictionary.

Background – Artefact Removal in Visual Data

Visual data artefacts and/or noise can often be introduced into visual data during processing, particularly during processing to compress visual data or during transmission of the visual data across a network. Such introduced artefacts can include blurring, pixelation, blocking, ringing, aliasing, missing data, and other marks, blemishes, defects, and abnormalities in the visual data. These artefacts in visual data can degrade the user experience when viewing the visual data. Furthermore, these artefacts in visual data can also reduce the effectiveness of visual data processing techniques, such as image super resolution, as well as other visual tasks such as image classification and segmentation, that use processed images as an input.

Lossy compression, in which a visual data is encoded using inexact approximations, is a particularly common source of artefacts. Lossy compression is often required to reduce the size of a digital image or video in order to transmit it across a network without using an excessive amount of bandwidth. High visual data compression ratios can be achieved using lossy compression, but at the cost of a reduction in quality of the original visual data and the introduction of artefacts.

The transmission of visual data across a network can itself introduce artefacts to the visual data through transmission errors between nodes in the network.

Current methods of removing artefacts (herein referred to as visual data fidelity correction) generally only correct a specific types of artefact. Examples of such techniques include deblocking oriented methods, such as Pointwise Shape-Adaptive Discrete Cosine Transform (hereafter referred to as Pointwise SA-DCT), which deal with blocking artefacts. Such techniques do not perform well, and can also introduce further artefacts as a side effect, such as the over smoothing of visual data.

Summary of Invention

Aspects and/or embodiments are set out in the appended claims. These and other aspects and embodiments are also described herein.

Certain aspects and/or embodiments seek to provide techniques for generating hierarchical algorithms that can be used, when converting original high-quality visual

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data into lower-quality visual data, to allow recreation of higher-quality visual data from the lower-quality visual data without significant loss in quality between the original high-quality visual data and the higher quality visual data.

Further aspects and/or embodiments seek to provide techniques for reconstruction and/or enhancement from lower-quality visual data to higher-quality visual data.

Other aspects and/or embodiments seek to provide techniques for machine learning.

General Training Method

According to an aspect, there is provided a method for developing an enhancement model for low-quality visual data, the method comprising the steps of: receiving one or more sections of higher-quality visual data; training a hierarchical algorithm, wherein the hierarchical algorithm is operable to increase the quality of one or more sections of lower-quality visual data to substantially reproduce the one or more sections of higher-quality visual data; and outputting the hierarchical algorithm.

Training hierarchical algorithms can allow enhancement and/or reconstruction models to be developed for enhancing visual data in at least one embodiment. In some embodiments visual data can be image data and/or video data. Furthermore, in some embodiments enhancement models can be developed to increase the accuracy of higher-quality visual data that can be reproduced from lower-quality visual data in comparison to original higher-quality visual data. In at least one embodiment, knowledge of the original visual data can allow the hierarchical algorithm to be trained (and/or developed) based on knowledge of both the original visual data and the low-quality visual data in order to train a hierarchical algorithm to substantially reproduce the original visual data from the low-quality visual data.

Optionally, the hierarchical algorithm is developed from a known initialisation.

In some embodiments, the hierarchical algorithm can be developed from a known initialisation, for example of a hierarchical function or basis. In some of these embodiments, the hierarchical function or basis can be for example haar wavelets or one or more pre-trained hierarchical algorithms or sets of hierarchical algorithms. In at least one embodiment, providing a known initialisation allows the training of hierarchical algorithms to be accelerated, and the known initialisation can be closer to the best solution especially when compared to starting from a random initialisation. In some

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embodiments, a trained hierarchical algorithm can be developed for input visual data, wherein the trained hierarchical algorithm is developed for that input data based on the selected most similar pre-trained algorithm. In at least one embodiment, the selection of the one or more most similar pre-trained algorithm(s) can be made based on one or more metrics associated with the pre-trained models when compared and/or applied to the input data. In some embodiments, metrics can be any predetermined measure of similarity or difference. In some embodiments, the most similar pre-trained algorithm can be used as a starting point for developing a trained or tailored algorithm for the input data as a tailored algorithm does not have to undergo as extensive development as needed when developing an algorithm from first principles.

Optionally, the method is performed at a first network node within a network. Furthermore, optionally the hierarchical algorithm may be transmitted to a second network node in the network.

By lowering the quality of visual data (for example by lowering the resolution of video data) in some embodiments, less data can be sent across a network from a first node to a second node in order for the second node to display the visual data from the first node. In some embodiments, the lower quality visual data together with a model to be used for reconstruction can allow for less data to be transmitted than if the original higher-quality version of the same visual data is transmitted between nodes.

Optionally, the one or more sections of lower-quality visual data are generated from the one or more sections of higher-quality visual data. Furthermore, optionally the one or more sections of lower-quality visual data may be generated from the high-quality visual data using a process comprising down-sampling.

By lowering the quality of a section of visual data in some embodiments, less data can be sent in order to transmit the visual data over a network. Further, in some embodiments, sending both the lower quality version together with a model to be used for reconstruction can still result in less data being transmitted than if the original higher-quality version of the same section of visual data is transmitted alone.

Optionally, the one or more sections of lower-quality visual data are generated from the one or more sections of higher-quality visual data using a process comprising compression and/or quantisation.

Lossy compression, a reduction in frame rate, a reduction in pixel data precision (e.g. from 32-bit to 16-bit) and quantisation of visual data are methods for producing lower-quality visual data from higher-quality visual data and can be used in some embodiments to generate lower-quality visual data from higher-quality visual data.

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Optionally, the one or more sections of higher-quality visual data and/or lower quality visual data comprise any of: a single frame, a sequence of frames and a region within a frame or sequence of frames. Optionally, the one or more sections of higher-quality visual data and/or the one or more sections of lower-quality visual data may comprise an image, a sequence of images, a section of video or an output of a video game.

Depending on the visual data being processed in an embodiment, models can be generated for sections of visual data comprising a single frame, a sequence of frames or a region within a frame or sequence of frames. Each of these options can be used in some or all embodiments in order to provide a method of enhancing or reconstructing visual data to produce higher quality visual data.

General Enhancement / Reconstruction

According to another aspect, there is provided a method for enhancing lower-quality visual data using hierarchical algorithms, the method comprising the steps of: receiving one or more sections of lower-quality visual data; applying a hierarchical algorithm to the one or more sections of lower-quality visual data to enhance the one or more sections of lower-quality visual data to one or more sections of higher-quality visual data, wherein the hierarchical algorithm was developed using a learned approach; and outputting the one or more sections of higher-quality visual data.

In some embodiments, a section of visual data that has been transmitted across a network can be enhanced using hierarchical algorithms. By applying a hierarchical algorithm in some or all of these embodiments, a higher-quality version of the visual data can be output for input lower-quality visual data. Therefore, in some embodiments, only lower-quality visual data need to be transmitted over the network. In other embodiments, lower-quality visual data can be transmitted over the network along with one or more hierarchical algorithms that can be used to enhance lower-quality visual data.

Optionally, the hierarchical algorithm is selected from a library of learned hierarchical algorithms.

In some embodiments, a stored library of learned hierarchical algorithms allows selection of a hierarchical algorithm for comparison without having to develop them or obtain them from an external source. In some embodiments, the comparison can be between a plurality of algorithms in the library. Use of such a library, in at least some embodiments, may result in the faster selection of a suitable hierarchical algorithm for

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enhancing the visual data or, in some embodiments, the most suitable hierarchical algorithm in a library (for example, by basing a measure of suitability on a predetermined metric).

Optionally, the selection of the hierarchical algorithm from the library of learned hierarchical algorithms is determined by metric data associated with the lower-quality visual data.

In some embodiments, it is assumed that the closer the features of the hierarchical algorithm are to those of metric data associated with the lower-quality visual data, the more accurate a reconstruction can be created using that particular hierarchical algorithm. Therefore, by using associated metric data in some embodiments in this way, an appropriate model may be more accurately chosen from the plurality of hierarchical algorithms available.

Optionally, the steps of receiving the one or more sections of lower-quality visual data and applying the hierarchical algorithm to the one or more sections of lower quality visual data occur substantially simultaneously.

In some embodiments, by receiving the one or more sections of lower-quality visual data and substantially simultaneously applying the hierarchical algorithm to one or more sections of lower-quality visual data, the time taken to enhance the visual data can be reduced. This is especially beneficial for live broadcasting embodiments, where it can be advantageous for the time taken for visual data processing before transmission to be minimised.

Optionally, the one or more sections of lower-quality visual data are generated from one or more sections of original higher-quality visual data.

In some embodiments, by generating lower-quality visual data from original higher-quality visual data and transmitting the lower-quality visual data instead of the original higher-quality visual data, less data needs to be processed or sent across a network.

Offline Training

According to another aspect, there is provided a method for developing an enhancement model for visual data, the method comprising the steps of: receiving one or more sections of higher-quality visual data and one or more sections of lower-quality visual data corresponding to the one or more sections of higher-quality data; developing a hierarchical algorithm, wherein the hierarchical algorithm is operable to substantially

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reproduce the one or more sections of higher-quality visual data from the corresponding one or more sections of lower-quality visual data; and storing the developed hierarchical algorithm in a library of developed hierarchical algorithms.

In some embodiments, by developing and storing hierarchical algorithms trained to enhance visual data in a library of enhancement algorithms, trained hierarchical algorithms can be selected from the library for repeated use to reduce the need for individual training from scratch every time enhancement of visual data is required. In some of these embodiments, this approach can save computational expense and speed up the transmission of visual data across a network, for example where it is possible to choose a suitable model for visual enhancement from the library rather than train a new one. It also allows for hierarchical algorithms to be trained in advance of the transmission of visual data, for at least some embodiments, removing time constraints that can be present when training hierarchical algorithms substantially immediately before visual data is transmitted.

Optionally, the developed hierarchical algorithm is stored associated with metric data relating to a content type of the higher-quality visual data and/or lower-quality visual data from which the hierarchical algorithm was developed.

In some embodiments, by storing the trained model in the library with metric data relating to the associated visual data, optionally where the metric data can be used to determine whether the trained model would be suitable for use with visual data having similar metric data, such metric data can be used to compare to metric data associated with further visual data to select a suitable hierarchical algorithm to enhance that further visual data. This means that, in at least some of these embodiments, a specific hierarchical algorithm need not be trained for every set of visual data; existing trained hierarchical algorithms can instead be used to enhance similar sets of visual data to that on which they were trained.

Optionally, the hierarchical algorithm is developed from a known hierarchical algorithm.

In some embodiments, developing a new hierarchical algorithm from a known hierarchical algorithm that was trained on similar visual data to the visual data on which the new algorithm is to be trained can reduce the time and/or computational effort required to train the new hierarchical algorithm.

Optionally, the known hierarchical algorithm is stored in the library of developed hierarchical algorithms.

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For some embodiments, having one or more known algorithms stored in a library of previously developed algorithms can allow for these algorithms to be accessed quickly and easily, increasing the efficiency of the training process.

Optionally, the method is performed at a network node within a network.

By performing the method at a network node in some embodiments, the resulting trained hierarchical algorithms can be transmitted across the network to further network nodes at which they are required. It also allows, in at least some embodiments, for the library of trained models to be stored remotely from the location at which the training takes place.

Optionally, the method additionally comprises a step of encoding the one or more sections of higher quality visual data and/or the one or more sections of lower-quality visual data.

Optionally, the step of encoding the one or more sections of higher quality visual data and/or the one or more sections of lower-quality visual data occurs after the step of developing the hierarchical algorithm.

Visual data is often encoded prior to transmission across a network, or storage in a memory, in embodiments. By encoding the visual data after the hierarchical algorithm has been trained in at least some embodiments, the visual data is then ready for transmission or storage. The trained hierarchical algorithm will then be operable to enhance the quality of decoded visual data in these embodiments.

Optionally, the method additionally comprises a step of refining the hierarchical algorithm after the step of encoding the one or more sections of higher quality visual data and/or the one or more sections of lower-quality visual data.

By refining the hierarchical algorithm after the encoding of the visual data in some embodiments, the hierarchical algorithm can be trained to enhance the quality of the encoded visual data without the visual data having to be decoded first. In some of these embodiments, this can decrease the time required to decode and enhance the lower-quality visual data to substantially reproduce the higher-quality visual data.

According to a further aspect, there is provided a method for reducing the amount of data to be transferred when communicating visual data over a network from a first node to a second node, the method at the first node comprising the steps of: reducing the quality of one or more sections of higher- quality visual data to one or more sections of lower- quality visual data; selecting at least one algorithm operable to increase the quality of at least one section of lower- quality visual data using the higher- quality visual data to optimise the selection of the algorithm, wherein the algorithm corresponds to at

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least the one section of lower quality visual data; transmitting the one or more sections of lower- quality visual data to the second node; and transmitting to the second node one or more references corresponding to the one or more selected algorithms that correspond to the one or more sections of lower- quality visual data transmitted to the second node; wherein the second node is able to identify the selected algorithm using the transmitted one or more references and substantially reproduce the higher- quality visual data from the transmitted lower- quality visual data using the identified selected algorithms that corresponds to each section of lower- quality visual data.

According to another aspect, there is provided a method for increasing the quality of a section of visual data communicated over a network from a first node to a second node, the method at the second node comprising the steps of: receiving a lower-quality visual data via a network; receiving a corresponding reference to an algorithm operable to increase the quality of the lower-quality visual data, the algorithm selected with the knowledge of a higher-quality visual data from which the lower- quality visual data was generated; and using the algorithm to increase the quality of the lower-quality visual data to substantially recreate the higher-quality visual data.

According to a further aspect, there is provided a system for reducing the amount of data transferred when communicating visual data over a network, the system comprising two or more nodes wherein a first node is configured to: reduce the quality of one or more sections of higher-quality visual data to one or more sections of lower-quality visual data; select at least one algorithm operable to increase the quality of at least one section of lower-quality visual data using the higher-quality visual data to optimise the selection of the algorithm, wherein the algorithm corresponds to at least the one section of lower quality visual data; transmit the one or more sections of lower-quality visual data to the second node; and transmit to the second node one or more references to the one or more algorithms that correspond to the one or more sections of lower-quality visual data transmitted to the second node; wherein the second node is configured to: receive a lower-quality visual data via a network; receive a corresponding reference to the algorithm operable to increase the quality of the lower-quality visual data, the algorithm selected with the knowledge of a higher-quality visual data from which the lower-quality visual data was generated; and use the algorithm to increase the quality of the lower-quality visual data to substantially recreate the higher-quality visual data.

By transmitting a lower-quality version of a visual data in some embodiments, such as a section of low-quality visual data or series of visual data sections, together

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with a library reference to an algorithm (i.e. any or all of an algorithm, reconstruction algorithm, model, reconstruction model, parameters or reconstruction parameters) to aid reconstruction of higher quality visual data, such as a high-resolution video frame or series of frames, in at least some embodiments less data can be transferred over a network to enable high-quality visual data to be viewed compared to transmitting the high quality visual data alone.

Optionally, the steps of transmitting the one or more sections of lower-quality visual data to the second node and transmitting to the second node one or more references corresponding to the one or more selected algorithms that correspond to the one or more sections of lower-quality visual data transmitted to the second node occur together, or substantially simultaneously.

By transmitting both visual data and one or more references to algorithms in a library of algorithms, a reduced amount of data can be transmitted as only one or more references to algorithms are transmitted instead of the algorithms themselves.

Optionally, the algorithm is a hierarchical algorithm.

In some embodiments, the algorithms used are hierarchical algorithms. It should be noted that algorithms could also be referred to as models, representations, parameters or functions. In some of these embodiments, hierarchical algorithms can enable substantially accurate reconstruction of visual data, e.g. produce a higher quality high-resolution video from the low-resolution video that is transmitted, for example where quality can be measured by a low error rate in comparison to the original high-resolution video.

Optionally, the algorithm is a non-linear algorithm.

In some embodiments, the use of non-linear algorithms can be more flexible and expressive than dictionary learning based approaches, and use fewer coefficients for the reconstruction of higher-quality visual data. In some of these embodiments, this can allow the reconstruction of the sections of higher-quality to be substantially accurate.

Optionally, the algorithm is selected from a library of algorithms stored at any of: the first node; the second node; a centralised database in the network; or a distributed database in the network.

In some embodiments, a library of algorithms can allow for the selection of an substantially optimal, if not the most optimal, algorithm available in the library to reconstruct the lower-quality visual data into higher quality visual data. In some of these embodiments, the use of a library can also allow the selected algorithm to be referred to by a reference identifier. In certain embodiments, libraries can be provided at both

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nodes, and/or in centralised or distributed databases, and optionally can use common or synchronised reference identifiers for the same algorithms.

Optionally, the received reference corresponds to an algorithm stored in a library at the second node.

By providing common or synchronised libraries of algorithms at both the first and the second nodes in at least some embodiments, and by transmitting a reference or reference identifier when transmitting the corresponding lower-quality visual data to allow selection of matching algorithms from both libraries using the reference identifier to identify the selected algorithm, only the reference identifier and the lower-quality visual data needs to be transmitted between the nodes thus data transmission is reduced as the algorithm itself doesn't need to be transmitted.

Optionally, if the second node cannot identify the selected algorithm, the second node sends a request to any of: the first node; a centralised database; or a distributed database for transmission of the selected algorithm to the second node.

In some embodiments, by configuring the second node to be able to request models from a node (for example a first node or alternatively another node or a node to which multiple libraries are synchronised, depending on embodiment) in situations where the libraries at the second node and other node are not synchronised, the higher-quality visual data can still be reconstructed even if the transmitted reference does not correspond to an algorithm stored at the second node. This can prevent errors in the reconstruction process in some embodiments.

Optionally, the algorithm comprises one or more convolutional neural networks.

In some embodiments, convolutional neural networks can achieve substantially optimal reconstruction of higher-quality visual data from lower-quality visual data (when the reconstructed higher-quality visual data is compared to the original high-quality visual data) while being relatively small in data size, for example when compared to over-complete dictionaries.

Optionally, the high-quality visual data is divided into smaller sections based on similarities between a plurality of sections of the high-quality visual data.

In some embodiments, by dividing the visual data into smaller sections, where the sections can be sequences of frames or portions of one or more frames, and where the division can be based on a particular metric for similarity, more efficient models can be selected. For example, in some embodiments multiple sections can be grouped, all of which comprise part of a landscape shot, and one model can be used to reconstruct the scene, i.e. sequence of frames, as opposed to a using a different model for every

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separate frame in the scene. In some embodiments, if the next scene in the visual data is very different (for example a scene with significant movement after a scene showing a still landscape), then the scene can be detected as being very different and a new model can be selected accordingly for the scene. In some embodiments, specific models can be selected for each scene or section, allowing at least some optimisation or adapting of the reconstruction model(s) in comparison to the use of a generic model for the whole of the visual data.

Optionally the one or more sections comprises any of: a single frame, a sequence of frames and a region within a frame or sequence of frames.

Depending on the visual data being processed, in some embodiments models can be selected for sections of visual data comprising a single frame, a sequence of frames or a region within a frame or sequence of frames. This selection can be necessary in some of these embodiments in order to provide the most efficient method of reconstructing a higher quality version of a part of the original visual data.

Optionally, the visual data is converted into a sequence of sections, optionally before the quality is lowered.

Separating the visual data into a sections, for example into a series of frames or images in some embodiments, allows for the individual sections to be down-sampled, thus reducing the size of visual data, and thereby can allow for lower quality sections to be transmitted as re-encoded visual data in the original code (or optionally re-encoded using a more optimal codec and/or at a lower quality in some embodiments).

Optionally, down-sampling is used to reduce the quality of one or more sections of higher-quality visual data to one or more sections of lower-quality visual data.

By lowering the quality of the section of visual data in some embodiments, less data needs to be sent across a network from a first node to a second node in order for the second node to receive the file. In these embodiments the lower quality version together with a reference to the model to be used for reconstruction can still allow for less data to be transmitted than if the original higher-quality version of the same section of visual data is transmitted.

Optionally, the steps of transmitting the one or more sections of lower-quality visual data to the second node and transmitting to the second node the references to the one or more algorithms that correspond to the one or more sections of lower-quality visual data transmitted to the second node occur substantially simultaneously.

By transmitting the lower quality section of visual data and the model reference simultaneously in some embodiments, the reconstruction process can be initiated

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substantially instantaneously on arrival of the data, as opposed to there being a delay between the arrival of the section of visual data and the model reference or vice versa. In some embodiments, both the model and the section of visual data are necessary for a higher-quality version of the section of visual data to be reconstructed such that the reconstructed visual data is of substantially the same quality as the original higher-quality visual data.

Online Training

According to an aspect, there is provided a method for enhancing visual data when communicating visual data over a network from a first node to a second node, the method at the first node comprising the steps of: reducing the quality of one or more sections of higher-quality visual data to one or more sections of lower-quality visual data; developing at least one hierarchical algorithm operable to increase the quality of the one or more sections of lower quality visual data using the one or more sections of higher-quality visual data to enhance the developed at least one hierarchical algorithm, wherein the developed at least one hierarchical algorithm corresponds to the one or more sections of lower quality visual data; transmitting the one or more sections of lower-quality visual data to the second node; and communicating to the second node at least one of the developed at least one hierarchical algorithms that corresponds to the one or more sections of lower-quality visual data transmitted to the second node; wherein the second node is able to substantially reproduce the one or more sections of higher-quality visual data from the transmitted one or more sections of lower-quality visual data using the developed at least hierarchical algorithm that corresponds to the one or more sections of lower-quality visual data.

According to a further aspect, there is provided a method for enhancing visual data when communicating visual data over a network from a first node to a second node, the method at the second node comprising the steps of: receiving one or more sections of lower-quality visual data via a network; receiving a corresponding at least one hierarchical algorithm operable to increase the quality of the one or more sections of lower-quality visual data, the at least one hierarchical algorithm developed with the knowledge of one or more sections of higher-quality visual data corresponding to the one or more sections of lower-quality visual data; and using the at least one hierarchical algorithm to increase the quality of the one or more sections of lower-quality visual data to substantially recreate the one or more sections of higher-quality visual data.

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According to another aspect, there is provided a system for reducing the amount of data transferred when communicating visual data over a network, the system comprising two or more nodes wherein a first node is configured to: reduce the quality of one or more sections of higher-quality visual data to one or more sections of lower-quality visual data; develop at least one hierarchical algorithm operable to increase the quality of the one or more sections of lower quality visual data using the one or more sections of higher-quality visual data to enhance the developed at least one hierarchical algorithm, wherein the developed at least one hierarchical algorithm corresponds to the one or more sections of lower quality visual data; transmitting the one or more sections of lower-quality visual data to the second node; and communicate to the second node at least one of the developed at least one hierarchical algorithms that corresponds to the one or more sections of lower-quality visual data transmitted to the second node; wherein the second node is configured to: receive one or more sections of lower-quality visual data via a network; receive a corresponding at least one hierarchical algorithm operable to increase the quality of the one or more sections of lower-quality visual data, the at least one hierarchical algorithm developed with the knowledge of one or more sections of higher-quality visual data corresponding to the one or more sections of lower-quality visual data; and use the at least one hierarchical algorithm to increase the quality of the one or more sections of lower-quality visual data to substantially recreate the one or more sections of higher-quality visual data.

In some embodiments, by developing a hierarchical algorithm for enhancing the quality of a specific set of lower-quality visual data, a more accurate enhancement of that visual data can be achieved at a receiving node in a network. In some of these embodiments, having knowledge of the higher-quality visual data to which the lower-quality visual data corresponds can lead to the training and/or development of more accurate hierarchical algorithms. In further of these embodiments, having knowledge of the compression settings of the lower-quality visual data can also help in training and/or development of more accurate hierarchical algorithms and, in such embodiments, training hierarchical algorithms on visual data having the same compression settings can provide substantially accurate hierarchical algorithms for those compression settings. Furthermore, in some embodiments, communicating the lower-quality algorithm across the network along with the associated lower-quality visual data can reduce the amount of data required to be transmitted across the network when compared with the transmission of the higher-quality data alone. For some embodiments, this is especially

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true in the case where the higher-quality visual data is at a significantly higher quality than the lower-quality visual data.

Optionally, the developed at least one hierarchical algorithm is selected from a plurality of hierarchical algorithms developed in parallel at the first node.

Optionally, the at least one hierarchical algorithm is developed in parallel to the encoding of the lower-quality visual data.

In some embodiments, developing multiple hierarchical algorithms in parallel while encoding the visual data can speed up the process of preparing the visual data and hierarchical algorithm for communication across a network. In some of these embodiments, by developing multiple hierarchical algorithms in parallel, a greater number of possible algorithm structures can be explored and the most suitable chosen.

Optionally, the steps of transmitting the one or more sections of lower-quality visual data to the second node and communicating to the second node the developed at least one hierarchical algorithm that corresponds to the one or more sections of lower-quality visual data transmitted to the second node occur substantially simultaneously.

By transmitting the visual data and communicating the associated hierarchical algorithm substantially simultaneously in some embodiments, the reconstruction process at the second node can begin as soon as the hierarchical algorithm is received. This can reduce the delay, in some of these embodiments, between receiving lower-quality visual data and outputting higher-quality visual data.

Optionally, the communicating to the second node of the at least one of the developed at least one hierarchical comprises transmitting the developed at least one hierarchical algorithm to the second node.

In some embodiments, transmitting the whole of the developed hierarchical algorithm to the second node ensures that the developed hierarchical algorithm is available for use at the second node.

According to a further aspect, there is provided a method for reducing the amount of data to be transferred when communicating visual data over a network from a first node to a second node, the method at the first node comprising the steps of: reducing the quality of a section of higher-quality visual data to a section of lower-quality visual data; analysing a first example based model for the use of reconstruction of the lower-quality section of visual data; analysing a further one or more example based models for the use of reconstruction of the lower-quality section of visual data; selecting one or more example based models from a plurality of example based models to use based on a specified metric; transmitting the section of lower-quality visual data to the second

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node; and transmitting to the second node the one or more selected example based models that correspond to the lower-quality section of visual data transmitted to the second node; wherein the second node is able to substantially reproduce the higher-quality section of visual data from the transmitted lower-quality section of visual data using the one or more example based models that corresponds to the lower-quality section of visual data.

According to another aspect, there is provided a method for increasing the quality of a lower-quality section of visual data communicated over a network from a first node to a second node, the method at the second node comprising the steps of: receiving a lower-quality section of visual data via a network; receiving a corresponding example based model operable to increase the quality of the lower-quality section of visual data; and using the example based model to increase the quality of the lower-quality section of visual data to substantially recreate the higher-quality section of visual data.

According to a further aspect, there is provided a system for reducing the amount of data to be transferred when communicating visual data over a network, the system comprising two or more nodes wherein a first node is configured to: reduce the quality of a higher-quality section of visual data to a lower-quality section of visual data; analyse a first example based model for the use of reconstruction of the lower-quality section of visual data; analyse one or more example based models for the use of reconstruction of the lower-quality section of visual data; select one or more example based models from a plurality of example based models to use based on a specified metric; transmit the section of lower-quality visual data to the second node; and transmit to the second node the one or more example based models that correspond to the section of lower-quality visual data transmitted to the second node; wherein the second node is configured to: receive a lower-quality section of visual data via network; receive one or more corresponding example based models operable to increase the quality of the lower-quality section of visual data; and use the one or more example based models to increase the quality of the lower-quality section of visual data to substantially recreate the higher-quality section of visual data.

According to an aspect, there is provided a method for increasing the quality of a lower-quality section of visual data, the method at the first node comprising the steps of: analysing a first example based model for the use of increasing the quality of the lower-quality section of visual data; analysing a further one or more example based models for the use of increasing the quality of the lower-quality section of visual data; and selecting one or more example based models from a plurality of example based models to use

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based on a specified metric; wherein the quality of the lower-quality section of visual data is able to be substantially increased using the one or more example based models that corresponds to the lower-quality visual data.

In some embodiments, by transmitting a section of lower-quality visual data over a network together with an example based model to aid reconstruction of high-quality visual data, less data can be transferred over the network to enable a higher-quality visual data to be displayed when compared to transmitting higher-quality visual data alone. In some of these embodiments, by selecting one or more example based models from a plurality of example based models, higher-quality visual data is operable to be reconstructed from the lower-quality visual data and the one or more example based models together. As any example based models used in such embodiments are already in existence and just need to be selected and not created, the delay between the recording of the higher-quality visual data and emission of the reconstructed higher-quality visual data can be minimised. Some of these embodiments can therefore be used for the live broadcast of visual data pertaining to an event. As there exists a plurality of example based models, in some embodiments optional analysis of a plurality of models allows for the selection of an example based model which, when used in the reconstruction of a lower-quality section of visual data, will generate the highest quality output data on reconstruction compared to other selectable models. The visual data to be transmitted can be recorded in the form of higher-quality visual data in some embodiments, the quality of which is then reduced before transmission as outlined above. The visual data can, in alternative embodiments, be recorded in the form of lower-quality visual data, which requires no further decrease in quality before transmission. In some embodiments, visual data can be video and or image data. In some embodiments, quality can relate to the resolution of visual data and/or other attributes such as a higher or lower frame rate.

In some embodiments, a combination of two or more example based models may provide an optimum resource for reconstruction of the lower-quality section of visual data. In some of these embodiments, the two or more example based models can be combined in such a way so as to form a new example based model that is transmitted alongside the lower-quality section of visual data. The lower-quality section of visual data can further be transmitted alongside more than one example based model in some embodiments, if that provides a required level of reconstruction into a higher-quality visual data.

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In some embodiments, the live section of visual data transmitted will be at a lower quality. Aspects disclosed herewith can still be used in order to increase the quality of the section of visual data in some embodiments, even without an original high-quality version.

Optionally, one or more sample sections of visual data are transmitted from the first node to the second node in advance of a live transmission; and a subset of example based models is selected from the plurality of example based models based on a specified metric from the one or more sample sections of visual data; wherein the one or more example based models used to substantially increase the quality of the live transmission is selected from the subset of example based models.

Optionally, one or more sample sections of visual data are transmitted from the first node to the second node in advance of a live transmission; wherein one or more example based models can be generated in advance of the live transmission based on a specified metric from the one or more sample sections of visual data.

Optionally, one or more sample sections of visual data are transmitted from the first node to the second node in advance of a live transmission; wherein one or more example based models from the plurality of example based models can be modified in advance of the live transmission based on a specified metric from the one or more sample sections of visual data.

The process of selecting the example based model to be used in some embodiments can be made more efficient by providing a smaller pool of example based models from which the selection can be made. Computational effort can thereby not be wasted in at least some of these embodiments, as a reconstruction using an example based model that is very unlikely to be used as the selected model for the relevant visual data, e.g. frame or video, will not be performed.

In some embodiments, by transmitting a section of visual data in advance of the live broadcast, example based models that are likely to be used can be grouped into a subset of the total plurality of example based models available.

During the live broadcast, in some embodiments, one or more example based models can be selected from the subset, rather than from the entire available library of models. If deemed necessary, in at least some embodiments, or if sufficient time is available before the live broadcast in other embodiments, the section of visual data can be transmitted in advance of the live broadcast and this can allow for the modification of an existing example based model or generation of a new example based model so as to

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provide a model or models for the more accurate reconstruction from a lower-quality section of visual data.

Optionally, the example based model comprises any of: a generative model; a non-linear hierarchical algorithm; or a convolutional neural network; or a recurrent neural network; or a deep belief network; or a dictionary learning algorithm; or a parameter; or a mapping function.

Optionally the example based model comprises a specific parameter or mapping function for the reconstruction of data.

In embodiments, the example based model can be one of a number of different model types. This increases the flexibility of the method and allows accurate reconstruction of the higher quality visual data in such embodiments.

Optionally the higher-quality visual data is divided into smaller sections based on similarities between a plurality of sections of the higher-quality visual data.

In some embodiments, by dividing the visual data into smaller sections or 'scenes', based on a particular metric for similarity, more efficient models can be generated. For example, in some embodiments multiple sections can be selected, all of which comprise part of a landscape shot, and only one model will be required to reconstruct the scene as opposed to a marginally different model for every separate section. If the next scene in the visual data is very different, for example a scene with significant movement, then in some embodiments this will be detected as such and a new model generated accordingly for the scene. Specific models can be trained for each scene or section in some embodiments, enabling the reconstruction approach to be adaptive and to allow at least some optimisation of reconstruction.

Optionally a section of visual data can comprise any of: a single frame; or a sequence of frames; or a region within a frame or sequence of frames.

Depending on the visual data being processed, in some embodiments models can be generated for sections of visual data comprising a single frame, a sequence of frames or a region within a frame or sequence of frames. Each option could be necessary in some embodiments in order to provide the most efficient method of reconstructing a higher-quality version of a part of the original visual data.

Optionally the visual data is converted to a sequence of sections before the quality is reduced.

By separating the visual data into sections, for example by separating video data into a series of frames in some embodiments, the amount of data is temporarily increased, as the reductions in data from any compression methods previously used on

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the video file will be undone. However in some of these embodiments, this allows for the individual sections to be down-sampled thus reducing the size of the visual data, thereby allowing for lower-quality sections to be transmitted as re-encoded visual data in the original or optionally a more optimal codec but at a lower quality.

Optionally analysis of any two or more example based models occurs in parallel.

By analysing multiple example based models in parallel in some embodiments, the time taken to select a suitable example based model from a library of models can be reduced. This is especially beneficial for live broadcasting embodiments, where it can be advantageous for the time taken for processing visual data before transmission to be minimised.

In some embodiments, a pipeline of analysis can be performed for multiple subsequent sections of visual data in parallel. In some of these embodiments, analysis can be performed for subsequent sections of visual data in respect of compression settings and/or to classify the section or sections into categories in order to perform further content-specific analysis, where this further analysis can be performed once the visual data has been decoded, and in some embodiments this analysis can allow a reduction of the number of models considered for use with the visual data for enhancement or as starting points for training a model.

Optionally, a plurality of example based models are stored in a library.

In some embodiments, a stored library of example based models at the first node allows the analysis process to quickly select example based models for comparison without having to obtain them from the network. This, in turn, may result in a faster selection of the most suitable model for transmission across the network in some of these embodiments.

Optionally the sections of visual data are transmitted in the chronological order according to the section of higher-quality visual data.

By transmitting the sections of visual data in chronological order in some embodiments, the time difference between a section of visual data being recorded and a reconstructed higher-quality visual data being received by the second node can be minimised. For live broadcasting embodiments, this means that the lag between an event happening in front of a camera and a viewer watching a reconstructed version of the event can be reduced.

Optionally the sections of visual data are transmitted in the order in which they were transmitted by the first node.

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Optionally the quality of the lower-quality sections of visual data is increased according to the order in which the sections of visual data were transmitted by the first node.

Some sections of visual data might be easier to process than others, for example a section of video comprising a single black frame would require less computational effort to process than a fast-moving scene. Therefore in some embodiments the sections of visual data that are easier to process could arrive at the second node before the more difficult to process sections. If the visual data is to be reconstructed and viewed in the order in which it was originally recorded in such embodiments, any sections of visual data which arrive out of sequence at the second node can be buffered in some of these embodiments and the sections placed in a chosen order, before increasing the quality and outputting the reconstructed visual data.

Optionally the analysis of an example based model for the use of reconstruction of the lower-quality section of visual data comprises the further steps of: extracting features of a section of the higher-quality visual data; and using the extracted features to select a predetermined example based model from the plurality of predetermined example based models to provide initial parameters for the developed example based model.

The closer the features of the example based model match those extracted from the corresponding section of visual data, the more accurate a reconstruction can be created using that particular example based model, in at least some embodiments. Therefore by extracting features from a section of the higher-quality visual data in some embodiments an appropriate model may be more accurately chosen from the plurality of example based models available.

Optionally the specified metric used to select and/or modify and/or generate an example based model is based on generating the highest quality output data following reconstruction, preferably wherein quality can be defined using any of: an error rate; a peak signal-to-noise ratio; or a structural similarity index.

A reconstructed section of visual data of the highest quality according to any of the above metrics can be desirable to a viewer, as it is liable to show the truest representation of the original higher-quality visual data, at least for some embodiments. In such embodiments, the broadcaster of the original higher-quality visual data is also likely to prefer that the viewer sees the visual data as it has been prepared, without distortion from the down sampling and transmission process.

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Optionally the higher-quality section of visual data is divided into smaller sections based on similarities between a plurality of sections of the higher-quality visual data.

In some embodiments, by dividing the visual data file into smaller sections or 'scenes', based on a particular metric for similarity, less data needs to be transmitted over the network. For example, in some embodiments multiple sections can be selected, all of which comprise part of a landscape shot, and only one model will be required to reconstruct the scene to an acceptable level as opposed to a marginally different model for every separate section. If the next scene in the visual data is very different in such embodiments, for example a scene with significant movement, then it will be detected as such using the extracted features as described above and a new model can be selected accordingly.

Optionally a section comprises any of: a single frame, a sequence of frames and a region within a frame or a sequence of frames.

Depending on the visual data being processed, in some embodiments models can be selected for sections of visual data comprising a single frame, a sequence of frames and a region within a frame or a sequence of frames. In these embodiments, each or all approaches could be necessary in order to provide the most efficient method of reconstructing a higher-quality version of a part of the original visual data.

Optionally the steps of transmitting the section of lower-quality visual data to the second node and transmitting to the second node the example based model that corresponds to the section of lower-quality visual data transmitted to the second node occur substantially simultaneously.

By transmitting the lower-quality section of visual data and the example based model simultaneously in some embodiments, the reconstruction process can be initiated substantially simultaneously on arrival of the data, as opposed to a delay between the arrival of the section of visual data and the example based model or vice versa. Both the example based model and the section of visual data are necessary for a higher-quality version of the section of visual data to be reconstructed, in some embodiments, and so any delay between their arrivals will result in a delay between the original visual data being transmitted from a first node and the reconstructed visual data being viewed at a second node.

Optionally the step of lowering the quality of a section of visual data is performed using down-sampling.

By lowering the quality of the section of visual data in some embodiments, less data needs to be sent across a network from a first node to a second node in order for a

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second node to receive the section of visual data. In these embodiments the lower-quality version, together with an example based model to be used for reconstruction, can still allow for less data to be transmitted than if original higher-quality section of visual data is transmitted.

Optionally a library is stored at both the first and second nodes, and a reference to one or more example based models from the library at the first node is transmitted to the second node.

It can advantageous in some embodiments to minimise the amount of data sent over a network. Higher-resolution videos can comprise significant amounts of data, which can be slow to transmit over existing network infrastructures such as the Internet. Some embodiments can provide a solution to the problem of video transmission over a network by transmitting instead a lower-quality section of video and an example based model, as described above. In some embodiments, in order to further reduce the amount of data transmitted over a network, a lower- quality section of visual data can be transmitted along with a reference to an example based model, in lieu of the example based model itself. In some of these embodiments the reference comprises less data than the example based model to which it refers. In such embodiments a library of similarly referenced example based models can be accessed from both the first and second nodes, so that once a model is selected at the first node and the reference transmitted, the correct model to be used at the second node can be identified.

Optionally, an off-site computing system performs a method comprising the steps of: receiving a lower- quality section of visual data; analysing a first example based model for the use of reconstruction of the lower- quality section of visual data; analysing a further one or more example based models for the use of reconstruction of the lower-quality section of visual data; selecting one or more example based models from a plurality of example based models to use based on a specified metric; generating a higher- quality section of visual data from the lower- quality section of visual data using the one or more example based models that correspond to the lower- quality visual data.

Optionally, there is provided a method further comprising the step of: receiving a higher- quality section of visual data from a third node, before transmitting the higher-quality section of visual data to the first node.

Optionally, one or more of the nodes is based in an off-site computing system.

In some embodiments off-site, or 'cloud computing', systems allow for the performance of computerised tasks on a server not necessarily local to the site of the recording or reconstruction of a section of visual data. This allows for more powerful

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servers to be used according to the budget available for such services, and hence increased parallel processing of different example based models in some of these embodiments. The off-site system used in such embodiments could also provide a backup of any sections of visual data passing through the servers, thereby offering a solution in the case of loss of data at a site local to the recording or reconstruction of a section of visual data. If the computing system is scalable, as is preferable, then a growing amount of visual data processing work can be accommodated should the need arise in these embodiments.

Sub-Pixel Convolutions

According to an aspect, there is provided a method for enhancing one or more sections of lower-quality visual data using a hierarchical algorithm, the method comprising the steps of: receiving one or more sections of lower-quality visual data; enhancing the one or more sections of lower-quality visual data to one or more sections of higher-quality visual data using the hierarchical algorithm, wherein at least the first step of the hierarchical algorithm is performed in a lower-quality domain; and wherein the hierarchical algorithm operates in both a higher-quality domain and the lower-quality domain.

In embodiments, an algorithm performing at least the first processing steps of as enhancement in a lower quality domain ensures the visual data is at least partially if not substantially processed whilst still in lower-quality, reducing the computational complexity of the enhancement. Subsequent processing steps may move to the higher-quality domain to undertake further processing and output higher-quality visual data in such embodiments. Optionally, in some of these embodiments, only the last processing step or steps are performed in the higher-quality domain.

In some embodiments, resampling into the higher dimension space of visual data from a low-quality to high-quality domain happens before being processed through a super resolution network for enhancement, for example in some of these embodiments being enhanced using bicubic interpolation, but this enhancing does not add information useful for super resolution and forces the network to perform subsequent computation in a higher-quality domain when for example extracting feature maps and performing non-linear mapping. This "initial upscaling" makes the computation of the network/algorithm computationally expensive and increases memory requirements. In some embodiments,

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the low quality domain is a low resolution domain while the high quality domain is a high resolution domain.

Optionally, this method can be used as a filtering approach in place of other resampling or upsampling filters for use with encoding and decoding of visual data.

In some embodiments, using the method as a filter for visual data codecs can provide very high computational efficiency, and therefore can also provide minimal energy costs in performing such filtering. In these or other embodiments, the method can provide a filter that is fast and/or flexible in expression and that can perform substantially accurate filtering in at least some embodiments.

Optionally, an activation function can follow the use of the method as a filtering approach.

Optionally, the first step of the hierarchical algorithm comprises extracting one or more features from the one or more sections of lower-quality visual data.

In embodiments, extracted features may be used to produce a value or series of values based on a metric from the input data. In some embodiments, the metric can then be used to select a hierarchical algorithm from the library which is most appropriate for the input data, as each hierarchical algorithm has associated metric values based on the input data from which the models were respectively trained, the selection based on the similarity between the metrics associated with the input data and each of the pre-trained models.

Optionally, the last step of the hierarchical algorithm comprises producing higher-quality visual data corresponding to the lower-quality visual data, and at least the last step of the hierarchical algorithm may be performed in the higher-quality domain.

In some embodiments, by using the last step of the hierarchical algorithm to perform enhancement from the lower-quality domain after feature maps have been extracted and non-linear mapping has been performed in the lower-quality domain, the layers other than the final layer are less computationally expensive and require less memory than if they were operating in high resolution space and the final layer can perform more complex upscaling.

In some embodiments, the final layer can be a sub-pixel convolutional layer that is capable of upscaling low resolution feature maps into high resolution output, thus avoiding using a non-adaptive generic or handcrafted bicubic filter, and allowing for a plurality of more complex upscaling filters for each feature map. Further, in some of these embodiments, having the final layer perform super resolution from the lower resolution space can reduce the complexity of the super resolution operation.

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Optionally, the higher-quality visual data is at a higher resolution than the lower-quality visual data, wherein the lower-quality visual data may contain a higher amount of artefacts than the higher-quality visual data.

In some embodiments, separating the visual data into a series of sections allows for the individual sections to be down-sampled thus reducing the visual data size, thereby allowing for lower quality sections to be transmitted as re-encoded visual data in the original or optionally a more optimal codec but at a lower resolution.

Optionally, the hierarchical algorithm comprises a plurality of connected layers, and the connected layers may be sequential.

Optionally, the at least one section lower-quality visual data comprises any of: a single frame of lower-quality visual data, a sequence of frames of lower-quality visual data, and a region within a frame or sequence of frames of lower-quality visual data. Furthermore, the lower-quality visual data may comprise a plurality of frames of video.

Depending on the visual data being processed, in some embodiment models can be generated for sections of visual data comprising a single frame, a sequence of frames or a region within a frame or sequence of frames. In these embodiments, some or each of these options could be used in order to provide the most efficient method of reconstructing a higher quality version of a part of the original visual data.

Optionally, the hierarchical algorithm differs for each section of visual data.

In some embodiments, each section of visual to be transferred is likely to be at least slightly different from the preceding section. These embodiments it can therefore allow for more accurate reconstruction if the hierarchical algorithm to be transmitted alongside each section of visual data is also different in order to account for these differences in the sections of visual data. For such embodiments, a new model can therefore be generated for each section of visual data accordingly.

Optionally, the hierarchical algorithm is selected from a library of algorithms.

In some embodiments, providing libraries of algorithms allows selection of an algorithm from the libraries and allows for modifications to be made to the stored hierarchical algorithms to enhance the visual data, reducing the computational complexity.

Optionally, the standardised features of the at least one section of received lower-quality visual data are extracted and used to select the hierarchical algorithm from the library of algorithms.

In some embodiments, extracted standardised features are used to produce a value or series of values based on a metric from the input data. In these embodiments,

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the metric can then be used to select the pre-trained model from the library which is most appropriate for the input data, as each model in the library has associated metric values based on the input data from which the models were respectively trained, the selection based on the similarity between the metrics associated with the input data and each of the pre-trained models.

Optionally, the hierarchical algorithm to be selected from the library of algorithms is based on generating the highest quality version of the lower-quality visual data, preferably wherein quality can be defined by any of: an error rate; a bit error rate; a peak signal-to-noise ratio; or a structural similarity index.

The predetermined metrics used in some embodiments to determine the hierarchical algorithm to be selected can be based on a predicted quality of the output data for each pre-trained model. In some of these embodiments, quality can be defined by any or all of: an error rate; a peak signal-to-noise ratio; or a structural similarity index.

Spatio-temporal approach

According to an aspect there is provided a method for enhancing at least a section of lower-quality visual data using a hierarchical algorithm, the method comprising the steps of: receiving at least a plurality of neighbouring sections of lower-quality visual data; selecting a plurality of input sections from the received plurality of neighbouring sections of lower quality visual data; extracting features from the plurality of input sections of lower-quality visual data; and enhancing a target section based on the extracted features from the plurality of input sections of lower-quality visual data.

In some embodiments, performing the enhancement on the extracted features reduces the computational expense of the enhancement by using hierarchical algorithms trained on the lower-quality visual data.

Optionally, the target section corresponds to one of the received plurality of neighbouring sections of lower-quality visual data. Alternatively, the target section may not correspond to one of the received plurality of neighbouring sections of lower-quality visual data.

In some embodiments, having the target section correspond to one of the received sections allows the enhancement to work in the spatial domain. Conversely, in some embodiments, when the target section does not correspond to one of the received sections, then enhancement can be used to predict sections occurring between received sections, or alternatively to predict future sections.

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Optionally, the at least one section of lower-quality visual data comprises any of: a single frame of lower-quality visual data, a sequence of frames of lower-quality visual data, and a region within a frame or sequence of frames of lower-quality visual data. The lower-quality visual data may further comprise a plurality of frames of video.

Depending on the visual data file being processed, in some embodiments models can be selected for sections of visual data comprising a single frame, a sequence of frames or a region within a frame or sequence of frames. In these embodiments each could be necessary in order to provide the most efficient method of reconstructing a higher quality version of a part of the original visual data.

Optionally, at least one of the plurality of selected input sections and the target sections are frames of lower-quality visual data, and the at least one of the plurality of selected input sections occurs sequentially before the target section. Furthermore, at least one of the plurality of selected input sections and the target sections may be frames of lower-quality visual data, and the at least one of the plurality of selected input sections may occur sequentially after the target section.

In some embodiments, having one of the selected input sections occur sequentially in time before or after the target section of the lower-quality visual data enables the enhancement to predict a possible future section, or section still to be received, but that is not included in the any possible target section. As such, in some of these embodiments, having a section before or after the target section may also enable the enhancement to predict a section occurring between two sections.

Optionally, the hierarchical algorithm comprises a plurality of layers, furthermore the layers may be any of sequential, recurrent, recursive, branching or merging.

Having a number of layers in some embodiments, which may or may not be sequential, recurrent, recursive, branching or merging allows different levels of processing to occur at different times and the layers can work in parallel, ensuring optimal efficiency when enhancing the lower-quality visual data.

Optionally, the extracting the subset of features is based upon a predetermined extraction metric.

In some embodiments, enabling a variety of features to be extracted as set by the predetermined extraction metric ensures the enhancement can be tailored to a particular system. As such, in some of these embodiments the computational expense can increased or decreased appropriately based on system resources.

Optionally, the received plurality of neighbouring sections of lower-quality visual data are consecutive sections of lower-quality visual data.

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In some embodiments the use of consecutive sections of lower-quality visual data enables more accurate enhancement of the lower-quality visual data. Receiving a plurality of sections or consecutive sections providing more information used to be able to be used when enhancing sections around the received sections of lower-quality visual data.

Optionally, a predetermined algorithm metric used to determine the hierarchical algorithm to be selected.

In some embodiments, having a plurality of predetermined algorithms which may be selected based on a predetermined algorithm metric ensure optimal efficiency when enhancing the visual data by having a library of hierarchical algorithms which have already been determined to enhance the quality of visual data. In these embodiments, these predetermined algorithms may then be used as a basis for further enhancements.

Optionally, predetermined algorithm metric is based on generating the highest quality version of the lower-quality visual data, preferably wherein quality can be defined by any of: an error rate; a bit error rate; a peak signal-to-noise ratio; or a structural similarity index. Furthermore, standardised features of the received plurality of neighbouring sections of lower quality visual data may be extracted and used to select the hierarchical algorithm from the library of algorithms.

In some embodiments, a reconstructed section of visual data of the highest quality according to any of the above metrics can be desirable to a viewer, as it is liable to show the truest representation of the original higher- quality visual data. In these embodiments, the broadcaster of the original higher- quality visual data is also likely to prefer that the viewer sees the visual data as it has been prepared, without distortion from the down sampling and transmission process.

Optionally, other data can be provided to the algorithm. Optionally, the other data can be optical flow between frames. Optionally, the optical flow between frames can be calculated outside of the algorithm or can be part of the training of the algorithm.

In some embodiments, other data can be fed into the network, such as optical flow between the frames or a measure thereof. In these embodiments, the optical flow can be calculated separately outside the neural network or can be incorporated into the training of the neural network. In these embodiments, this data can simply be concatenated onto the end of each frame data. In some embodiments it is not sent during transmission. In other embodiments, a variant of optical flow can be extracted from the encoded video (as it forms a basis of the inter-frame compression).

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Enhancing Visual Data

According to a aspect there is provided a method for enhancing at least a section of lower-quality visual data, the method comprising steps of: receiving at least a section of the lower-quality visual data; selecting a hierarchical algorithm from a plurality of hierarchical algorithms, wherein the step of selection is based on a predetermined metric and wherein the hierarchical algorithms were developed using a learned approach and at least one of the hierarchical algorithms is operable to increase the quality of the lower-quality visual data; and using the selected hierarchical algorithm to increase the quality of the lower-quality visual data to create a higher-quality visual data.

Some embodiments provide a method for enhancing at least a section of visual data that has been transmitted across a network. In these embodiments, by selecting a hierarchical algorithm based on a predetermined metric, a suitable hierarchical algorithm can be chosen from a library of algorithms that will be able to more accurately recreate the original visual data than a generic hierarchical algorithm.

Optionally, the lower-quality visual data is divided into smaller sections based on similarities between a plurality of sections of the original visual data.

In some embodiments, by dividing the visual data into smaller sections or 'scenes', based on a particular metric for similarity, more efficient models can be generated. For example, in some embodiments multiple sections can be selected, all of which comprise part of a landscape shot, and only one hierarchical algorithm will be required to remove artefacts from the scene as opposed to a marginally different model for every separate section. In some of these embodiments, if the next scene in the visual data is very different, for example a scene with significant movement, then it will be detected as such and a new hierarchical algorithm can be generated accordingly. In some embodiments, specific hierarchical algorithms can be trained for each scene or section, enabling the artefact removal approach to be adaptive and to allow at least some optimisation of the artefact removal.

Optionally, the predetermined metric is based on a content-type and a measure of artefact severity of the lower-quality visual data. Furthermore, the artefact severity may be based on at least one artefact which may be any one of, or combination of: blocking, blurring, pixelation, ringing, aliasing, missing data, and other marks, blemishes, defects, and abnormalities in visual data.

In some embodiments, by basing the predetermined metric on the artefact severity of the lower-quality visual data, the artefact correction model resulting from the

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training and optimisation process can be referenced by the artefact severity of the scene it relates to. In these embodiments, this allows for a more accurate selection of a suitable artefact removal model when selecting a model from the library to clean new visual data.

Optionally, the plurality of hierarchical algorithms is any of: pre-trained hierarchical algorithms on example data; or manually created hierarchical algorithms.

In some embodiments, a pre-trained hierarchical or manually created hierarchical algorithm will be able to more accurately recreate the original visual data than a generic artefact removal hierarchical algorithm

Optionally, if a suitable hierarchical algorithm is not present in the plurality of hierarchical algorithms, a generic hierarchical algorithm is selected instead.

In some embodiments, a generic hierarchical algorithm may be used instead of a specific, trained model in situations where the library of algorithms does not include an visual data artefact removal model that has been trained on a similar enough content type and artefact graded to the received visual data. In these embodiments, the generic hierarchical algorithm may then be more accurate in removing the artefacts than the specifically trained hierarchical algorithms available.

Accelerating Machine Optimisation Processes

According to an aspect, there is provided a method for training learned hierarchical algorithms, the method comprising the steps of: receiving input data; generating metrics from the input data; selecting at least one hierarchical algorithm from a plurality of predetermined hierarchical algorithms based on comparing the generated metrics from the input data and like metrics for each of the plurality of predetermined hierarchical algorithms; developing the selected hierarchical algorithm based on the input data; and outputting a developed hierarchical algorithm.

Providing a plurality of pre-trained sets of parameters or models in some embodiments allows the training of a machine learning process to be accelerated. In these embodiments, input data to be processed by a trained machine learning process can have a tailored model, or set of parameters, developed for that input data based on the selected most similar pre-trained model. In such embodiments, the selection of the one or more most similar pre-trained model(s) can be done based on one or more metrics associated with the pre-trained models compared to the input data. In at least some of these embodiments the most similar pre-trained model can be used as a

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starting point for developing the tailored model for the data as a tailored model does not have to undergo as extensive development as needed when developing a model from first principles. In some embodiments, using a similar or the most similar pre-trained model can also help with avoiding or escaping local minima (for incorrect solutions) during training.

Optionally, the method further comprises the step of storing the developed hierarchical algorithm with plurality of predetermined hierarchical algorithms along with the generated metrics from the input data.

In some embodiments, each new tailored model is then stored in a library of pre-trained models. In these embodiments, repeating or identical input data can re-use a tailored model that already exists without any further modification. In such embodiments, the closer a model is to an optimised version the less computation is required to generate a more optimal model. In these embodiments, as more signals and data are processed, an increasingly more extensive collection of models can be established in the library, requiring reduced development for tailored models for new data thereby saving computational effort.

Optionally, the plurality of predetermined hierarchical algorithms may be any of: pre-trained hierarchical algorithms on example data; or manually created hierarchical algorithms.

In some embodiments, the predetermined hierarchical algorithms can be based on example data or manually created to allow a user to create specific behaviours in any eventual trained model or set of parameters.

Optionally, the step of developing the selected hierarchical algorithm may be based on the input data comprises developing a more optimised hierarchical algorithm.

In some embodiments, developing the predetermined hierarchical algorithms can improve the example-based set of parameters to create a more optimised set of parameters.

Optionally, the hierarchical algorithm comprises at least one of any of: a specific parameter for the reconstruction of data; or a mapping function for the reconstruction of data.

In some embodiments, each hierarchical algorithm can be used to provide for the reconstruction of data. In some of these embodiments, the reconstruction process can vary, and therefore the model can comprise different features, coefficients and/or parameters that would allow for reconstruction and each layer of the hierarchical algorithm can comprise features, coefficients and/or parameters. Further, in some

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embodiments, the parameters for the reconstruction of visual data can comprise one or more hierarchical algorithms.

Optionally, the plurality of hierarchical algorithms may be stored in a repository.

For ease of access to the plurality of predetermined example-based models, in some embodiment the models can be stored in a repository. In these embodiments, the repository can take the form of a library. In some embodiments, the repository can be located on a remote device and/or distributed computing system (such as a cloud computing and/or storage service and/or distributed networked system or peer-to-peer system).

Optionally, the method may comprise the further steps of: extracting features of the input data; and using the extracted features to select a predetermined hierarchical algorithm from the plurality of predetermined hierarchical algorithms to provide initial parameters for the developed hierarchical algorithm.

In some embodiments, extracted standardised features are used to produce a value or series of values based on a metric from the input data. In these embodiments, the metric can then be used to select the pre-trained model from the library which is most appropriate for the input data, as each model in the library has associated metric values based on the input data from which the models were respectively trained, the selection based on the similarity between the metrics associated with the input data and each of the pre-trained models.

Optionally, the metrics may be based on generating the highest quality output data, preferably wherein quality can be defined using any of: an error rate; a peak signal-to-noise ratio; a distance metric; a similarity measure; or a structural similarity index.

In some embodiments, the predetermined metrics used to determine the hierarchical algorithm to be selected is based on a predicted quality of the output data for each pre-trained model. In some of these embodiments, quality can be defined by any or all of: an error rate; a peak signal-to-noise ratio; or a structural similarity index.

Optionally, the hierarchical algorithm is selected based on providing optimal initialisation data when in use

By providing initialisation data which is optimal in at least some embodiments, thereby being as close as possible to the section of visual data being analysed, fewer iterations are required to adapt the model into a form to allow for the highest quality reconstruction according to any of the metrics above. In these embodiments,

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computational effort and time is therefore reduced when processing the section of visual data.

Enhancing Model Libraries

According to an aspect, there is provided a method for enhancing visual data when communicating visual data over a network from a first node to a second node, the method at the first node comprising the steps of: developing at least one modified hierarchical algorithm from a known hierarchical algorithm operable to substantially recreate at least one section of higher-quality visual data; transmitting to the second node references to one or more known hierarchical algorithms from which the modified hierarchical algorithms were developed; and transmitting to the second node one or more modifications to the one or more known hierarchical algorithms operable to reproduce the one or more modified hierarchical algorithms from the known hierarchical algorithms; wherein the second node is able to recreate substantially the higher-quality visual data using the modified hierarchical algorithm.

According to another aspect, there is provided a method for enhancing visual data when communicating visual data over a network from a first node to a second node, the method at the second node comprising the steps of: receiving a reference to a known algorithm corresponding to a section of higher-quality visual data; receiving corresponding modifications to the known hierarchical algorithm operable to produce a modified hierarchical algorithm, the modified hierarchical algorithm developed with the knowledge of the section of higher-quality visual data; and using the modified algorithm to substantially recreate the section of higher-quality visual data.

In some embodiments, knowledge of the section of higher-quality visual data can comprise knowing the encoder settings and/or the content category for at least one of the low-quality visual data, original visual data and the higher-quality visual data. In some of these embodiments, the content category can be based on a predetermined set of categories or a determines set of categories.

According to a further aspect, there is provided a system for enhancing visual data when communicating visual data over a network, the system comprising two or more nodes, wherein a first node is configured to: develop at least one modified hierarchical algorithm from a known hierarchical algorithm operable to substantially recreate at least one section of higher-quality visual data; transmit to the second node references to one or more known hierarchical algorithms from which the modified

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hierarchical algorithms were developed; and transmit to the second node one or more modifications to the one or more known hierarchical algorithms operable to reproduce the one or more modified hierarchical algorithms from the known hierarchical algorithms; wherein a second node is configured to: receive a reference to a known algorithm corresponding to a section of higher-quality visual data; receive corresponding modifications to the known hierarchical algorithm operable to produce a modified hierarchical algorithm, the modified hierarchical algorithm developed with the knowledge of the section of higher-quality visual data; and use the modified algorithm to substantially recreate the section of higher-quality visual data.

In some embodiments, by transmitting a reference to a known algorithm and modifications to that algorithm that allow a modified algorithm to be produced to enable reconstruction of a high- quality section or series of sections of visual data, less data can be transferred over a network to enable a high- quality visual data to be viewed compared to transmitting the high quality visual data. In some of these embodiments the algorithms, also known as models, representations or functions, can also be more accurate and therefore enable a more accurate reconstruction, i.e. produce a higher quality high- quality visual data, for example where quality can be measured by a low error rate in comparison to the original high- quality visual data.

Optionally, known hierarchical algorithm is selected from a library of hierarchical algorithms stored at the first node.

Optionally, the reference received by the second node corresponds to a known hierarchical algorithm stored in a substantially matching library at the second node.

Optionally, if the second node cannot identify the known hierarchical algorithm, the second node sends a request to the first node for transmission of the known hierarchical algorithm from the first node to the second node.

In some embodiments, by providing common or synchronised libraries of algorithms at both the first and the second nodes, and by transmitting a reference or reference identifier when transmitting the corresponding lower- quality visual data to allow selection of matching algorithms from both libraries using the reference identifier to identify the selected algorithm, only the reference identifier, the lower- quality visual data and the modifications to the stored hierarchical algorithms need to be transmitted between the nodes thus data transmission is reduced as the full algorithm doesn't need to be transmitted.

Optionally, the modified hierarchical algorithm is stored in a library at the first node after being developed.

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In some embodiments, by storing the newly developed algorithm at the first node, the algorithm may be used as a starting point to develop further modified algorithms for similar high quality visual data, increasing the efficiency of the method in future situations.

Optionally, the modified hierarchical algorithm is stored in a library at the second node after transmission of the one or modifications to the known hierarchical algorithm from the first node to the second node.

In some embodiments, storing the modified algorithm at the second node after it has been recreated from the known algorithm and the transmitted modifications allows it to be referenced in the future when the modified algorithm is used as a starting point to develop a new algorithm at the first node. In such embodiments, this can prevent duplication.

In some embodiments, the first node may transmit known algorithms to the second node prior to sending the modifications required to make the modified algorithm to ensure that the required known algorithm is present at the second node. In such embodiments, this can reduce errors.

Optionally, one or more representations of the one or more sections of higher-quality visual data are transmitted to the second node and to which the one or more modified hierarchical algorithms are applied to substantially reproduce the one or more sections of higher-quality visual data.

In some embodiments, by transmitting representations of the higher quality visual data to the second node the reconstruction of the higher quality visual data can be aided by applying the modified reconstruction model to the representation, but still with less data being transferred across the network than if the higher quality visual data had been transmitted.

Optionally, one or more sections of lower-quality visual data corresponding to the one or more sections of higher-quality visual data are transmitted to the second node and to which the one or more modified hierarchical algorithms are applied to substantially reproduce the one or more sections of higher-quality visual data.

Optionally, down-sampling is used to reduce the quality of one or more sections of higher-quality visual data to one or more sections of lower quality visual data.

Optionally, the one or more sections of lower-quality visual data are generated from the one or more sections of higher-quality visual data using a process of compression and/or quantisation.

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In some embodiments, by lowering the quality of the section of visual data, less data needs to be sent across a network from a first node to a second node in order for the second node to receive the file. In these embodiments, the lower quality version together with a model to be used for reconstruction can still allow for less data to be transmitted than if the original higher-quality version of the same section of visual data is transmitted (where the quality can be determined by the resolution and/or the level of compression).

Strided Convolutions

According to an aspect, there is provided a method for enhancing at least a section of lower-quality visual data using a hierarchical algorithm, the method comprising steps of: receiving at least one section of lower-quality visual data; extracting a subset of features, from the at least one section of lower-quality visual data; forming a plurality of layers of reduced-dimension visual data from the extracted features; and enhancing the plurality of layers of reduced dimension visual data to form at least one section of higher-quality visual data wherein the at least one section of higher-quality visual data corresponds to the at least one section of lower-quality visual data received.

In some embodiments, extracting a subset of features from a section of lower quality visual data enables performance to be increased by only performing the enhancement on the subset of features as opposed to the entirety of the lower quality visual data, thereby reducing the amount of computation, whilst still achieving acceptable enhancements.

Optionally, the extracted subset of features is dependent upon one or more predetermined factors.

In some embodiments, the use of a predetermined factor to extract the subset of features enables the method to be tailored to a plurality of systems of different capabilities, and allows customisation of the amount of data to extract, allowing for a more accurate selection of a reconstruction model to enhance the lower quality visual data in an appropriate amount of time.

Optionally, the number of layers is dependent upon the one or more predetermined factors.

In some embodiments, the number of layers being based upon the one or more predetermined factors ensures the reconstructed higher-quality visual data corresponds to the lower-quality visual data received.

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Optionally, the lower-quality visual data comprises a plurality of sections of video data.

In some embodiments, video may be used in the method, enabling the techniques to be applied to lower-resolution video data and upscaling it to corresponding higher resolution video data.

Optionally, the at least one section of lower-quality visual data comprises any of: a single frame of lower-quality video data, a sequence of frames of lower-quality video data, and a region within a frame or sequence of frames of lower-quality video data.

In some embodiments, depending on the visual data being processed, models can be used for sections of video data comprising a single frame, a sequence of frames or a region within a frame or sequence of frames. In some of these embodiments, each option could be necessary in order to provide the most efficient method of reconstructing a higher resolution version of a part of the received video file. In some embodiments, regions can include areas within a section, or segmentation between the background and foreground within a section, or some other content-based segmentation such as saliency based segmentation (i.e. where on each section of visual data a viewer is most likely to look).

Optionally, the hierarchical algorithm differs for each section of visual data.

In some embodiments, the use of different hierarchical algorithms for each section of visual data enables the most efficient hierarchical algorithm to be used for a particular section as opposed to using a single hierarchical algorithm for the entire visual data.

Optionally, the hierarchical algorithm is selected from a library of algorithms.

In some embodiments, a library of a plurality of algorithms allows for efficient selection of an hierarchical algorithm from the plurality of algorithms without delays due to communication links.

Optionally, standardised features of the at least one section of received lower-quality visual data are extracted and used to select the hierarchical algorithm from the library of algorithms.

Optionally, the hierarchical algorithm to be selected from the library of algorithms is based on generating the highest quality version of the lower-quality visual data, preferably wherein quality can be defined by any of: an error rate; a bit error rate; a peak signal-to-noise ratio; or a structural similarity index.

In embodiments, a variety of options are available in order to select which algorithm in the library of algorithms will output the best enhanced and enhanced visual

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data from the received visual data, for example an error rate such as the bit error rate can be used

General Aspects

It should be noted that in some aspects and/or embodiments, the terms model and/or algorithm and/or representation and/or parameters and/or functions can be used interchangeably.

It should also be noted that visual data, in some embodiments, may comprise image and/or video data.

Optionally, the modified hierarchical algorithm is trained using a learned approach.

In some embodiments, hierarchical or non-hierarchical algorithms can be substantially accurate and therefore enable a more accurate reconstruction, i.e. produce higher quality high- quality visual data from the low- quality visual data that is transmitted, for example where quality can be measured by resolution or by a low reproduction error rate in comparison to the original high- quality visual data. In some embodiments, using a learned approach can substantially tailor the hierarchical model or models for each portion of low-quality visual data.

Optionally, the learned approach comprises machine-learning techniques. The modified hierarchical algorithm may also be a non-linear hierarchical algorithm, which may comprise one or more convolutional neural networks.

In some embodiments, non-linear models can be substantially accurate in reconstructing higher- quality sections of visual data than dictionary-based approaches. In these embodiments, through using a learning-based approach, i.e. an approach that does not rely on pre-defined visual data features and operators, the model(s) can be optimised for each section or sequence of sections.

In some embodiments, the training of convolutional neural networks can be more computationally complex than dictionary learning for a similar accuracy, but the resulting model or algorithm can also be more flexible in representing visual data while using fewer coefficients for the reconstruction. In these embodiments, the resultant convolutional neural network model to be transmitted alongside the lower- quality visual data can be both smaller and can be more accurate in the reconstruction of a higher-quality visual data.

Some aspects can provide an improved technique for generating reconstruction

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parameters that can be used, when converting an original high- quality video into a down-sampled low- quality video, to allow recreation of a higher- quality version of the video from down-sampled low- quality video without significant loss in quality, for example having a low reconstruction error in comparison with the original high- quality video, and with a reduction in visual data transferred over a network. In such aspects, the application of such a technique can reduce the data transmitted when transmitting visual data in comparison with existing techniques while enabling reproduction of the visual data at its original quality without significant loss in quality in comparison to the original visual data (where quality can be defined by objective metrics such as error rate, PSNR and SSIM as well as subjective measures). In such aspects, such a proposed technique can allow minimal changes to be made to the overall infrastructure of video service providers, as it can augment most existing video compression techniques, and can provide advantages in video encoding and video streaming applications.

Optionally, the higher-quality visual data is at a higher- quality than the lower-quality visual data.

Optionally, the lower-quality visual data contains a higher amount of artefacts than the higher-quality visual data.

Optionally, the hierarchical algorithm performs visual data enhancement, preferably using super- quality techniques.

Optionally, the hierarchical algorithm uses a spatio-temporal approach.

In some embodiments, optionally for use for a section of visual data, the example based model may be a neural network and can use spatio-temporal convolution. In some embodiments, separating visual data into a series of sections allows for the individual sections to be down-sampled thus reducing the visual data size, thereby allowing for lower quality sections to be transmitted as re-encoded visual data in the original or optionally a more optimal codec but at a lower quality . In some embodiments, a spatio-temporal network can allow an improvement in performance by exploiting the temporal information in the visual data and, for example, within a similar scene in sequential sections of visual data, there may be stationary sections of background in the sequential sections providing information relevant for the higher- quality version of that scene such that temporally consecutive sections can be used to super resolve one section.

Aspects and/or embodiments include a computer program product comprising software code to effect the method and/or apparatus of other aspects and/or embodiments herein described.

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References to visual data can be references to video data and/or image data in some aspects and/or embodiments and vice versa. References to low-quality and/or lower-quality can be references to low-resolution and/or lower-resolution in some aspects and/or embodiments and vice versa. References to high-quality and/or higher-quality and/or highest quality and/or original quality can be references to high-resolution and/or higher-resolution and/or highest-resolution and/or original resolution in some aspects and/or embodiments and vice versa. References to sections can be references to frames and/or portions of frames in some aspects and/or embodiments and vice versa. References to enhance or enhancement can be references to upscale and/or upscaling in some aspects and/or embodiments and vice versa.

Brief Description of Drawings

Embodiments of the present invention will now be described, by way of example only and with reference to the accompanying drawings having like-reference numerals, in which:

Figure 1 illustrates an over-complete dictionary of 16 x 16 atoms;

Figure 2a illustrates the layers in a convolutional neural network with no sparsity constraints;

Figure 2b illustrates the layers in a convolutional neural network with sparsity constraints;

Figure 3 illustrates the encoding process to generate for transmission, from high-resolution visual data, a combination of low-resolution visual data and convolution neural network able to use super resolution to increase the resolution of the low-resolution data;

Figure 4 illustrates the decoding process using the low-resolution visual data and convolution neural network to recreate a version of the high-resolution visual data;

Figure 5 is a flowchart illustrating the method steps for encoding a visual data for transmission using the process of Figure 3;

Figure 6 is a flowchart illustrating the method steps for decoding the visual data and convolution neural network data generated using the method shown in Figure 5;

Figure 7 is a diagram of an efficient sub-pixel convolutional network according to an embodiment, featuring two feature map extraction layers built with convolutional neural networks, and a sub-pixel convolutional layer that aggregates the feature maps from low-resolution space and builds the super resolution image in a single step;

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Figure 8 is a diagram of the network architecture according to an embodiment for super resolution using three input frames where only the input layer is modified to jointly handle three input frames for the super resolution prediction of only the middle frame while the hidden layers are identical to those in Figure 7;

Figure 9 is a flow chart illustrating the method steps for a machine learning process;

Figure 10 illustrates the encoding process to generate for transmission, from high resolution visual data and known convolutional neural networks, low resolution visual data and modifications to the known convolutional neural network;

Figure 11 illustrates the decoding process using the low resolution visual data and a reference to a known convolutional neural network, along with modifications to that network, to recreate a version of a high resolution visual data;

Figure 12 illustrates a further encoding process to generate for transmission, from high resolution visual data and known convolutional neural networks a modified convolution neural network; and

Figure 13 illustrates a further decoding process using a reference to a known convolutional neural network, along with modifications to that network, to recreate a version of a high resolution visual data;

Figure 14 is a flowchart illustrating the method steps for a conventional image enhancement process from a lower resolution original visual data to a higher resolution visual data;

Figure 15 is a flowchart illustrating the method steps for an image enhancement process according to an embodiment, where visual data is up-scaled from a lower-resolution original visual data to a higher-resolution visual data, using a combination of the received visual data and a convolutional neural network selected from a library, the convolutional neural network able to use super resolution techniques to increase the resolution of the received visual data;

Figure 16 is a flowchart illustrating the method steps for an image enhancement process to: generate a down-sampled visual data for transmission from a higher-resolution original visual data, the transmission of the down-sampled visual; and an image enhancement process to upscale from the down-sampled visual data to a higher-resolution visual data, using a combination of the received down-sampled visual data and a convolutional neural network selected from a library, the convolutional neural network able to use super resolution techniques to increase the resolution of the received down-sampled visual data;

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Figure 17 is a flowchart illustrating the method steps for an image enhancement process according to the embodiment in Figure 16, with additional steps for encoding visual data at another node prior to transmitting the encoded visual data to the node performing the method of Figure 16;

Figure 18 is a flowchart illustrating the method of Figure 15, with the additional steps of extracting a reduced dimension representation and concatenating the visual data to create a reduced dimension representation of the separated frame;

Figure 19 is a flowchart illustrating the method of Figure 16, with the additional steps of extracting a reduced dimension representation and concatenating the visual data to create a reduced dimension representation of the separated scene;

Figure 20 is a flowchart illustrating the method steps for an image enhancement process according to the embodiment in Figure 19, with additional steps for encoding visual data at another node prior to transmitting the encoded visual data to the node performing the method of Figure 19;

Figure 21 illustrates the selection of pixels from visual data based upon a predetermined value to produce reduced resolution visual data for processing by the method illustrated in Figures 18 through 20;

Figure 22 illustrates an overview of a method of generating models for use in image artefact removal;

Figure 23 illustrates a method of using the image artefact removal models;

Figure 24 illustrates an alternative method of using the image artefact removal models;

Figure 25 illustrates the encoding process to generate, for transmission, from high resolution video data, a combination of low resolution visual data and a reference to an algorithm able to use super resolution to increase the resolution of the low resolution visual data;

Figure 26 illustrates the decoding process using the low resolution visual data and the algorithm corresponding to the received reference to recreate a version of the high resolution visual data; and

Figure 27 illustrates the method steps of the encoding process to generate for transmission, from original visual data being recorded through to the transmitted package of a lower-resolution scene along with a hierarchical algorithm.

Specific Description

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Various embodiments will now be described in detail with reference to the Figures referenced above.

Reduction of Complexity In Neural Networks

With reference to Figures 2a and 2b, various possible configurations of neural network for use in at least some embodiments shall now be described in detail.

An example layered neural network is shown in Figure 2a having three layers 10, 20, 30, each layer 10, 20, 30 formed of a plurality of neurons 25, but where no sparsity constraints have been applied so all neurons 25 in each layer 10, 20, 30 are networked to all neurons 25 in any neighbouring layers 10, 20, 30. The example simple neural network shown in Figure 2a is not computationally complex due to the small number of neurons 25 and layers. Due to the density of connections, however, the arrangement of the neural network shown in Figure 2a won't scale up to larger sizes of network, i.e. the connections between neurons/layers, easily as the computational complexity soon becomes too great as the size of the network scales and scales in a non-linear fashion.

Where neural networks need to be scaled up to work on inputs with a high number of dimensions, it can therefore become too computationally complex for all neurons 25 in each layer 10, 20, 30 to be networked to all neurons 25 in the one or more neighbouring layers 10, 20, 30. A predetermined initial sparsity condition is used to lower the computational complexity of the neural network, for example when the neural network is functioning as an optimisation process, by limiting the number of connection between neurons and/or layers thus enabling a neural network approach to work with high dimensional data such as images.

An example of a neural network is shown in Figure 2b with sparsity constraints, according to at least one embodiment. The neural network shown in Figure 2b is arranged so that each neuron 25 is connected only to a small number of neurons 25 in the neighbouring layers 40, 50, 60 thus creating a neural network that is not fully connected and which can scale to function with, higher dimensional data – for example as an optimisation process for video. The smaller number of connections in comparison with a fully networked neural network allows for the number of connections between neurons to scale in a substantially linear fashion.

Alternatively, in some embodiments neural networks can be use that are fully connected or not fully connected but in different specific configurations to that described in relation to Figure 2b.

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Further, in some embodiments, convolutional neural networks are used, which are neural networks that are not fully connected and therefore have less complexity than fully connected neural networks. Convolutional neural networks can also make use of pooling or max-pooling to reduce the dimensionality (and hence complexity) of the data that flows through the neural network and thus this can reduce the level of computation required. In some embodiments, various approaches to reduce the computational complexity of convolutional neural networks can be used such as the winograd algorithm or low-rank matrix approximations.

End-to-end Super Resolution Enhancement Model Generation & Reconstruction

Although initially designed to enhance single image frames, super resolution techniques can also be used on multiple frames in some embodiments. To apply these techniques in such embodiments, multiple low-resolution frames can be gathered together and the sub-pixel shifts between the individual frames can be used to create a higher resolution image than the original. In such embodiments, a series of frames can be combined to form a higher resolution video than was originally provided.

To improve on the above described dictionary-based approach for encoding and decoding video using super resolution techniques, in at least some embodiments it is proposed to use deep learning techniques and convolutional neural network models instead of dictionary learning techniques and dictionary-based models.

Dictionary learning is closely related to sparse coding techniques, while deep learning is only more loosely connected with sparse coding. Sparse coding is an effective mechanism that assumes any natural image can be sparsely represented in a transform domain. Sparse coding is a technique used to automatically find a small number of representative patterns which, when combined in the right proportions, reproduce the original input patterns. The sparse coding for an input then consists of those representative patterns. From a signal processing perspective, it follows that complicated signals can be broken down into a small, i.e. sparse, number of simple signals.

The transform domain can be a dictionary of image atoms, which can be learnt through a training process known as dictionary learning that tries to discover the correspondence between low-resolution and high-resolution sections of images (or "patches"). Dictionary learning uses a set of linear representations to represent an image

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and where an over-complete dictionary is used, a plurality of linear representations can be used to represent each image patch to increase the accuracy of the representation.

In at least some embodiments, instead it is proposed to use machine learning with deep learning techniques that can instead create non-linear representations of an image or sequence of images.

When using machine learning and sparse coding principles, a training process is used to find optimal representations that can best represent a given signal, subject to predetermined initial conditions such as a level of sparsity.

When using convolutional neural networks in at least some embodiments, the efficiency in terms of computational and memory cost can be important.

In some embodiments, convolutional neural network models (or hierarchical algorithms) can be transmitted along with the low-resolution frames of video data because the convolutional neural network models reduce the data transmitted in comparison with learned dictionaries being transmitting along with the low-resolution images, especially in comparison to transmitting learned over-complete dictionaries with the low-resolution images, in the case where the models and dictionaries have the same level of reconstruction accuracy.

The convolutional neural network models of some embodiments allow the reconstruction process and image representation to be non-linear. This is in contrast to the dictionary-based approach, which represents images in a linear fashion, as described above. The convolutional neural network models of some embodiments offer reconstruction with a feed-forward mechanism based on image convolution that is able to be computed in parallel and for which methods with high computational speed are available, such as the AMD® Tiled Convolution approach which can be used for fast image filtering.

The series of convolutions in a convolutional neural network model of some embodiments allow the neural network to be used to search for pixel correlations in a region far larger than the initial patch decomposition, but applying a weighting to weaken the importance of correlations for locations further away from the pixel of interest. In contrast, linear sparse coding approaches like dictionary learning are restricted to looking for correlations in an initial patch size, to avoid the computational complexity of searching the entire image. As a result, the method of these embodiments can more fully exploit the natural or non-local redundancies of the video frames and between a sequence of video frames.

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In some embodiments, optionally the convolutional neural network models only assume local spatial or spatio-temporal correlations in an image or video. This assumption is in contrast to the assumption that small data patches must be well represented by a restricted number of atoms from a dictionary, which is a sparsity constraint applied to dictionary learning and over-complete dictionary approaches.

In some embodiments, recurrent neural network models can be used. Recurrent neural network models have single layers that are used iteratively. The layers of a recurrent neural network model can be unrolled into a number of layers in order to be treated in a similar fashion to convolutional neural networks, in some embodiments.

Referring now to Figures 3 and 5, a technique that can be used in method, apparatus and/or system embodiments to encode video data will now be described in detail.

Original video data 70 is a high-resolution video, for example having a resolution of 1920 pixels by 1080 pixels (also known as "1080p" video) or 3840 pixels by 2160 pixels (also known as "4K" video). This video data can be encoded in a variety of known video codecs, such as H.264 or VP8, but can be any video data that can be decoded into the component frames of the video. The original video data 70 is provided as input visual data for encoding using the technique.

The original video data 70 is then split into single full-resolution frames at step 80 (or step 190), i.e. into a sequence of images at the full resolution and/or quality of the original video data 70. For some video codecs, this will involve "uncompressing" or restoring the video data as, for example, common video compression techniques remove redundant (non-changing) features from sequential frames.

Optionally, at step 90 (or step 190), in some embodiments the full-resolution frames can be grouped into scenes or sections of frames having common features, otherwise known as "scene selection". The video data is split or clustered into scenes to enable more specific training and optimisation. By scene, it is meant a consecutive group or sequence of frames, which at the coarsest level can be the entire video, a single frame or at the most granular level can be or a section/segment of a frame.

The exact approach employed for splitting frames into scenes can be performed in many ways, depending on embodiment, with the four main approaches being described below:

A first approach is the use of the frame-type groupings of the underlying video codec. In this approach, a scene is defined in the encoded video by each group of pictures (sometimes referred to by the abbreviation "GoP"), for example between two I-

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frames. This is probably the simplest approach for scene selection and does not require much additional computation to perform scene analysis of the video, but the approach does not allow any flexibility in the level of granularity in the definition of each scene.

The second approach is the use of a scene or shot transition detector, for example as described in the paper "A Unified Model for Techniques on Video-Shot Transition Detection" by Jesús Bescós, Guillermo Cisneros, José M. Martínez, José M. Menéndez, and Julián Cabrera as published in IEEE TRANSACTIONS ON MULTIMEDIA, VOL. 7, NO. 2, APRIL 2005 on pages 293-307 which is incorporated herein by reference. This approach proposes a unified detection model to detect camera-shot transitions in video, detecting both abrupt and gradual camera-shot transitions.

The third approach is the use of a clustering approach after applying an unsupervised learning or dimensionality reduction approach such as K-means clustering or manifold learning or Principle Component Analysis (PCA) etc. A suitable K-means clustering approach is detailed in the paper "Constrained K-means Clustering with Background Knowledge" by Kiri Wagstaff, Claire Cardie, Seth Rogers and Stefan Schroedl as published in the Proceedings of the Eighteenth International Conference on Machine Learning, 2001, p. 577-584. A suitable manifold learning approach is proposed in the paper "Algorithms for manifold learning" by Lawrence Cayton published on June 15, 2005. Both of these papers are herein incorporated by reference.

The fourth approach is to use a range of predefined scene classes and then automatically classifying scenes using the predefined classes. Examples of this approach can be found in the paper "Nonparametric Scene Parsing: Label Transfer via Dense Scene Alignment" by Ce Liu, Jenny Yuen and Antonio Torralba having IEEE reference 978-1-4244-3991-1/09 and the paper "80 million tiny images: a large dataset for non-parametric object and scene recognition" by Antonio Torralba, Rob Fergus and William T. Freeman. Both of these papers are herein incorporated by reference.

The exact approach for how a scene is defined is independent from the rest of the approach, and will vary by embodiment, although it will have an impact on the training time and the reconstruction performance so there is a level of optimisation required for each possible embodiment to find a balance between the speed and the accuracy of the scene detection step.

Alternatively, no scene matching needs to be performed at step 90 (or step 190) in some embodiments. A further alternative for some embodiments is to perform only very basic time-stamping of the video, to determine how to reassemble the video frames

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for later stages in the technique, for example during transmission or during playback of the video.

Regardless whether the video has been broken into frames or scenes (i.e. groups of multiple frames) in step 90 (or step 190) or remains as a sequence of frames from step 80 (or step 190), each frame is down-sampled into lower resolution frames at a suitably lower resolution. Optionally, in some embodiments this step can occur before the frames are grouped into scenes in step 80 (or step 190), so step 90 (or step 190) can be exchanged with step 90 (or step 190) in these alternative embodiments. The lower-resolution frame can, for example, be 33% to 50% of the data size relative to the data size of the original-resolution frame, but in should be appreciated that in embodiments the lower resolution can be any resolution that is lower than the original resolution of the video.

In step 110 (or step 200), in at least one embodiment super resolution techniques are employed to create a specific model using machine learning for each frame, so that the model can be used to substantially recreate the original resolution version of a lower-resolution frame and trained using machine learning based on knowledge of the original-resolution frame. This step is termed the training and optimisation process. In some embodiments, generic models can be developed for types of scene or frame. Alternatively, in other embodiments, models can be developed for each scene.

By employing a deep learning approach to generating the model in embodiments, a non-linear hierarchical model can be created in some of these embodiments to reconstruct a higher-resolution frame from the lower-resolution frame.

An example of a deep learning approach, but in respect of only still images and without use of the original image to optimise the reconstruction model, is described in the paper "Learning a Deep Convolutional Network for Image Super-Resolution" by Chao Dong, Chen Change Loy, Kaiming He, and Xiaoou Tang published in D. Fleet et al. (Eds.): ECCV 2014, Part IV, LNCS 8692, pp. 184–199, 2014 and this paper is incorporated herein by reference. This paper relates to using super resolution techniques when trying to obtain an unknown high resolution version of a given low resolution image and proposes the use of a convolutional neural network to learn mappings between low resolution and high resolution images.

While the creation of non-linear hierarchical models is more computationally complex than creating linear models using dictionary learning approaches, in at least some embodiments it can be more flexible. Further, the non-linear models created in

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some of these embodiments can use only a few coefficients to enable reconstruction in comparison to the dictionary-based approach, thus such models can require less data to be transmitted. Still further, the non-linear models used in some embodiments can be more accurate in reconstructing higher-resolution frames than dictionary-based approaches. The non-linear models created in some embodiments are small convolutional neural networks rather than over-complete dictionaries. In contrast to the local patch averaging approach that tends to be used in reconstruction by dictionary learning approaches, the use of a convolutional neural network model in embodiments also allows a more appropriate filter to be learned for final reconstruction where neighbouring patches are considered, which can avoid unintended smoothing of the reconstructed higher-resolution image.

The training and optimisation process in embodiments can be configured according to a desired trade-off between computational time spent and desired quality of results. In general, the number of iterations used during the training process yields approximately logarithmic gains in reconstruction accuracy, so in some embodiments it is preferred to use an automatic threshold to stop further optimisation. When favouring quality of results in embodiments, the automatic threshold can be set to a predetermined value of reconstruction error, for example by calculating the mean squared error, but other methods can be used. Alternatively, in some embodiments the automatic threshold can be set to limit the training and optimisation process to a predetermined number of iterations. As a further alternative, in some embodiments a combination of these two factors can be used.

In some embodiments, step 120 (or step 210), the portion of the low-resolution video and the reconstruction model for that portion of video are output for transmission. Optionally, in some embodiments the video and model can be stored together within a suitable data container format such as a Matroska Multimedia Container (otherwise known as a MKV container). Alternatively, in some embodiments the video and model can be combined with other sections or the entire video and placed into a suitable data container format. In some embodiments, at step 120 (or step 210), the low-resolution video frames can be re-encoded using either the original video codec applied to the original video data 70 or, alternatively, a more optimal video codec can be applied to the video data to produce output video data 130. Optionally, if scene detection or time stamping was performed, in some embodiments the data output for transmission can include either a list of scenes or time stamp data respectively, or this data could be stored within the data container.

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In embodiments there can be a number of variations to the encoding framework described above. For the above described technique, it can be assumed in many embodiments that there would be a one-to-one mapping between scene and model, however this does not need to hold true as a local cluster of scenes could be used to train each model in some embodiments. Conversely, it could also be possible in some embodiments to use several similar models to initialise (by way of a weighted average) initial parameters for training new unseen scenes. It may also be sufficient to simply weight the models without requiring any further optimisation in some embodiments - similar to label fusion methods used in medical imaging for example.

Referring now to Figures 4 and 6, embodiments for reconstructing the video encoded using the technique will now be described in detail.

First, the data 130 is received from the network. In embodiments, the data received 130 depends on how the data was prepared for transmission in step 120 (or 210) as detailed above in the various possible embodiments and the prepared data can include the video data and one or more reconstruction models for that video data. In some embodiments, it is possible that the video data and one or more reconstruction models are not transmitted and/or received simultaneously so some buffering may be required to wait for all of the components required to decode or reconstruct the higher-resolution video from the data transmitted over the network.

At steps 140 and 150 (and step 220), the received data is prepared for reconstruction depending on the embodiment. In most embodiments, this step involves separating the low-resolution video from the reconstruction models (step 220). Optionally, in some embodiments the low-resolution video is decompressed using the video codec used for transmission into full-resolution image frames (step 230) and each of the frames is matched up with the corresponding reconstruction model, which are also unpacked into frame-by-frame order (step 240).

At step 160 (step 250), the reconstruction model is applied to each of the frames to output higher-resolution frames depending on the embodiment. The reconstruction, or decoding, process in most embodiments involves applying the optimised super resolution convolutional neural network model, or reconstruction model, for each scene in order to restore the lower-resolution video to its original resolution having substantially the same quality as the original high-resolution video. Given the corresponding models for each lower-resolution frame, the original higher-resolution frames can be reconstructed with high accuracy for at least some of these embodiments.

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The complexity of the reconstruction process can be far simpler, i.e. require less computation, when compared to that of training the model in most embodiments. In most embodiments, the reconstruction process is very similar to a single iteration of the training process, however there is no optimisation required and the process simply applies the learnt convolutional neural network model to reconstruct the image on a patch-by-patch basis. In some embodiments, a singular model is applied to each scene and can be sent as accompanying data in the video container ahead of the scene in which it is used. In some embodiments, the model associated with each scene can either be indexed in a data stream, synchronised with the video and audio stream, or indexed in a frame-to-model look-up table which can be sent ahead of the video stream depending on the embodiment.

The image reconstruction in most embodiments has a linear computational complexity, dependent on the total number of pixels of each frame, as the reconstruction process requires a series of convolution functions (typically less than 3) to be applied for each relevant image patch centred around each pixel. A basic reconstruction step for each image is as described in the paper "Learning a Deep Convolutional Network for Image Super-Resolution" by Chao Dong, Chen Change Loy, Kaiming He, and Xiaoou Tang published in D. Fleet et al. (Eds.): ECCV 2014, Part IV, LNCS 8692, pp. 184–199, 2014, and this step can be used with or without modification in some embodiments however, in some of these embodiments these functions can be applied in parallel across multiple images and in some embodiments it can be feasible to perform real-time reconstruction for video playback.

Super resolution operates on a patch-by-patch basis in most embodiments, but it may not be necessary to perform super resolution for every single patch of an image in some embodiments. In some embodiments, where the patch is flat and smooth, using a bi-cubic upscaling can be sufficient. It may be faster in some embodiments, for both training and reconstruction, if these patches could be bypassed. To identify these patches, one approach as set out in the paper "Coupled Dictionary Training for Image Super-Resolution" by Jianchao Yang, Zhaowen Wang, Zhe Lin, Scott Cohen and Thomas Huang (as published in IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 21, NO. 8, AUGUST 2012), incorporated by reference, can be used in some embodiments to filter out patches which have low variances and ignoring these areas of the image. Alternatively, in other embodiments edge detectors could be used instead to identify areas of interest.

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Further still, in some embodiments some level of inter-frame comparison can be used to identify regions of the image which do not change from frame to frame, thereby eliminating areas of the image from duplicating the efforts of super resolution reconstruction which occur in a previous frame. In these embodiments the underlying video code for the low-resolution video can be used to identify the regions of change as part of its inter-frame compression mechanism and this information could be taken advantage for more efficient real-time super resolution reconstruction and video playback. In addition, in some embodiments an auxiliary data-structure, such as a random fern, can be used to keep track of the uniqueness of patches that have been reconstructed. Given that an image may contain many repeating patches, use of this approach in some embodiments could prevent unnecessary reconstruction of patches whereby the result is already known (in another patch). Similar approaches have been used in key frame detection for real-time camera localisation for augmented reality applications.

The proposed method and system of encoding and decoding video of at least some of the embodiments can augment existing video compression and decompression codecs. By using the same codec as used to create the video data, the low resolution video that is transmitted can be encoded with the same video codec but at a lower resolution that that of the original in some embodiments. Thus, in some embodiments the proposed method and system can be independent of the original codec used to create and compress the video. Alternatively, in some embodiments it is possible to select an alternative codec for transmission and to re-encode the video back into the original codec when the video data has been transmitted, uncompressed and restored to a high resolution version of the original video data.

By incorporating, for example in some embodiments, image enhancement techniques into a video compression process, a reduction in resolution of the video during transmission can be achieved and thus lower amounts of data are transmitted because the image can be enhanced at the node receiving the reduced-resolution video to recreate the video at the original resolution. By using super resolution as the image enhancement technique in such embodiments, and with the knowledge of the original high-resolution image before applying image enhancement techniques, it is possible to down-sample the original high-resolution image to a lower-resolution image and choose one or more representations from a library of representations that can be used to create a high-resolution image from the down-sampled image based on the knowledge of the original image. In such embodiments, this results in only a down-sampled image and the

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super resolution reconstruction model or parameter being transmitted over a network instead of the original high resolution video, thus decreasing the amount of data transferred while maintaining a similar level of image quality relative to the original once the high-resolution image has been recreated.

At step 170, in some embodiments each of the segments of video are output from the reconstruction process as higher-resolution frames at the same resolution as the original video 70. In these embodiments, the quality of the output video 180 is substantially similar to that of the original video 70, within the error bounds optionally applied by the machine learning process that develops the reconstruction model at step 110 (or step 200) of the encoding process.

At step 180, in some embodiments the segments of video are combined such that the video can be displayed. Optionally at step 170 or 180, in other embodiments the video can be re-encoded with the original codec used on the original video 70 or a more predetermined optimal codec, to enable playback on a decoder or display device.

In most embodiments, the proposed technique does not perform conventional compression by rearranging the original data and discarding redundant data or data deemed to be of least importance such that the majority of the data is intact. Instead, in these embodiments the technique determines a series of simple light-weight functions through machine learning that can be used to reconstruct the original data while minimising the reconstruction error given some pre-defined cost function (a number of optimisation or search frameworks common to machine learning can be used, such as gradient descent or stochastic gradient descent). Thus, it follows that the technique of these embodiments can be described as an optimisation process of the reconstruction functions rather than the data redundancy/reduction process of conventional compression techniques.

Sub-Pixel Convolution

Referring now to Figures 3 and 5, embodiments using another technique to encode visual data will now be described in detail. These embodiments can be used in combination with other embodiments and alternative and optional embodiments described elsewhere in this specification.

Again, in these embodiments, original video data 70 is provided into the method or system and is a high-resolution video, for example having a resolution of 1920 pixels by 1080 pixels (also known as "1080p" video) or 3840 pixels by 2160 pixels (also known

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as "4K" video). This video data can be encoded in a variety of known video codecs, such as H.264 or VP8 but can be any visual data for which the system or method is able to decode into the component sections.

The original video data 70 is then split into single full-resolution frames at step 80 (or step 190), i.e. into a sequence of images at the full resolution of the original video data 70. For some video codecs, this will involve "uncompressing" or restoring the video data as, for example, common video compression techniques remove redundant (non-changing) features from sequential frames.

Optionally, at step 90 (or step 190), the full-resolution frames can be grouped into scenes or sections of frames having common features, otherwise known as "scene selection". The video data is split or clustered into scenes to enable more specific training and optimisation. By scene, it is meant a consecutive group or sequence of frames, which at the coarsest level can be the entire video or at the most granular level can be a single frame.

To super resolve a low-resolution image to high-resolution space, it is necessary to increase the dimensionality of the low-resolution image to match that of the high-resolution image at some point during the operation of the example based model or convolutional neural network. By upscaling the low-resolution image to a high-resolution as an input to an example-based model, the example-based model does not need to learn the super resolution filters to perform upscaling from the low-resolution space to a high-resolution space but this approach can sacrifice reconstruction accuracy and introduces computational complexity as all subsequent processing must occur at the high resolution dimensionality.

Referring to Figure 7, there is shown an efficient sub-pixel convolutional neural network (ESPCN) 700 having a low-resolution input image 710 with two feature map extraction layers 720, 730 built with convolutional neural networks and a sub-pixel convolution layer 740 that aggregates the feature maps from low-resolution space and builds the super resolution image 750 in a single step.

In an embodiment, as shown in Figure 7, the high-resolution data is super resolved from the low-resolution feature maps only at the very end of the network, in the final or last layer of the network, therefore avoiding the need to perform most of the computation in the larger high-resolution dimensionality. As processing speed depends substantially directly on the input image dimensionality, operation in the low-resolution space will allow for faster processing. Further, by performing feature map extraction before upscaling, more complex and more accurate upscaling (i.e. additional

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reconstruction accuracy) is possible by the final or last layer of the network as an upscaling or resampling function can be learned and is content and data adaptive as compared to the applying an explicit generic or handcrafted interpolation filter to perform upscaling (for example, a bicubic interpolation filter) that is heuristically chosen beforehand.

The task of the example based model, in some embodiments a single image super resolution network, is to estimate a high resolution image given a low resolution image that is downscaled or downsampled from a corresponding high resolution image. In some cases, for example video compression,the down sampling operation can be deterministic and known: to produce the low resolution image from the high resolution image, the high resolution image can be convolved using a Gaussian filter (but other filters can be used), thus simulating a point spread function in a camera, then downsampled by a upscaling ratio r. However general super resolution and upscaling are typically not deterministic and in some embodiments, in order to mitigate for non-deterministic operations, training can be performed for a range of different down sampling operations. In other embodiments, estimation can be performed, for example by training a classifier or some visual comparison, and optionally this could be parametised for the super resolution process in some embodiments. In general, both the low and high resolution image have C colour channels, thus can be represented as real-valued tensors of size $H \times W \times C$ and $rH \times rW \times C$ respectively. In some embodiments, rather than recovering an high resolution image from an upscaled and interpolated version of the low resolution image, instead the low resolution image is used by a three layer convolutional network to avoid upscaling before the low-resolution image is fed into the network. In the network, a sub-pixel convolution layer is applied to upscale the low resolution feature maps to produce a high resolution image using super resolution.

For a network composed of L layers, the first $L-1$layers can be described as follows:

$$f^1(\boldsymbol{I}^{LR};\, W_1, b_1) = \emptyset\,(W_1 * \boldsymbol{I}^{LR} + b_1)\,,$$
$$f^l(\boldsymbol{I}^{LR};\, W_{1:l}, b_{1:l}) = \emptyset\,(W_l * f^{l-1}(\boldsymbol{I}^{LR}) + b_l)\,,$$

where $W_l, b_l, l \in (1, L-1)$ are learnable network weights and biases respectively. W_l is a 2D convolution tensor of size $n_{l-1} \times n_l \times k_L \times k_L$, where n_l is the number of features at level l, $n_0 = C$, and k_l is the filter size and level l. The biases b_l are vectors

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of length n_1. The non-linearity function $\emptyset$ applies element-wise and is fixed. The last layer f^1 has to convert the low resolution feature maps to a high resolution image I^{SR}.

In an embodiment, the high-resolution data is super resolved from the low-resolution feature maps by a sub-pixel convolution layer, to learn the upscaling operation for image and video super resolution. If the last or final layer performs upscaling, feature extraction occurs through non-linear convolutions in the low-resolution dimensions, so a smaller filter size can be used to integrate the same information relative to doing so in the high-resolution dimensions thus reducing computational complexity.

In an embodiment, the convolutional neural network consists of a plurality of non-linear mapping layers followed by a sub-pixel convolution layer. The benefit is the reduced computational complexity compared to a three-layer convolutional network used to represent the patch extraction and representation, non-linear mapping and reconstruction stages in the conventional sparse-coding-based image reconstruction methods and using an upscaled and interpolated version of the low-resolution input. The convolutional neural network of the embodiment uses learned filters on the feature maps to super resolved the low-resolution data into high-resolution data (instead of using hand crafted interpolation or a single filter on the input images/frames).

Instead of using a deconvolution layer to recover resolution from max-pooling and other image down-sampling layers, according to some embodiments upscaling of a low-resolution image is performed by convolution.

In an embodiment, convolution is performed with a fractional stride of $\frac{1}{r}$ in the low-resolution space, which can be implemented by interpolation, perforate or un-pooling from low-resolution space to high-resolution space followed by a convolution with a stride of 1 in high-resolution space.

In another embodiment, convolution with a stride of $\frac{1}{r}$ in the low-resolution space is performed with a filter W_d of size k_s with a weight spacing $\frac{1}{r}$ to activate different parts of W_d for the convolution. The weights that fall between the pixels are not activated and therefore not calculated. The number of activation patterns is r2 and each activation pattern, according to its location, has at most $\left(\frac{k_s}{2}\right)^2$ weights activated. These patterns are periodically activated during the convolution of the filter across the image depending on different sub-pixel: mod (x, r), mod (y, r) where x, y are the output pixel co-ordinates in high-resolution space. In the situation where mod (k_s, rks) = 0, for a neural network with l layers, the low-resolution feature maps $f^{l-1}(I^{LR})$ from the last non-linear mapping layer

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are aggregated to produce the final estimate of the high-resolution image $f^L(I^{LR})$ using the following formula:

$$I^{SR} = f^L(I^{LR}) = PS\,(W_L * f^{L-1}(I^{LR}) + b_L$$

where W_L and b_L represent learnable filters and biaises respectively. The final convolution filter W_L is of size $n_{L-1} \times r^2C \times k_L \times k_L$, where C is the number of colour channels in the original image and r the resampling ratio. PS is a periodic shuffling operator. Thus, after the convolution, but before applying PS, we have a tensor that has dimension $rH \times rW \times C \cdot r^2$, where h and v are horizontal and vertical dimensions of the high-resolution image. The result of applying PS is a $rH \times rW \times C$ array, i.e. the same dimensions as the high-resolution image. This is achieved by periodic shuffling PS described in the following way:

$$PS(T)_{x,y,c} = T_{\lfloor x \rfloor, \lfloor y \rfloor, c \cdot r \cdot mod(y,r) + c \cdot mod(x,r)}$$

It is easy to see that when $k_L = \frac{k_S}{r}$ and $mod\,(k_S, r) = 0$it is equivalent to sub-pixel convolution in the low-resolution space with the filter W_d. This last layer, or sub-pixel convolution layer, produces a high resolution image from the low resolution feature maps directly, with a more distinguishable filter for each feature map and can operate with increased efficiency as the operation of the periodic shuffling described can be processed in parallel in a single cycle.

Given a training set consisting of high resolution image examples $I_n^{H\,R}, n = 1 \ldots N$, the corresponding low resolution images $I_n^{L\,R}, n = 1 \ldots N$ are generated, and the pixel-wise mean squared error (MSE) of the reconstruction is calculated as an objective function to train the network:

$$l(W_{1:L}, b_{1:L}) = \frac{1}{r^2HW} \sum_{x-1}^{rH} \sum_{x-1}^{rW} (I_{x,y}^{H\,R} - f_{x,y}^{L}(I^{LR}))^2$$

Referring to Figure 8, there is shown a network architecture 800 for super resolution using three input frames 810a, 810b and 810c (and then 810b, 810c and 810d). Only the input layer of the neural network is modified to jointly handle three input frames for the super resolution prediction of only the middle frame 830b (or 830c). The hidden layers 820a, 820b) are identical to those shown in Figure 7.

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As shown in Figure 8, in an embodiment, spatio-temporal convolutions are performed in the initial layer of the neural network. Using a spatio-temporal input layer as an extension of the network to handle video data allows reconstruction performance to be improved for video data by exploiting the temporal redundancy between consecutive frames in a video.

In some embodiments, the settings $I = 3$, $(f_1, n_1) = (5, 64)$, $(f_2, n_2) = (3, 32)$, and $f_3 = 3$ can be used. In the training phase of these embodiments, $17r \times 17r$ pixel sub-images were randomly selected from the training ground truth images I^{HR}, where r is the upscaling factor. In other embodiments, other parameters can be chosen based on the available computing hardware and/or training time. To synthesise the low resolution samples I^{LR}, I^{HR} were blurred using a Gaussian filter in these embodiments and were sub-sampled by the upscaling factor. In these embodiments, the sub-images were extracted from original images with a stride of $(17 - \sum \bmod (f, 2)) \times r$ from I^{HR} and a stride of $(17 - \sum \bmod (f, 2))$ from I^{LR}. In other embodiments, arbitrary sized sub-images can be selected: smaller sub-images can enable faster updates in training (as updates can be made faster since fewer convolutions are required per sub-image) and can also allow more individual training examples to be used and can further allow an increase in representations; while larger sub-images can be more process-efficient for batch systems, particularly where there is sufficient training data available. It can be noted that in most embodiments the lower limit on sub-image size is dependent on the filter sizes used in a neural network while the upper limit is memory- and dataset- related. This ensures that all pixels in the original image appear once and only once as the ground truth of the training data. $\tanh$ may be used as the activation function in these embodiments. In some embodiments, the training may stop after no improvement of the cost function is observed after 100 epochs. In some of these embodiments, the initial learning rate may be set to 0.01 and final learning rate may be set to 0.0001 and updated gradually when the improvement of the cost function is smaller than a threshold μ.

In some embodiments, the network is adapted for video super-resolution with a modification to the input layer. Instead of handling single frames independently, consecutive frames are jointly processed by feeding the consecutive multi-frame data such that the input can be expressed or converted into a three-dimensional vector of corresponding patches from multiple frames such that the temporal changes between consecutive frames are captured to the network. In an alternative embodiment, fixed temporal sampling can be used where videos have varying or different framerates,

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optionally selecting the lowest frame rate when the network is trained. After patch extraction, the data is processed by hidden layers through the network and results in an output layer producing a single frame of high-resolution image corresponding to the network prediction of the middle frame in the input consecutive frames. In some alternative embodiments, there are both multiple input frame and multiple output frames.

In use for video processing, blocks of 3, 5 and 7 (or more) consecutive video frames may be used to super resolve the middle frame or frames. It should be noted that an increased number of frames could become impractical as each additional frame provides decreasingly less of a gain in accuracy. In order to handle the first and last frames of videos that do not have enough neighbouring frames to form a block of consecutive frames, the first and last frame may be repeated 1, 2 and 3 times respectively. The peak signal to noise ratio (PSNR) may be used as the performance metric to evaluate the models used.

Referring now to Figures 4 and 6, an embodiment for reconstructing the video encoded using the technique will now be described in detail.

First, the data 130 is received from the network. The data received 130 depends on how the data was prepared for transmission in step 120 (or 210) as detailed above and will include the video data and one or more reconstruction models for that video data. It is possible that the video data and one or more reconstruction models are not transmitted and/or received simultaneously so some buffering may be required to wait for all of the components required to decode or reconstruct the higher-resolution video from the data transmitted over the network.

At steps 140 and 150 (and step 220), the received data is prepared for reconstruction. This step generally involves separating the low-resolution video from the reconstruction models (step 220). Optionally, the low-resolution video is decompressed using the video codec used for transmission into full-resolution image frames (step 230) and each of the frames is matched up with the corresponding reconstruction model, which are also unpacked into frame-by-frame order (step 240).

At step 160 (step 250), the reconstruction model is applied to each of the frames to output higher-resolution frames. The reconstruction, or decoding, process involves applying the optimised super resolution convolutional neural network model, or reconstruction model, for each scene in order to restore the lower-resolution video to its original resolution having substantially the same quality as the original high-resolution video. Given the corresponding models for each lower-resolution frame, the original higher-resolution frames can be reconstructed with high accuracy.

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In a further embodiment, at least a portion of the process described within Figure 3 can take place within a 'cloud computing' system. In this embodiment, original video data 70 is transmitted to an off-site computing system wherein one or more of the processes outlined in this specification take place. A different section of video data may be processed in parallel on the off-site computing system. The limit of the number of sections of video processed in parallel is dependent on the computational complexity of the sections of video and the processing power of the cloud servers. Once the cloud-based processing is complete, data can be transmitted back to a local computing system. The cloud service can be used as a real-time relay server, receiving lower-resolution videos, the resolutions of which are then to be increased before being re-transmitted. This arrangement can relay data from bandwidth-restrained locations to locations where there is not such a constraint on bandwidth.

In a further embodiment, the training process for the example based models takes place exclusively for the reconstruction of the high-frequency components of the higher-resolution section of video. The results may then be added as a residue to a section of video reconstructed using bi-cubic interpolation.

In a further embodiment, the architecture of any convolutional neural networks used in the reconstruction process is amended such that the upscaling, in terms of physically changing the number of pixels, occurs in the middle or the last layer of the network by way of a deconvolution function. The first layer of the network is described as obtaining low resolution features whilst the high resolution features are only learnt in the last layer. It is not necessary to learn the low resolution features in a high resolution space. By keeping the resolution low for the first couple of layers of convolutions, the number of operations required can be reduced. The computational performance then depends more on the resolution of the input rather than resolution of the output. Alternatively, the network layers can be reorganised such that the output of the sub-pixel convolution layer of the convolutional neural network (which can be the last layer or a preceding layer, depending on the embodiment) predicts the square of the upscaling factor number of pixels (e.g. r^2) instead of the number of upscaling factor pixels (e.g. r). The other pixels represent the neighbouring pixel to the original input pixel in low resolution. Every 4 pixels must then be reshaped and reordered to form the high resolution image. A higher video processing speed can be obtained using this approach whilst maintaining a high level of quality for the output. The number of convolutions required is therefore reduced. This embodiment may be used in conjunction with any other embodiment.

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In some and other embodiments, a neural network can have multi-stage upscaling (or other function) where an earlier layer upscales and then a later layer upscales, for example a middle layer upscales by 2x and then the last layer upscales by 2x. This type of "chained" approach can allow for neural networks to be trained in a long network (or "chain") of functional layers, for example having a range of upscaling factors (e.g. 2x, 3x and 4x) with multiple upscaling layers and output layers. One of more of these layers can be sub-pixel convolution layers of the described embodiments.

The complexity of the reconstruction process is far simpler compared to that of training the model. The process is very similar to a single iteration of the training process however there is no optimisation required and it is simply applying the learnt convolutional neural network model to reconstruct the image on a patch-by-patch basis. The size of a single patch may vary, according to the resolution requirements of the output section of video. The patch size will be determined offline via hyper-parameter optimisations when training models. Generally, a larger patch size will reduce the computational requirements for processing a section of video, and also reduce the bandwidth required to transmit the section of video. When bandwidth is particularly limited, the processing power of an end user terminal is low, or a user is willing to endure a lower quality section of video, the patch size may be increased to allow for video transmission under one or more of those circumstances. The quality of the reconstruction will be compromised but the processing power required at the end-user terminal will be significantly reduced.

A singular model is applied to each scene and can be sent as accompanying data in the video container ahead of the scene in which it is used. The model associated with each scene can either be indexed in a data stream, synchronised with the video and audio stream, or indexed in a frame-to-model look-up table which can be sent ahead of the video stream.

At step 170, each of the segments of video are output from the reconstruction process as higher-resolution frames at the same resolution as the original video 70. The quality of the output video 180 is substantially similar to that of the original video 70, within the error bounds optionally applied by the machine learning process that develops the reconstruction model at step 110 (or step 200) of the encoding process.

At step 180, the segments of video are combined such that the video can be displayed. Optionally at step 170 or 180, the video can be re-encoded with the original codec used on the original video 70 or a more predetermined optimal codec, to enable playback on a decoder or display device.

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The use of the final layer to perform super resolution can be used to perform upscaling for low-resolution images and/or video without knowledge of any original high-resolution content or where there is no higher-resolution content for the low-resolution images and/or video. Additionally, the use of the spatio-temporal approach can be used to perform upscaling for low-resolution images and/or video without knowledge of any original high-resolution content or where there is no higher-resolution content for the low-resolution images and/or video. Further, both the use of the final layer to perform super resolution and the use of the spatio-temporal approach can be used in combination to perform upscaling for low-resolution images and/or video without knowledge of any original high-resolution content or where there is no higher-resolution content for the low-resolution images and/or video. Specifically, some embodiments can use one or more generic example based models, for example selecting these from a library of generic example based models and for example applying some criteria in selecting such example based models, that use either or both of example based models having a final layer that performs super resolution and/or use a spatio-temporal approach in the input layer of the example based model.

Real Time Model Development/Selection

Referring now to Figure 27, an embodiment using the technique to encode visual data will now be described in detail. These embodiments can be used in combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

Original video data 2740 can be provided into the method or system of the embodiment using a camera 2735 and usually comprises a high-resolution video, for example having a resolution of 1920 pixels by 1080 pixels (also known as "1080p" video) or 3840 pixels by 2160 pixels (also known as "4K" video). This video data can be encoded in a variety of known video codecs, such as H.264 or VP8, but can be any video data for which the system or method is able to decode into the component frames of the video depending on the embodiment.

In some embodiments, the original video data 2740 is then split into single full-resolution frames within step 150 i.e. into a sequence of images at the full resolution of the original video data 140. In some of these embodiments, for some video codecs, this will involve "uncompressing" or restoring the video data as, for example, common video compression techniques remove redundant (non-changing) features from sequential

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frames.

In some embodiments, model selection or at least initial model selection can be performed based on the uncompressed video data.

Optionally, within step 2750, in some embodiments the full-resolution frames can be grouped into scenes or sections of frames having common features, otherwise known as "scene selection". The video data is split or clustered into scenes to enable more specific optimisation. By scene, it is meant a consecutive group or sequence of frames comprising a section of video, which at the coarsest level can be the entire video or at the most granular level can be a single frame. In some embodiments, the scenes can be arranged according to the order in which they were filmed or into a sequence for appropriate decoding of any group of pictures (as scenes will typically comprise related visual content and appropriate ordering can allow compression to work efficiently, for example).

In some embodiments, regardless whether the video has been broken into frames or scenes (i.e. groups of multiple frames) in step 150 or remains as a sequence of frames from step 140, each frame can down-sampled into lower-resolution frames at a suitably low resolution. Optionally, in some embodiments this step can occur before the frames are grouped into scenes in step 150. In some embodiments, the lower-resolution frame is optionally 33% to 50% of the data size relative to the data size of the original-resolution frame, but can be any resolution that is lower than the original resolution of the video. In other embodiments, the quality can be reduced by quantisation and/or compression instead of reducing the resolution of the visual data or in addition to reducing the resolution of the visual data.

At step 2755, a scene is selected in some embodiments. In this embodiment used for real-time encoding, this scene can initially be the first frame chronologically that was recorded by the camera 2735, or the first frame appearing in the original video file 2740. Following this frame, a second frame to be recorded or a second frame appearing in the original video file 2740 can next be selected. After that would appear a third frame, and so on, until the broadcast was complete.

A first example based model is taken from a library of example based models and analysed for use in the reconstruction of data in step 2760. A second example based model can be taken and analysed in parallel in step 2770, as can a third example based model as shown in step 180. There is no fixed upper limit to the variable n, variable n being the number of example based models which can be analysed in parallel, where n is at least two.

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In step 2795, the most accurate example based model is chosen to be used for the reconstruction of data. The most accurate example based model can be defined as an example based model which would result in the highest quality of reconstruction, wherein quality can be defined using any of: an error rate; a peak signal-to-noise ratio; or a structural similarity index when compared to the original video file 2740.

In step 210, the lower-resolution scene and the example based model for the reconstruction of that scene are output for transmission over a network. Optionally, a reference to the model can be transmitted in lieu of the actual model. This requires a synchronised or matched library at both the transmitting and receiving nodes of the process, such that the reference can be used by the library at the transmitting node, and the model identified from the reference to the same model in the library at the receiving node as in the library at the transmitting node.

Optionally, the video and model (or model reference) can be stored together within a suitable data container format such as a Matroska Multimedia Container (otherwise known as a MKV container). Alternatively, the video and model can be combined with other sections, or the entire video and placed into a suitable data container format. At step 210 the low-resolution video frames can be re-encoded using either the original video codec applied to the original video data 2740 or, alternatively, a more optimal video codec can be applied to the video data to produce a smaller output file. Optionally, if scene detection or time stamping was performed, the data output for transmission can include either a list of scenes or time stamp data respectively, or this data could be stored within the data container.

There can be a number of variations to the encoding framework described above. For the above described technique, it can be assumed that there would be a one-to-one mapping between scene and example based model, however this does not need to hold true as each scene could be accompanied by more than one example based model.

Referring now to Figure 5, an embodiment for reconstructing the video encoded using the technique will now be described in detail.

First, the transmitted data 210 is received from the network. The data received 210 depends on how the data was prepared for transmission in step 2750 as detailed above and will include the video data and one or more reconstruction models for that video data. It is possible that the video data and one or more reconstruction models are not transmitted and/or received simultaneously so some buffering may be required to wait for all of the components required to decode or reconstruct the higher-resolution video from the data transmitted over the network.

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At step 220, the transmitted data is prepared for reconstruction. This step comprises separating the low-resolution video from the one or more example based models. Optionally, the low-resolution video is decompressed using the video codec used for transmission into full-resolution image frames and each of the frames is matched up with the corresponding reconstruction model, which are also unpacked into frame-by-frame order.

At step 250, the reconstruction model is applied to each of the scenes to output higher-resolution scenes. The reconstruction, or decoding, process involves applying the optimised super resolution convolutional neural network model, or reconstruction model, for each scene in order to restore the lower-resolution video to its original resolution having substantially the same quality as the original high-resolution video. Given the corresponding models for each lower-resolution scene, the original higher-resolution scenes can be reconstructed with high accuracy, where accuracy is defined as above.

This embodiment of the invention requires no optimisation, and comprises applying a previously learnt example based model to reconstruct a scene, and does not necessarily include any adaptation or modification of the existing example based models in the library. The one or more example based models associated with each scene can be indexed in a data stream, synchronised with the video and audio stream, or indexed in a frame-to-model look-up table that can be sent ahead of the video stream.

The image reconstruction has a linear computational complexity dependent on the total number of pixels of each frame, as it requires a series of convolution functions (typically less than 3) to be applied for each relevant image patch centred around each pixel. The basic reconstruction step for each image can be used with or without modification in some embodiments from the approach described in the paper "Learning a Deep Convolutional Network for Image Super-Resolution" by Chao Dong, Chen Change Loy, Kaiming He, and Xiaoou Tang published in D. Fleet et al. (Eds.): ECCV 2014, Part IV, LNCS 8692, pp. 184–199, 2014, however these functions can be applied in parallel across multiple images and it is feasible to perform real-time reconstruction for video playback.

Within step 250, each of the segments of video is output from the reconstruction process as higher-resolution frames and at substantially the same resolution as the original video 2440.

Further within step 250, the segments of video are combined such that the video can be displayed. Optionally the video can be re-encoded with the original codec used on the original video 2740 or a predetermined more optimal codec, to enable playback

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on a decoder or display device.

In a further embodiment, at least a portion of the process described within Figure 27 can take place within a 'cloud computing' system. In this embodiment, the original video file 2740 is transmitted to an off-site computing system, preferably a scalable computing system, where the first scene is prepared 2750. As before, a plurality of example based models 2760, 2770, 2780, 2790 can then be analysed for their use in reconstruction of the data, before a most accurate model 2795 is chosen and a transmitted package 210 prepared. The transmitted package 210 is then sent from the cloud server to a local server, where the reconstruction process 220, 230, 240, 250 can take place. While the first scene is being processed in this way, a second section of video can be processed in parallel on the off-site computing system. The limit of the number of sections of video processed in parallel is dependent on the computational complexity of the sections of video and the processing power of the cloud servers. The cloud service can be used as a real-time relay server, receiving lower-resolution videos, the resolutions of which are then to be increased before being re-transmitted. This arrangement can relay data from bandwidth-restrained locations to locations where there is not such a constraint on bandwidth.

In a further embodiment, one or more sections of video are transmitted via the process outlined above, in advance of a live recording. Example based models that are likely to be useful can therefore be identified before they are required, and the library of models from which they are selected reduced to those more likely to be used. The selection procedure 2795 can therefore be made faster or with reduced computation, as there are fewer models to choose between, hence the lag between the recording of an event and the higher-resolution reconstruction being displayed can be reduced compared to comparing the performance of all of the models in the library of models.

Model Libraries

Referring now to Figure 25, an embodiment using another technique to encode visual data will now be described in detail. These embodiments can be used in combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

Original video data 2510 is provided into the method or system using the technique and is a high-resolution video, for example having a resolution of 1920 pixels by 1080 pixels (also known as "1080p" video) or 3840 pixels by 2160 pixels (also known

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as "4K" video). This video data can be encoded in a variety of known video codecs, such as H.264, VP8 or VP9 but can be any video data for which the system or method is able to decode into the component frames of the video.

The original video data 2510 is then split into single full-resolution frames at step 2520, i.e. into a sequence of images at the full resolution of the original video data 2510. For some video codecs, this will involve "uncompressing" or restoring the video data as, for example, common video compression techniques remove redundant (non-changing) features from sequential frames.

Optionally, at step 2520, the full-resolution frames can be grouped into scenes or sections of frames having common features, otherwise known as "scene selection". The video data is split or clustered into scenes to enable more specific training and optimisation. By scene, it is meant a consecutive group or sequence of frames, which at the coarsest level can be the entire video or at the most granular level can be a single frame.

Regardless of whether the video has been broken into frames or scenes (i.e. groups of multiple frames) or remains as a sequence of frames, each frame is down-sampled into lower resolution frames at a suitably lower resolution for transmission over a network, for example the Internet. Optionally, this step can occur before the frames are grouped into scenes in step 2520. The lower-resolution frame is optionally 25% to 50% or 10% to 50% of the data size relative to the data size of the original-resolution frame, but the lower resolution can be any resolution that is lower than the original resolution of the video. This will result in the full lower resolution video being smaller in size than the original-resolution video.

An analysis step 2530 is performed on the frames of the down-sampled video in order to find a reconstruction model from a library that can be used to increase the resolution of the scene and enhance the quality of the video. A model is selected based on one or more metrics of the selected scene that can be compared to metrics associated with the reconstruction models stored in the library, and an image enhancement procedure is performed on the down-sampled scene. The quality of the enhanced scene is compared with the original using objective metrics such as error rate, PSNR and SSIM and/or subjective measures. An appropriate model is then selected at step 240 based on these quality comparisons. The library from which the models are selected comprises a set of pre-trained models which have been generated from example, or training, videos and which are associated with metrics to enable comparison of the video from which the models were generated with the selected scene being

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enhanced. The library from which the model is selected may be stored at one or more specific nodes in the network, or may be distributed over two or more nodes.

By employing a deep learning approach when creating the models, a non-linear hierarchical model can be selected to reconstruct a higher-resolution frame from the lower-resolution frame.

The non-linear models are more accurate in reconstructing higher-resolution frames than dictionary-based approaches. The non-linear models selected are small convolutional neural networks rather than over-complete dictionaries. In contrast to the local patch averaging approach that tends to be used in reconstruction by dictionary learning approaches, the use of a convolutional neural network model also allows a more appropriate filter to be selected for final reconstruction where neighbouring patches are considered, which can avoid unintended smoothing of the reconstructed higher-resolution image.

In step 2550, the portion of the low-resolution video and a library reference for reconstruction model for that portion of video are output for transmission. Optionally, the video and library reference can be stored together within a suitable data container format such as a Matroska Multimedia Container (otherwise known as a MKV container). Alternatively, the video and library reference can be combined with other sections or the entire video and placed into a suitable data container format. At step 2550, the low-resolution video frames can be re-encoded using either the original video codec applied to the original video data 2510 or, alternatively, a more optimal video codec can be applied to the video data to produce output video data. Optionally, if scene detection or time stamping was performed, the data output for transmission can include either a list of scenes or time stamp data respectively, or this data could be stored within the data container. Optionally, a list (or data stream) of model references that is synchronised with the output low resolution video frames can also be included. Alternatively, the transmission package can include a list of references to library content/models/parameters for each frame, which can be ordered by either frame playback or decode order, and this can be synchronised to the video frames. A further alternative is that the transmission package can include a list of scene transitions (at defined frame intervals) and then a list of references to library content/models/parameters for a matching number of scenes or transitions.

Referring now to Figure 26, an embodiment for reconstructing the video encoded using the technique will now be described in detail.

First, the data 2610 is received from the network. The data received 2610

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depends on how the data was prepared for transmission in step 2550 as detailed above and will include the video data and one or more library references to reconstruction models for that video data. It is possible that the video data and one or more library references are not transmitted and/or received simultaneously so some buffering may be required to wait for all of the components required to decode or reconstruct the higher-resolution video from the data transmitted over the network.

At steps 2620 and 2630, the received data is prepared for reconstruction. These steps generally involve separating the low-resolution video from the library references to reconstruction models. Optionally, the low-resolution video is decompressed using the video codec used for transmission into full-resolution image frames and each of the frames is matched up with the corresponding library reference to a reconstruction model, which are also unpacked into frame-by-frame order.

At step 2630, the reconstruction model corresponding to the library reference is obtained from a stored library of reconstruction models and at step 2640 is applied to each of the frames to output higher-resolution frames. The reconstruction, or decoding, process involves applying the reconstruction model for each scene in order to restore the lower-resolution video to its original resolution having substantially the same quality as the original high-resolution video. Given the corresponding models for each lower-resolution frame, the original higher-resolution frames can be reconstructed with high accuracy.

The complexity of the reconstruction process is far simpler compared to that of training the model. The process, known as the feed-forward process or pass for neural networks, is very similar to a single iteration of the training process however there is no optimisation required and it is simply applying the selected convolutional neural network model to reconstruct the image on a patch-by-patch basis. In comparison, training neural networks can also incorporate a back-propagation process or pass, depending on embodiment. A singular model is applied to each scene and the library reference to it can be sent as accompanying data in the video container ahead of the scene in which it is used. The library reference associated with each scene can either be indexed in a data stream, synchronised with the video and audio stream, or indexed in a frame-to-model look-up table which can be sent ahead of the video stream.

At step 2650, each of the segments of video are output from the reconstruction process as higher-resolution frames at the same resolution as the original video 210. The quality of the output video is substantially similar to that of the original video 210, within the error bounds optionally applied by the machine learning process that selects

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the reconstruction model at step 2650 of the encoding process.

At step 2650, the segments of video are combined such that the video can be displayed. Optionally at step 2650, the video can be re-encoded with the original codec used on the original video 2510 or a more predetermined optimal codec, to enable playback on a decoder or display device.

Upscaling & Visual Data Enhancement

Super resolution approaches are usually split into learning- or example-based approaches and interpolation-based (multi-frame) approaches. Some embodiments are concerned only with learning- or example-based approaches to super resolution. Specifically, these embodiments can work with most or all learning- or example-based techniques where there can be a set of different upscaling results depending on the selected parameters for the techniques.

In some embodiments, super resolution techniques can output representations that can be used to enhance the higher-resolution images created from lower-resolution images. To improve the effectiveness of these representations in some embodiments, learning- or example-based approaches incorporate machine learning. When using dictionary representations for images, this combination is generally referred to as dictionary learning. In dictionary learning, where sufficient representations are not available in an existing library of representations (or there is no library available), machine learning techniques are employed to tailor dictionary atoms such that they can adapt to the image features and obtain more accurate representations.

It is noted that atoms are not selected locally within the dictionary, but instead are chosen as the linear combination that best approximates the signal patch for a maximum number of atoms allowed and irrespective of their location within the dictionary. Without a constraint that the atoms must be orthogonal to one another, larger dictionaries than the signal space that the dictionary is intended to represent can be created.

Embodiments can use dictionary learning reconstruction models or convolutional neural network reconstruction models for up-scaling, or a mixture of these two techniques. In some embodiments, a library of reconstruction models is stored that can be generated from example, or training, video data where both the original and reduced-resolution video can be compared. Along with the reconstruction models, in some embodiments data needs to be stored relating to the example or training video for each reconstruction model in the library to enable each model to be matched to a scene that

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is being up-scaled. In these embodiments the data stored relating to the example or training video can be metadata or metrics related to the video data, or it can be samples or features of the example or training video.

Referring now to Figure 15, embodiments using a technique 1500 to increase the resolution of visual data will now be described in detail. These embodiments can be used in combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

In these embodiments, received video data 1540 is provided into a decoder system and is a lower-resolution video encoded in a standard video format. This video format can be a variety of known video codecs, depending on the embodiment, and in embodiments can be codecs such as H.264 or VP8 or can be any visual data which the system is able to decode into component sections.

In embodiments, the system then separates video data 1510 into single frames at step 1520, i.e. into a sequence of images at the full resolution of the received video data 310. For some video codecs, depending on the embodiment, this will involve "uncompressing" or restoring the video data as, for example, common video compression techniques remove redundant (non-changing) features from sequential frames.

Optionally, as shown in Figure 16, in some embodiments the frames extracted in step 1520 from the video 1510 can be grouped into scenes or sections of frames having common features, otherwise known as "scene selection" in step 1610. In these embodiments step 1610 involves identifying sequential scenes once these are detected. In some of these embodiments, the detected scenes can enable a more accurate reconstruction model or models to be selected from the library of reconstruction models as appropriate from the scene or frames within the scene in step 1620, which is a modified version of step 1530 in process 1500 where the most appropriate model is selected on a frame-by-frame basis. By scene, it is meant a consecutive group or sequence of frames, depending on embodiment, which at the coarsest level can be the entire video or at the most granular level can be a single section of a frame.

Alternatively, and in order for any delay to be reduced between the arrival of the lower resolution video 1510 and the generation of a higher resolution output video 370, in some embodiments basic scene selection in step 1610 can be accomplished by grouping frames into scenes chronologically, for example by applying time stamps and collecting together a predetermined range of timestamps. Initially, in these embodiments the first frame or section of frame can be analysed and a metric created to enable

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reference to the library of reconstruction models in step 1620. In such embodiments, if a subsequent frame or section of a subsequent frame is sufficiently similar according to a comparison metric, then the subsequent frame or frames can be included as part of a group of frames with the first frame. In these embodiments, this process can continue until a subsequent frame is not sufficiently similar to the previous frame or frames, at which point the frame or group of frames are collated into a scene in step 410. in these embodiment the process then starts to find the next scene, starting from the insufficiently similar scene. In such embodiments, each scene is processed in the order in which it was decoded from the received video 1510.

Returning to the method 1500 shown in Figure 15, in some embodiments an analysis step 1530 is performed on the frames of the received video in order to find a reconstruction model from a library in step 1540 which can be used to increase the resolution of the scene and enhance the quality of the video in step 1550, based on a metric of the selected scene that can be compared to metrics associated with the reconstruction models stored in the library. A model in step 1540 is selected, and an image enhancement procedure is performed in step 1550 using both the model selected in step 1540 on the selected frame generated in step 1520 from the received video 1510. The library from which the model is selected in step 1540 comprises a set of pre-trained models which have been generated from example, or training, videos and which are associated with metrics to enable comparison of the video from which the models were generated with a selected frame being enhanced in step 1550.

There are a number of methods for feature extraction approaches that can be used to create metrics for each frame and therefore which can be stored in the library in association with the pre-trained reconstruction models. In many computer vision applications, a common approach is to use a visual bag-of-words approach. Other popular methods include histogram extraction and scale invariant feature transform (SIFT) or GIST features. After feature extraction in step 1530, each scene from a target video can be matched to the "most similar" scene from a library in a number of ways in step 1540. The simplest approach is to use a pre-defined similarity or distance metric such as, Manhattan distance, Euclidean distance or structural similarity (SSIM) or additionally, a learned distance metric. A k-nearest neighbour (kNN) data-structure such as a ball-tree or a locality-sensitive hash table can be used to facilitate a direct nearest-neighbour search. Alternatively, each unique scene can be thought of as being "labelled", then a variety of machine learning scene recognition and matching approaches can be used to classify new scenes into the "labelled" scenes of the library

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such as adversarial training techniques, where such techniques involve training another neural network to indicate whether the scene is labelled correctly.

In step 1560, the reconstructed scene for that section of video is optionally prepared for output 1510. Optionally at step 1560, the output video 1570 can be re-encoded with the original codec used on the original video 1510 or a more predetermined optimal codec, to enable playback on a decoder or display device.

It should be appreciated that the term 'frame', particularly in reference to grouping multiple frames into scenes, can refer to both an entire frame of a video and an area comprising a smaller section of a frame.

The video 1510 in process 1500 or 1600 can originate from physical media such as a DVD or other physical data storage medium, but can also originate from a local or remote streaming network service.

Referring now to Figure 17, a modified process 1700 (based on process 1600 but which could equally be a modified version of process 1500) is shown.

Here, process 1600 in some embodiments is modified with further steps. Specifically, step 1710 begins with a high resolution video file, for example at HD resolution. Then, at step 1720, the video is down-sampled to, for example, SD resolution to enable transmission over a bandwidth-restricted network. Optionally, in other embodiments, quantisation can be used to lower the bitrate of visual data such as video. At step 1730, the lower-resolution or quantised video (depending on embodiment) is transmitted over a network becoming the input video data 1510 of either process 1500 or 1600 described above in relation to Figures 15 or 16 respectively.

Further, output video 1570 in process 1500 or 1600 can be output directly to a display or may be stored for viewing on a display on a local or remote storage device, or forwarded to a remote node for storage or viewing as required.

In alternative embodiments, the input video concerned may be media for playback, such as recorded video or live streamed video, or it can be videoconference video or any other video source such as video recorded or being recorded on a portable device such as a mobile phone or a video recording device such as a video camera or surveillance camera.

It should also be appreciated that particular combinations of the various features described and defined in any aspects of the invention can be implemented and/or supplied and/or used independently.

Specific Description – Machine Learning Optimisation

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Embodiments relating to a dictionary learning approach with dictionary-based models and embodiments relating to a deep learning approach using convolutional neural network models will now be described. Other suitable machine learning techniques will also be able to benefit from using a library of pre-trained model. These embodiments can be used in combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

Referring now to Figure 9, an embodiment of a machine learning process will now be described in detail.

Data 910 is provided to the method or system 900, and may for example be in the form of a video data file or image data. Other data formats may also be used. Specific metrics are extracted from, or generated based on, the data in step 920. The metrics can based on measuring which of the pre-trained models generates the highest quality output data. Quality can be defined using any or a combination of: an error rate; a peak signal-to-noise ratio; or a structural similarity index. These metrics are then used to select a pre-trained model from a library 942 in step 930. The selected pre-trained model is then developed in step 940 so as to be more accurately able to perform the desired output function on the input data 910. The output model 950 can then be used on the input data 910 either immediately or at in future.

To generate the initial pre-trained models, the same process 900 can be used but instead of inputting live data 910, training or example data is used.

The developed model is then saved in the library 942 in step 941, to be used if required in the future. A model does therefore not have to be redeveloped if similar data is input in the future. The library 942 therefore grows as the system is used.

If employing a deep learning approach to generating the model in step 940, a non-linear hierarchical model 950 can be created.

The training and optimisation process 900 can be configured according to a desired trade-off between computational time spent and desired quality of results. In general, the number of iterations used during the training process 940 yields approximately logarithmic gains in reconstruction accuracy, so it is preferred to use an automatic threshold to stop further optimisation. When favouring quality of results, the automatic threshold can be set to a predetermined value of reconstruction error, for example by calculating the mean squared error, but other methods can also be used. Alternatively, the automatic threshold can be set to limit the training and optimisation process to a predetermined number of iterations. As a further alternative, a combination

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of these two factors can be used.

This process 900 can be of use in the fields of image and video enhancement. If the input data 910 is in the form of a section (frame or frames) of video, the selection of an initial model from the library 930 can be based on metrics associated with the style of video being processed, for example a fast-moving action scene, or a stationary background scene. The model 950 can then be developed in step 940 to more closely represent the section of video for which it is to be used.

The training and optimisation process 900 can also be considered in the case of image registration and alignment. An initialisation can be provided which is closer to the most optimal image alignment with regards to a metric, for example a distance metric cost function.

Specific Description – Enhanced Libraries

Referring now to Figure 10, an embodiment using the technique to encode visual data will now be described in detail. These embodiments can be used in combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

Original video data 1010 is provided into the method or system using the technique and is a high-resolution video, for example having a resolution of 1920 pixels by 1080 pixels (also known as "1080p" video) or 3840 pixels by 2160 pixels (also known as "4K" video). This video data can be encoded in a variety of known video codecs, such as H 264 or VP9 but can be any video data for which the system or method is able to decode into the component frames of the video.

The original video data 1010 is then split into single full-resolution frames at step 1020 , i.e. into a sequence of images at the full resolution of the original video data 210. For some video codecs, this will involve "uncompressing" or restoring the video data as, for example, common video compression techniques remove redundant (non-changing) features from sequential frames.

Optionally, at step 1020, the full-resolution frames can be grouped into scenes or sections of frames having common features, otherwise known as "scene selection". The video data is split or clustered into scenes to enable more specific training and optimisation. By scene, it is meant a consecutive group or sequence of frames, which at the coarsest level can be the entire video or at the most granular level can be a single frame.

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Regardless whether the video has been broken into frames or scenes (i.e. groups of multiple frames) in step 1020 or remains as a sequence of frames, each frame is either down-sampled into lower resolution frames at a suitably lower resolution, or reproduced as a set of representations of the frame such as a matrix of vectors with generalised information for portions of the frame or groups of one or more pixels. Optionally, this step can occur before the frames are grouped into scenes. The lower-resolution frame is preferably 33% to 50% of the data size relative to the data size of the original-resolution frame, while the representations of the frame can be anything from 1% to 50% of the data size of the original-resolution frame. The lower resolution frame can have any resolution that is lower than the original resolution of the video.

In step 1030, an analysis is performed on frames of the downsampled video, or on the representations, or on the models alone in order to find a reconstruction model from a library of models which can be used to either recreate a close approximation of the high-resolution video purely from a model, or recreate a close approximation of the high-resolution video from a set of representations of the high-resolution video, or increase the resolution of the downsampled video and enhance the quality of the video. An initial model is selected based on a metric of the selected scene that can be compared to metrics associated with the reconstruction models stored in the library. The selection of the initial model may be based on only these metrics, or alternatively multiple initial models may be applied independently to the downsampled video to produce an enhanced lower-resolution frame or recreate a frame, the quality of the enhanced or recreated frame being compared with the original scene to select the most appropriate initial model from the group. The quality of the recreated or enhanced scene is compared with the original using objective metrics such as error rate, PSNR and SSIM and/or subjective measures. An appropriate model is then selected at step 1040 based on these quality comparisons as well as whether to use solely a model, or a set of representations of the frame, or the lower-resolution frame. The library from which the models are selected comprises a set of pre-trained models which have been generated from example, or training, videos and which are associated with metrics to enable comparison of the video from which the models were generated with the selected scene being enhanced.

In step 1060, super resolution techniques are employed to create a specific model using the model selected at step 1040 as the initial model and using machine learning for each frame, so that the model can be used to substantially recreate the original resolution version of a lower-resolution frame, or a set of representations, or

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without use of either the original or lower-resolution frame or representations, and trained using machine learning based on knowledge of the original-resolution frame. This step is termed the training and optimisation process.

At step 1070, the optimised reconstruction model is saved to the library for future use as an initial model in step 1030.

Alternatively, the modified model can be developed from scratch, without using a known model as a starting point. A known model can then be compared with the generated model to produce a list of modifications required to produce the modified model from the known one.

In step 1050, the portion of the low-resolution video, or the representations and/or the reconstruction model for that frame or portion of video are output for transmission. Rather than transmit the full reconstruction model, a library reference to the initial model selected at step 1040 can be output, together with the modifications required to produce the reconstruction model from it. Alternatively, instead of the lower-resolution video, transmitting a representation of the image can further reduce the data transmitted. As a further alternative, only transmitting a model still further reduces the data transmitted. Optionally, the video or representations and model can be stored together within a suitable data container format such as a Matroska Multimedia Container (otherwise known as a MKV container). Alternatively, the video or representations and model can be combined with other sections or the entire video and placed into a suitable data container format. At step 250, the low-resolution video frames can be re-encoded using either the original video codec applied to the original video data 1010 or, alternatively, a more optimal video codec can be applied to the video data to produce output video data 1050. Optionally, if scene detection or time stamping was performed, the data output for transmission can include either a list of scenes or time stamp data respectively, or this data could be stored within the data container. Alternatively, a list of frame by frame references (which are ordered by either frame playback or decode order) can be used which is synced to the video frames. Another alternative is to include a list of scene transitions (as defined by frame numbers) along with an ordered list of references matching the number of scenes. The skilled person will appreciate that other examples are possible.

Referring now to Figure 11, an embodiment for reconstructing the video encoded using the technique will now be described in detail.

First, the data 1100 is received from the network. The data received 1100 depends on how the data was prepared for transmission in step 1050 as detailed above

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and will include the video data or representations of the video data and/or references to one or more initial reconstruction models for to recreate high-resolution video data, along with any modifications to the referenced models required to reproduce the final reconstruction models. It is possible that the video data or representations, references to the one or more initial reconstruction models and the modifications to those models are not transmitted and/or received simultaneously so some buffering may be required to wait for all of the components required to decode or reconstruct the higher-resolution video from the data transmitted over the network.

At steps 1120 and 1130, the received data is prepared for reconstruction. This step generally involves separating the low-resolution video or representations if transmitted from the references to known reconstruction models and the modifications to those models required to reproduce the optimised reconstruction model. Optionally, the low-resolution video is decompressed at step 1120 using the video codec used for transmission into full-resolution image frames and each of the frames is matched up with the corresponding reconstruction model, which are also unpacked into frame-by-frame order.

The reconstruction models developed at step 1170 are recreated from the reference to a known reconstruction model and the modifications received at step 1110. At step 1130 the received reference is used to locate the known reconstruction model from which the optimised reconstruction model was developed in a library of models stored at the second node. The received modifications are then applied to this known reconstruction model at step 1160, recreating the optimised reconstruction model. After this reconstruction has taken place, the optimised reconstruction model is saved in the library at the second node for future reference at step 1170 using the same reference as was used when saving the model to the first node's library at step 1170. An incremental (or decremental) counter can be used to create new references for the modified algorithm that would then be the same for both nodes (in a distributed system). Alternatively this could be performed via a centralised database.

At step 1140, the modified reconstruction model is applied to each of the frames or representations if transmitted to output higher-resolution frames, else are used to reproduce the higher-resolution frames without a low resolution frame or representations. The reconstruction, or decoding, process involves applying the optimised super resolution convolutional neural network model, or reconstruction model, for each scene in order to recreate higher resolution video having substantially the same quality as the original high-resolution video. Given the corresponding models and if

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transmitted each lower-resolution frame or set of representations, a higher resolution frame that is substantially visually identical to the original higher-resolution frames can be reconstructed with high accuracy.

At step 1150, each of the segments of video are output from the reconstruction process as higher-resolution frames at the same resolution as the original video 210. The quality of the output video 1150 is substantially similar to that of the original video 210, within the error bounds optionally applied by the machine learning process that develops the reconstruction model at step 1060 of the encoding process.

At step 1140, the segments of video are combined such that the video can be displayed. Optionally at step 1140, the video can be re-encoded with the original codec used on the original video 1010 or a more predetermined optimal codec, to enable playback on a decoder or display device.

A modified embodiment of the above-described method is shown in Figures 4 and 5. In this embodiment, the downsampled video is not transmitted from the first node to the second node. Instead, any data required to produce the reconstructed video can be included in the transmitted modifications to a known reconstruction model. It is possible that no data is required and that only the use of a model is required to reconstruct substantially the high-resolution video. The second node reconstructs the video using only the modified reconstruction model obtained by applying the modifications to the known reconstruction model referenced in the transmission and, if required, the data required to produce the reconstructed video. This method can advantageously be used to reduce further the amount of data transmitted across the network, reducing the amount of data required to be transmitted.

Figure 12 shows a further method for encoding video. The initial steps proceed as in Figure 10. The higher resolution video 1210 is prepared by separating it into scenes and down sampling at step 1220. An analysis of each scene is performed in step 1230 to determine which known models will be used as a starting point for the model optimisation process. One or more appropriate models are selected at step 1240 based on a metric of each scene or frame that can be compared to metrics associated with the reconstruction models stored in the library. The selected known models are optimised at step 1260 using machine learning. However, instead of being trained to reproduce the higher resolution video from the downsampled one, they are instead trained to substantially reproduce the higher resolution video 1210 using only the optimised model itself or the optimised model and any data that can be incorporated into the model to seed recreation of the video frame or scene. A reference to the starting known

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reconstruction model together with the modifications required to reproduce the optimised reconstruction model for each scene or frame are transmitted to the second node at step 1260, along with a list of scenes if known.

Figure 13 shows a further method of decoding the received information at the second node to reproduce substantially the higher resolution video. The package transmitted at step 1260 of Figure 12 is received by the second node at step 1310, and unpacked at step 1320. The references to known models are used to locate the known reconstruction models stored in a library at the second node at step 1330. The modifications corresponding to these known reconstruction models are then applied at step 1340 to reproduce the optimised reconstruction model generated by the machine learning process in step 1260 of Figure 12. This model is optimised to substantially reproduce the original higher resolution video 1260 without the need for it to be applied to a corresponding low resolution video sample. Hence the second node can substantially reconstruct the original high resolution video from only the modified reconstruction model. This reconstruction is performed at step 1350, and the resulting reconstructed higher resolution video is output at step 1360.

Specific Description – Artefact Removal

To improve on the above mentioned approaches for image artefact removal, it is proposed to use deep learning techniques and neural networks such as recurrent neural network and convolutional neural network models.

In some cases fully connected neural networks can't scale up to larger sizes of network easily as the computational complexity soon becomes too great as the size of the network scales, but this depends on the application of the neural network and also other factors such as the kernel and filter sizes.

Neural network models can be transmitted along with the low-resolution and/or low-bitrate and/or low quality frames of video data because size of a convolutional neural network model or recurrent neural network model data is small enough to do so compared with the size of a learned dictionary for the same level of accuracy. In comparison, the data size of learned dictionaries means that it is impractical for these dictionaries to be transmitting along with the low-resolution images, especially in where the dictionaries are learned over-complete dictionaries

Figure 22 illustrates an overview of embodiments of a method of generating models for use in image artefact removal. These embodiments can be used in

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combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

In some embodiments, training image or video file is selected at step 2210 from a library of training images or videos stored at a network node and divided up into frames, sub-images or sequences of images (collectively referred to herein as scenes) at step 2220 depending on its content. In these embodiments, the scene type can then be classified into a particular category depending on its content using a metric.

In some embodiments, at step 2230, image artefacts are purposefully generated in the scene by applying aggressive compression and/or quantisation algorithms to the scene, with the level of expected artefacts being controlled by the compression/quantisation level or quality level. This creates a training scene. In some of these embodiments an artefact grading technique is applied to this training scene at step 2240 to quantify the severity of the induced artefacts.

At step 2250, in some embodiments, an image artefact removal model is trained on the training scene using machine learning techniques. In these embodiments the image artefact removal model can be generated such that it substantially cleans the training scene of image artefacts. In some of these embodiments, image quality metrics are used to compare the "cleaned" scene with the original, and the training process can be continued until the comparison produces results within some pre-defined threshold.

In some embodiments, the resulting image artefact removal model is then saved at step 2260, along with metric data relating to the scene type classification and an artefact grade relating to the types and/or severity of the artefacts in the training scene.

The process can be repeated multiple times, depending on the embodiment, on the same training scene with different levels of compression and quantisation in order to train a set of models for different levels of artefact severity.

The process can also be repeated in some embodiments with different training scenes in order to generate a library of different image artefact removal models indexed by both their content type and artefact severity. In these embodiments a "matrix" of library models can be created, where one axis of the matrix can be thought of as the content type, and the other the artefact severity.

Each step of the above method, as used in some embodiments, will now be described in further detail.

The division of the training image or video into a scene or scenes at step 2220 can be achieved in several different ways in different embodiments. The training image or video may already be divided into scenes prior to being stored in the library of training

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images or videos in certain embodiments, hence this step of the method is not always necessary. For the training of the image artefact removal model, in some embodiments only one scene is used for each model generated. In these embodiments a single training image or video may therefore be used to train multiple different image artefact removal models relating to different content types present within the image or video.

Considering first the case of video data, in some embodiments the library video data can be split into single full-resolution frames, i.e. into a sequence of images at the full resolution of the original video data. For some video codecs, in certain embodiments, this will involve "uncompressing" or restoring the video data as, for example, common video compression techniques remove redundant (non-changing) features from sequential frames.

Optionally, in other embodiments the full-resolution frames can be grouped into scenes or sections of frames having common features, otherwise known as "scene selection". In such embodiments, the video data can be split or clustered into scenes to enable more specific training and optimisation. By scene, it is meant a consecutive group or sequence of frames, which at the coarsest level can be the entire video or at the most granular level can be a single frame or portion of a frame depending on embodiment.

For the training of the image artefact removal model, in some embodiments only one scene is used for each model generated. A single training image or video may therefore be used in such embodiments to train multiple different image artefact removal models relating to different content types.

Once a scene has been generated, in some embodiments it is classified using metrics relating to properties of the scene. In embodiments, metrics that can be used for this classification can include probability or distance, depending on the classifier type or clustering used in each embodiment, and some function of the error or differences can be included in the metric depending on embodiment. Example metrics can include the differences between pixels or histogram differences such as the sum of absolute differences or Euclidean distance in these embodiments. Example metrics can also include mean squared error and peak signal-to-noise ratio in some embodiments. Alternatively, in other embodiments classification can be performed according to predetermined trained classifications, for example there could exist predetermined trained classifications for a variety of scenes or objects such as outdoors, indoors, mountains, bike, etc. The probability would be determined by the classifier used in the embodiment, for example embodiments could use a statistical similarity measure such

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as the Kullback-Leibler divergence. In other embodiments, a further alternative would be to use machine learning to develop a metric to be applied to the image-space, which would determine a formula for the distances. This classification using metrics is used to distinguish between scenes containing different content in at least some embodiments. The metric data determined in this way effectively assigns the scene a content type in such embodiments.

After the scene has been generated and classified, in at least some embodiments it is compressed and/or quantised at step 2230. In these embodiments, the compression of the scene can be implemented using any well-known lossy image/video compression algorithm. In such embodiments, the quantisation methods may include both colour quantisation, using for example a median cut algorithm or a clustering algorithm, and frequency quantisation.

In embodiments, the compression or quantisation process introduces image artefacts to the scene, producing a training scene that will be used together with the original uncompressed and unquantised version of the scene to train and/or optimise an image artefact removal model. In these embodiments, different levels of artefact severity can be introduced by varying the level of compression and/or quantisation performed at this stage.

Before the training and optimisation process begins in some embodiments, the artefact severity of the training scene is determined at step 2240 by using an artefact grading algorithm. Examples of such algorithms that can be used in embodiments are found in the paper "No-Reference Image Quality Assessment in the Spatial Domain" by Anish Mittal, Anush Krishna Moorthy and Alan Conrad Bovik published in IEEE TRANSACTIONS ON IMAGE PROCESSING, Vol. 21, No. 12, DECEMBER 2012, which is incorporated herein by reference. By grading the artefact severity of a training scene in embodiments, image artefact removal models can be trained based on both scene content type and the severity of the artefacts present.

At step 250 the model training and optimisation process is performed on the training scene in some embodiments. Super resolution techniques and machine learning techniques are employed in some embodiments to create an image artefact removal model, such that the model can be used to substantially recreate the original "clean" version of the training scene. By employing a deep learning approach to generating the model in at least embodiments, a non-linear hierarchical model can be created to reconstruct the original clean scene from the compressed and/or quantised scene.

An example of a deep learning approach, but in respect of only still images and in

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relation to jpeg compression artefacts (but not, for example, other video artefacts such as motion blur and inter-frame artefacts), but which can be used with or without modification in some embodiments, is described in the paper "Compression Artifacts Reduction by a Deep Convolutional Network" by Chao Dong, Yubin Deng, Chen Change Loy, and Xiaoou Tang published as arXiv:1504.06993v1 [cs.CV] 27 April 2015 and this paper is incorporated herein by reference. This paper is related to generating an improved deep Super Resolution Convolutional Neural Network for image artefact removal from a shallow network model.

In some of the embodiments, the quality of the recreated or cleaned scene can be compared with the original using objective metrics such as error rate, PSNR and SSIM and/or subjective measures. In some of these embodiments, if the quality is found to be within some pre-defined threshold, then the model can be saved along with results from a classifier or outcomes identifying the scene content and the artefact severity that the model relates to. Otherwise, in some embodiments the training process continues until the predefined threshold is met. Alternatively or additionally, in some embodiments a pre-defined number of iterations of the machine learning process can be used to limit the computational time spent training the model.

In some embodiments, the image artefact correction model trained in this way may be one of a non-linear hierarchical algorithm, a convolutional neural network, a recurrent neural network, a multi-layer (neural) network, an artificial neural network, a deep belief network, a dictionary learning algorithm, a parameter, a mapping function, a multi-layer feed-forward network, a non-linear filter, a dictionary, set or series of parameters or functions, or a series of functions.

In some embodiments, the original training scene generated in the scene selection process is used to generate multiple models for the same scene content type by repeating the compression and quantisation process with different levels of compression and/or quantisation, or by using different compression and/or quantisation algorithms. In these embodiments, this approach introduces a different level of artefact severity to the scene. Further, in some of these embodiments the training and optimisation process can then be repeated to generate a new image artefact removal model for the same content, but a different level of artefact severity.

In some embodiments, the trained and/or optimised image artefact removal models are saved to a library of image artefact removal models. In some of these embodiments, each model in the library is associated with a classifier identifying the scene content and the artefact severity that the model was trained on. In these

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embodiments, the library can therefore be thought of as a "matrix" of example based models, with its rows corresponding to the scene content type, and its columns corresponding to the image artefact severity.

The library can be stored on a node within a network in certain embodiments.

Referring now to Figure 23, a method of using the image artefact removal models will now be described according to some embodiments.

A section of video or an image is received from a network at a receiving network node at step 2310 in some embodiments. In these embodiments, the data received depends on how the data was prepared for transmission at a transmitting network node and will include the video/image data or representations of the video/image data. It is possible in some of these embodiments that video data or representations is not transmitted and/or received simultaneously so some buffering may be required to wait for all of the components required before the artefact removal process can take place.

In some embodiments, at step 2320, the received video or image data is unpacked and divided into scenes depending on its content using the process described above in relation to the image artefact removal process. In some of these embodiments, the scenes are then classified at step 2330 using metrics to determine the scene content type.

Alternatively, in other embodiments the received video/image data can already have been divided into scenes and classified by the transmitting network node, in which case the data received by the receiving node will contain metadata for each of the scenes contained within it that identifies the scene content type.

In either case, in some embodiments, at step 2330, the received scenes are subjected to an artefact grading algorithm or classifier to determine the level of artefact severity present in the scene. In some of these embodiments the source of these artefacts can be the video/image compression and quantisation process performed by the transmitting node prior to transmission of the video/image data, or they could be introduced by faulty or lossy network transmission.

In some embodiments, the scene content type and image artefact severity are used to select the image artefact removal model from the library of image artefact removal models generated in the model creation process that best matches the scene content type and artefact severity of the received scene. In these embodiments, this matching may be performed at the receiving network node if the library is stored there. Alternatively, in other embodiments, if the library is stored remotely from the receiving network node, a request for the most suitable image artefact removal model may be

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transmitted from the receiving node to the location of the model library. In some of these embodiments the model library will then transmit the relevant image artefact removal model to the receiving network node. If no suitable image artefact removal is stored in the library then a generic model may be used instead. In such embodiments, a suitable model may be determined, for example, by requiring that the metric data relating to the content type and the artefact severity of the received video or image data lie within some predefined range of at least one of the image artefact removal models stored in the library.

In some embodiments, the image artefact removal model identified to be the most suitable (or the generic model in the case that no suitable model is present in the library or if the generic model is the most suitable model) is then applied to the received scene at step 2350 in order to substantially recreate the original video/image file largely free from image artefacts. In such embodiments, this fidelity correction process can result in a clean reconstructed video/image, which is then output by the receiving node at step 2360.

Referring now to Figure 24, an alternative method of using the image artefact removal models according to some embodiments will now be described.

In such embodiments, this method relates to the combined use of image artefact removal and super resolution techniques to reconstruct a video or image from a downsampled (i.e. lower resolution than an original higher resolution) video or image data received from a network.

In some embodiments, firstly, at step 2410, the data package is received from the network. In these embodiments, the data received in the package depends on how the data was prepared for transmission by the transmitting network node and can include downsampled video or image data or representations of the video or image data and/or details of one or more reconstruction models for recreating high-resolution video data from the downsampled video or image data. In such embodiments, these details may be the reconstruction models themselves, or references to known reconstruction models stored at the receiving node or on the network.

In some embodiments, it is possible that the video data or representations, references to the one or more initial reconstruction models and the modifications to those models are not transmitted and/or received simultaneously so some buffering may be required to wait for all of the components required to decode or reconstruct the higher-resolution video from the data transmitted over the network.

Next, at step 2420, the received data is prepared for reconstruction in some

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embodiments. In these embodiments, this step generally involves separating the low-resolution video/image or representations if transmitted from the details of the relevant reconstruction models. Optionally, in other embodiments, the low-resolution video or image is decompressed using the video or image codec used for transmission into full-resolution scenes and each of the frames is matched up with the corresponding reconstruction model, which are also unpacked into scene-by-scene order.

At step 2430, in some embodiments, if the scene content has not already been determined by the transmitting node, then it is now determined by the receiving node.

In some embodiments, the unpacked video or image scenes are then graded to determine their artefact severity using an artefact grading algorithm.

In some embodiments, at step 2440, the scene content type and image artefact severity are used to select the image artefact removal model from the library of image artefact removal models generated in the model creation process that best matches the scene content type and artefact severity of the received scene. In such embodiments, this matching can be performed at the receiving network node if the library is stored there. Alternatively, in other embodiments where the library is stored remotely from the receiving network node, a request for the most suitable image artefact removal model can be transmitted from the receiving node to the location of the model library. In such embodiments the model library will then transmit the relevant image artefact removal model to the receiving network node. If no suitable image artefact removal model is stored in the library then a generic model may be used instead in some of these embodiments.

In some embodiments, the image artefact removal model identified for each scene is then applied to the downsampled scene at step 2450 in order to substantially recreate the original downsampled image transmitted by the transmitting node. Alternatively, in other embodiments the identified model can be used after the upscaling process of step 2460 to substantially remove the upscaled image artefacts from the recreated higher resolution video.

At step 2460, in some embodiments the relevant reconstruction models are then applied to each of the scenes to output higher-resolution scenes. In such embodiments the reconstruction, or decoding, process can involve applying the optimised super resolution convolutional neural network model, or reconstruction model, for each scene in order to recreate higher resolution video or image having substantially the same quality as the original high-resolution video or image from which the downsampled video or image was generated by the transmitting node. Given the corresponding

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reconstruction models and each lower-resolution scene or set of representations, in some embodiments a higher resolution frame that is substantially visually identical to the original higher-resolution frames can be reconstructed with high accuracy.

In some embodiments, the reconstructed higher resolution scene is then output by the receiving node at step 470.

The above-described process is performed as a post-process to the standard decompression process used at the decoding node for received transmissions of, for example, video after the conventional decoding step and therefore "outside" the traditional compression pipeline in at least some embodiments.

Alternatively, in other embodiments, the image artefact removal process can be performed as part of the upscaling process itself. In such embodiments, several reconstruction models can be trained to reproduce the higher resolution image or video at the first node from a number of different downsampled images or videos, each with a different artefact severity. In such embodiments, these can either all be transmitted with the downsampled video, or the required model can be transmitted to the second network node from the first node once a request for the model containing the artefact severity of the received downsampled image or video has been sent from the second node to the first node. In either case, in some embodiments the model best matching the artefact severity of the received downsampled image or video is used to substantially recreate the original high resolution video.

Spatio-temporal Interpolation

In some embodiments, visual data being received may be of a lower than desirable quality, such as at a low resolution or a low frame rate. It will be appreciated other features may render the visual data lower than desirable quality. One or more hierarchical algorithms may be used to increase the quality of the visual data to a more desirable quality. For example, in some embodiments, the hierarchical algorithm may increase the resolution of the received visual data section or sections. In another embodiment the hierarchical algorithm may develop intermediate sections, such as a section to be placed between two received sections of visual data. In yet another embodiment, the hierarchical algorithm any be used to increase the quality of the received visual data by combining the above mentioned embodiments.

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These embodiments can be used in combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

In some embodiments, one or more hierarchical algorithms may be used to estimate higher-resolution versions of received lower-resolution frames. In such embodiments, upon receiving multiple lower-resolution frames, a hierarchical algorithm can be used to estimate a higher resolution version of a particular received frame. In some embodiments, on the receipt of three or more consecutive frames of lower-resolution visual data a hierarchical algorithm may be used to estimate a higher resolution version of one of the middle frames. In such embodiments, this estimation can be based not only on the lower-resolution version of the received frame, but also the lower-resolution version of the previous and subsequent frames also received. Alternatively, in other embodiments the hierarchical algorithm can be used to determine an unknown intermediate frame at the same resolution as previous and subsequent received frames.

Alternatively, in some other embodiments a hierarchical algorithm may be used to estimate higher-resolution versions of the received lower-resolution frames, as well as a higher-resolution version of an unknown intermediate frame. Furthermore, in some embodiments the hierarchical algorithm may also be used to estimate an unknown future or past frame based upon the received lower-resolution frames.

Online training

In some embodiments, new visual data being transmitted from a node to one or more other nodes has no hierarchical algorithms trained to enhance a lower-quality version of the new visual data. For example, in some embodiments this new visual data may be live broadcast video data and in some embodiments the new visual data may be streamed or rendered e-gaming video content. Where there exist no hierarchical algorithms for this new visual data, specific or generic hierarchical algorithms need to be trained in order to enhance lower-quality versions of the new visual data in some of these embodiments and as per some of the embodiments described elsewhere.

In some embodiments, multiple hierarchical algorithms can be trained in parallel on the same visual data. In such embodiments, this allows for wider range of hierarchical algorithms to be explored within a given timeframe. In some of these embodiments, the most suitable algorithm from these developed algorithms can be selected for

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transmission across the network with the visual data. In some embodiments, developing the hierarchical algorithms in parallel can be useful in situations where there is only a limited time available to develop the hierarchical algorithm.

In parallel to the development of hierarchical algorithms (whether singly or multiple in parallel), in some embodiments the visual data can be encoded in an encoder in preparation for its transmission across the network. In this way, the time taken to prepare both the hierarchical algorithm and the visual data for transmission can be reduced when compared to developing the hierarchical algorithm and encoding the visual data in series in such embodiments.

Once generic or specific hierarchical algorithms have been developed or trained, for example for a new game being streamed as e-gaming video content, these can be used to enhance the quality of lower-quality streamed visual data at receiving nodes.

These embodiments can be used in combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

Offline training

In some embodiments, new visual data to be transmitted from a node to one or more other nodes has no hierarchical algorithms trained to enhance a lower-quality version of the new visual data. For example, in some embodiments this new visual data may be new video data such as a new film or television series and in some embodiments the new visual data may be a computer game that will in the future be used to generate streamed e-gaming video content. Where there exist no hierarchical algorithms for this new visual data, specific or generic hierarchical algorithms need to be trained in order to enhance lower-quality versions of the new visual data in some of these embodiments and as per some of the embodiments described elsewhere.

Often, the visual data will be encoded prior to transmission across the network using an encoder in certain embodiments. The encoding process may introduce encoder specific artefacts to the visual data in such embodiments. By refining the hierarchical algorithm by performing further training steps on the encoded video in some embodiments, the hierarchical algorithm can be trained to substantially correct image artefacts introduced by the encoder.

In some embodiments the hierarchical algorithms can be trained using training data corresponding to the exact visual data that will be transmitted across the network.

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In such embodiments, this approach can be particularly useful in situations where the visual data is known in advance, and where the visual data is likely to be transmitted across the network multiple times. For example, in some embodiments the hierarchical models can be trained on sections of an episode of a TV program that will be made available on an on-demand streaming service. In such embodiments the models trained on that particular episode can be transmitted alongside the lower-quality visual data and be used to enhance the lower-quality visual data to a higher-quality version of that episode.

Alternatively, in other embodiments the hierarchical algorithms can be trained on training data that is similar, but not identical, to the expected visual data on which they are to be used. In such embodiment these trained models can be associated with metric data relating to properties of the visual data on which they were trained. In some of these embodiments, this metric data can later be used to select an appropriate hierarchical algorithm to use to enhance visual data for which no specific model has been trained. In some embodiments visual data is being generated and transmitted across the network substantially simultaneously, for example during a live broadcast. In such embodiments, there may not be enough time to generate a specific hierarchical algorithm for the visual data without introducing a substantial delay to the live broadcast. In such embodiments, selecting a hierarchical algorithm that has been pre-trained on similar visual data can reduce this delay.

Once hierarchical algorithms have been trained in order to enhance lower-quality versions of the new visual data these can be stored in order to be sent with the visual data or distributed to receiving nodes in advance of visual data being sent, depending on the embodiments.

These embodiments can be used in combination with other embodiments, and alternative and optional portions of embodiments, described elsewhere in this specification.

Strided Convolutions

Optionally, Figure 18 shows an alternative method 1800 of the method 1500 shown in Figure 15 according to some embodiments. In these embodiments, once the visual data 1510 has been separated into individual frames at step 1520, the dimension of the full resolution images 2110 extracted may be reduced based on at least one predetermined factor at step 1810. In these embodiments, at step 1810, the at least one

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predetermined factor may be used to select individual pixels from the extracted full resolution images 2110 to form a lower resolution representation 2120 of the extracted full resolution images 2110. For example, in some embodiments, a predetermined factor of 2 may indicate every other pixel in both the horizontal and vertical dimensions is selected, as shown in Figure 21. It will be appreciated that other values of the predetermined factor may be used in other embodiments, furthermore in some of these other embodiments both the horizontal and vertical dimensions may each have a different predetermined factor applied.

In some embodiments, the reduced dimension visual data may be concatenated in step 1820, to form a lower resolution representation 2120 of the extracted full resolution images 2110. In these embodiments, the lower resolution representation 2120 can then be used as a basis for any image enhancement techniques and analysis allowing for the use of larger super resolution networks without compromising the runtime. In some embodiments, different predetermined factors and sizes of super resolution network can be used to obtain optimum performance.

Alternatively, in other embodiments, Figure 19 shows a method 1900 based upon the method 1600 shown in Figure 16. In method 1900 of these other embodiments, steps 1810 and 1820 can occur after the frames are grouped into scenes in step 1610.

Referring now to Figure 20, a modified process 2000 according to some embodiments (based on process 1900 but which could equally be a modified version of process 1800) is shown.

In these embodiments, process 1900 is modified with further steps. Specifically, in some of these embodiments, step 1710 can begin with a high resolution visual data, for example at HD resolution. Then, at step 1720 of these embodiments, the visual data can be down-sampled to, for example, SD resolution to enable transmission over a bandwidth-restricted network. At step 1730 of these embodiments, the lower-resolution visual data can be transmitted over a network thus becoming the input visual data 310 of either process 1800 or 1900 described above in relation to Figures 18 or 19 respectively.

Specific Description – Flexibility of described aspects and embodiments

Any system feature as described herein may also be provided as a method feature, and vice versa.

As used herein, means plus function features may be expressed alternatively in terms of their corresponding structure.

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In particular, method aspects may be applied to system aspects, and vice versa.

Furthermore, any, some and/or all features in one aspect can be applied to any, some and/or all features in any other aspect, in any appropriate combination.

It should also be appreciated that particular combinations of the various features described and defined in any aspects of the invention can be implemented and/or supplied and/or used independently.

In alternative embodiments, the input visual data concerned may be media for playback, such as recorded visual data or live streamed visual data, or it can be videoconference video or any other visual data source such as video recorded or being recorded on a portable device such as a mobile phone or a video recording device such as a video camera or surveillance camera.

It should also be appreciated that the term 'visual data', may refer to a single image, a sequence of images, video, or a section of visual data.

It should further be appreciated that the term "enhancing" may refer to upscaling, increasing the resolution and/or quality of visual data. References to enhancing or increasing the quality of visual data can refer to upscaling or using enhancement techniques of the possible embodiments described. References to down sampling can refer to reducing the resolution and/or quality of visual data (for example by quantisation to lower the bit rate of the visual data).

It should also be appreciated that the term 'frame', particularly in reference to grouping multiple frames into scenes, can refer to both an entire frame of a video and an area comprising a smaller section of a frame.

In aspects and/or embodiments, the terms algorithms and/or models and/or parameters can be used interchangeably or exchanged with each other. Further, in aspects and/or embodiments, the terms hierarchical algorithm, hierarchical model and hierarchical parameter can be exchanged with the terms convolutional neural networks and/or convolutional neural network model, convolutional neural network algorithm, convolutional neural network parameter.

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CLAIMS:

1. A method for developing an enhancement model for low-quality visual data, the method comprising the steps of:

receiving one or more sections of higher-quality visual data

training a hierarchical algorithm, wherein the hierarchical algorithm is operable to increase the quality of one or more sections of lower-quality visual data to substantially reproduce the one or more sections of higher-quality visual data; and

outputting the hierarchical algorithm.

2. A method according to claim 1, wherein the hierarchical algorithm is trained using a learned approach.

3. A method according to claim 2, wherein the learned approach comprises machine learning techniques.

4. A method according to any preceding claim, wherein the hierarchical algorithm is a non-linear hierarchical algorithm.

5. A method according to claim 4, wherein the non-linear hierarchical algorithm comprises one or more convolutional neural networks.

6. A method according to any preceding claim, wherein the hierarchical algorithm is developed from a known hierarchical algorithm.

7. A method according to any preceding claim, wherein the method is performed at a first network node within a network.

8. A method according to claim 7, wherein the hierarchical algorithm is transmitted to a second network node in the network.

9. A method according to any preceding claim, wherein the one or more sections of lower-quality visual data are generated from the one or more sections of higher-quality visual data.

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10. A method according to claim 9, wherein the one or more sections of lower-quality visual data are generated from the high-quality visual data using a process comprising downsampling.

11. A method according to any of claims 9 or 10, wherein the one or more sections of lower-quality visual data are generated from the one or more sections of higher-quality visual data using a process comprising compression and/or quantisation.

12. The method according to any previous claim, wherein the hierarchical algorithm performs image enhancement, preferably using super-resolution techniques.

13. The method according to any previous claim, wherein the hierarchical algorithm uses a spatio-temporal approach.

14. The method according to any previous claim, wherein the lower-quality visual data comprises a plurality of frames of video.

15. The method according to any previous claim, wherein the hierarchical algorithm comprises a plurality of layers.

16. The method according to claim 15, wherein the layers are any of sequential, recurrent, recursive, branching or merging.

17. A method for reducing the amount of data to be transferred when communicating visual data over a network from a first node to a second node, the method at the first node comprising the steps of:

reducing the quality of one or more sections of higher-quality visual data to one or more sections of lower-quality visual data;

developing at least one example based model operable to increase the quality of the one or more sections of lower-quality visual data using the one or more sections of higher-quality visual data to optimise the developed at least one example based model, wherein the developed at least one example based model corresponds to the one or more sections of lower quality visual data;

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transmitting the one or more sections of lower-quality visual data to the second node; and

transmitting to the second node the developed at least one example based model that corresponds to the one or more sections of lower-quality visual data transmitted to the second node;

wherein the second node is able to substantially reproduce the one or more sections of higher-quality visual data from the transmitted one or more sections of lower-quality visual data using the developed at least one example based model that corresponds to the one or more sections of lower-quality visual data.

18. A method for increasing the quality of a section of visual data communicated over a network from a first node to a second node, the method at the second node comprising the steps of:

receiving one or more sections of lower-quality visual data via a network;

receiving a corresponding at least one example based model operable to increase the quality of the one or more sections of lower-quality visual data, the at least one example based model developed with the knowledge of one or more sections of higher-quality visual data from which the one or more sections of lower-quality visual data was generated; and

using the at least one example based model to increase the quality of the one or more sections of lower-quality visual data to substantially recreate the one or more sections of higher-quality visual data.

19. A system for reducing the amount of data transferred when communicating visual data over a network, the system comprising two or more nodes wherein a first node is configured to:

reduce the quality of one or more sections of higher-quality visual data to one or more sections of lower-quality visual data;

develop at least one example based model operable to increase the quality of one or more sections of lower-quality visual data using the one or more sections of higher-quality visual data to optimise the developed at least one example based model, wherein the developed at least one example based model corresponds to the one or more sections of lower quality visual data;

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transmit the one or more sections of lower-quality visual data to the second node; and

transmit to the second node the developed at least one example based model that corresponds to the one or more sections of lower-quality visual data transmitted to the second node;

wherein the second node is configured to:

receive one or more sections of lower-quality visual data via a network;

receive a corresponding developed at least one example based model operable to increase the quality of the one or more sections of lower-quality visual data, the developed at least one example based model developed with the knowledge of one or more sections of higher-quality visual data from which the one or more sections of lower-quality visual data was generated; and

use the developed at least one example based model to increase the quality of the one or more sections of lower-quality visual data to substantially recreate the one or more sections of higher-quality visual data.

20. A method or system respectively according to any of claims 17 to 19, wherein the example based model comprises any or a combination of any of: a non-linear algorithm; or an hierarchical algorithm; or a convolutional neural network; or a recurrent neural network; or a deep belief network; or a dictionary learning algorithm; or a parameter; or a mapping function.

21. A method or system respectively according to any of claims 17 to 20 wherein the high-quality visual data is divided into smaller sections based on similarities between a plurality of frames of the high-quality visual data.

22. A method or system respectively according to any of claims 17 to 21 wherein the one or more sections comprise any of: a single frame, a sequence of frames and a region within a frame or sequence of frames.

23. A method or system respectively according to any of claims 17 to 22, wherein the visual data is converted into a sequence of images, optionally before the quality is lowered.

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24. A method or system respectively according to any of claims 17 to 23, wherein down-sampling is used to reduce the quality of one or more sections of higher-quality visual data to one or more sections of lower-quality visual data.

25. A method or system respectively according to any of claims 17 to 24, wherein the steps of transmitting the one or more sections of lower-quality visual data to the second node and transmitting to the second node the developed at least one example based model that corresponds to the one or more sections of lower-quality visual data transmitted to the second node occur substantially simultaneously.

26. A method or system respectively according to any of claims 17 to 25, wherein the developed example based model is developed for each section of visual data to be transferred over the network.

27. A method or system respectively according to any of claims 17 to 26, wherein the developed example based model is developed using a method of machine learning.

28. A method or system respectively according to any of claims 17 to 27, wherein the example based model comprises a plurality of connected layers.

29. A method or system respectively according to claim 28 wherein the layers are sequential.

30. A method or system respectively according to any of claim 28 or claim 29, wherein a last of the layers is operable to increase the quality of the one or more sections of lower-quality visual data.

31. A method or system respectively according to any of claims 17 to 30, wherein the example based model is a neural network and preferably uses a spatio-temporal approach.

32. A method of training image artefact removal models, the method comprising the steps of:

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generating a plurality of training visual data from an original visual data;

developing an example based model for each of the training visual data operable to substantially recreate the original visual data from the training visual data the example based model was developed from; and

storing the example based models in a library of example based models;

wherein the training visual data contain a predetermined amount of artefacts.

33. A method according to claim 32, wherein the original visual data is divided into smaller sections based on similarities between a plurality of sections of the original visual data.

34. A method according to any of claims 32 to 33, wherein the example based model comprises any of: a non-linear hierarchical algorithm; or a convolutional neural network; or a recurrent neural network; or a deep belief network; or a dictionary learning algorithm; or a parameter; or a mapping function.

35. A method according to any of claims 32 to 34, wherein the training visual data are generated using at least one compression and/or quantisation algorithm.

36. A method according to any of claims 32 to 35, wherein the example based model is developed using a method of machine learning.

37. A method according to any of claims 32 to 36, comprising the additional step of determining a content type of the original visual data using metric data.

38. A method according to claim 37, comprising the additional step of determining a measure of artefact severity for each of the training visual data.

39. A method according to claim 38, wherein the example based models are classified in the library of example based models using metric data associated with the content type and the measure of artefact severity of the training visual data from which the example based models were developed.

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40. A method or system respectively according to any preceding claim, wherein the visual data comprises at least one of: an image, a sequence of images, or a section of video.

41. The method according to any previous claim, wherein a section of visual data comprises any of: a single frame of visual data, a sequence of frames of visual data, and a region within a frame or sequence of frames of visual data.

42. The method according to any previous claim, wherein the higher-quality visual data is at a higher-resolution than the lower-quality visual data.

43. A method according to any preceding claim, wherein the one or more sections of lower-quality visual data have a greater amount of artefacts than the one or more sections of higher-quality visual data.

44. The method of any previous claim, where in enhancing the quality of visual data means upscaling the quality of the visual data.

45. A system substantially as hereinbefore described in relation to Figures 2 to 6.

46. A method substantially as hereinbefore described in relation to Figures 2 to 6.

47. Apparatus for carrying out the method of any preceding claim.

48. A computer program product comprising software code for carrying out the method of any of claims 1 to 44.

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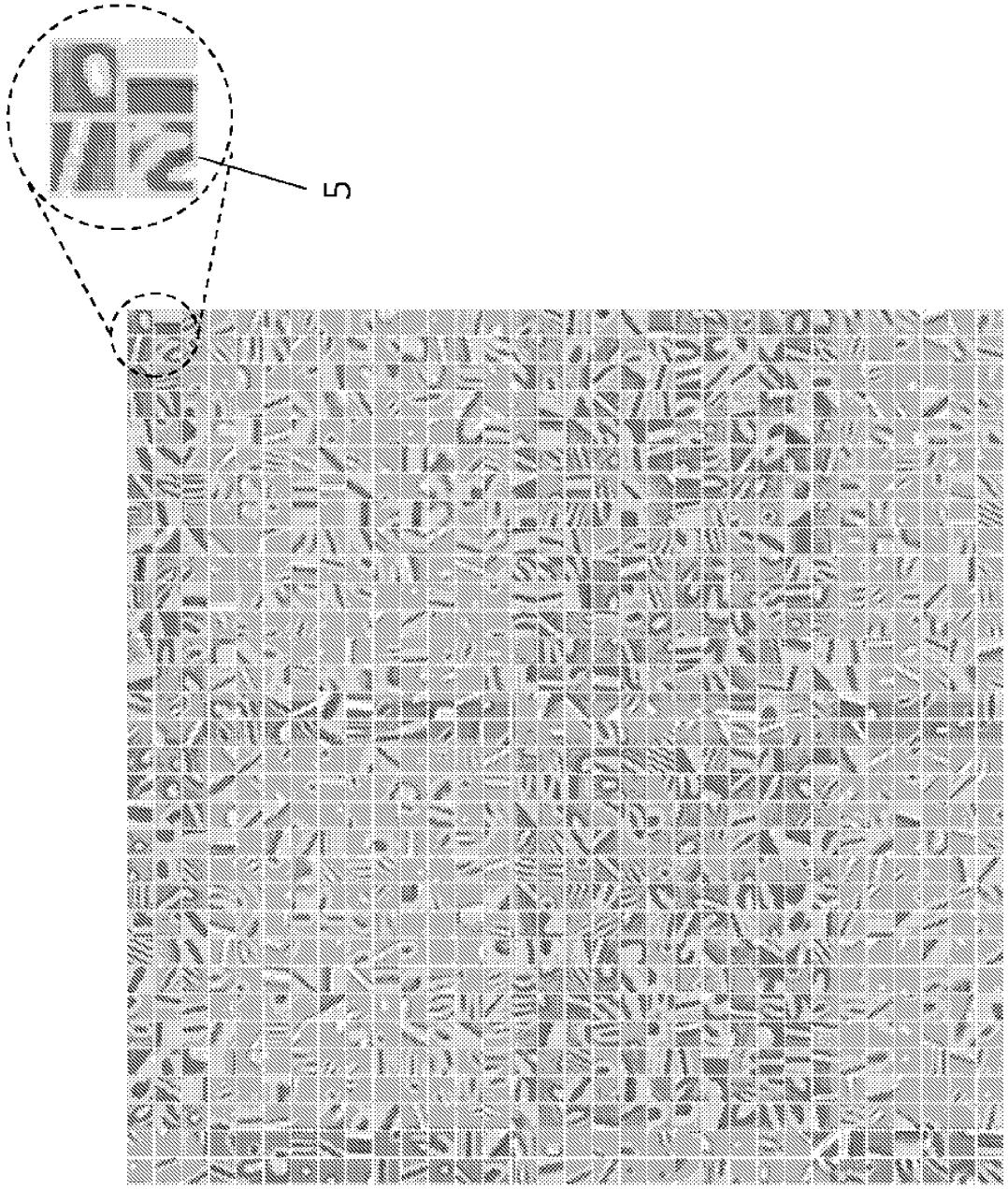


Fig. 1

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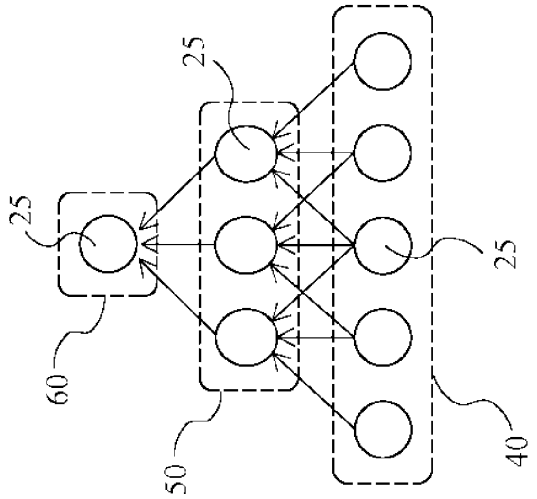


Fig. 2b

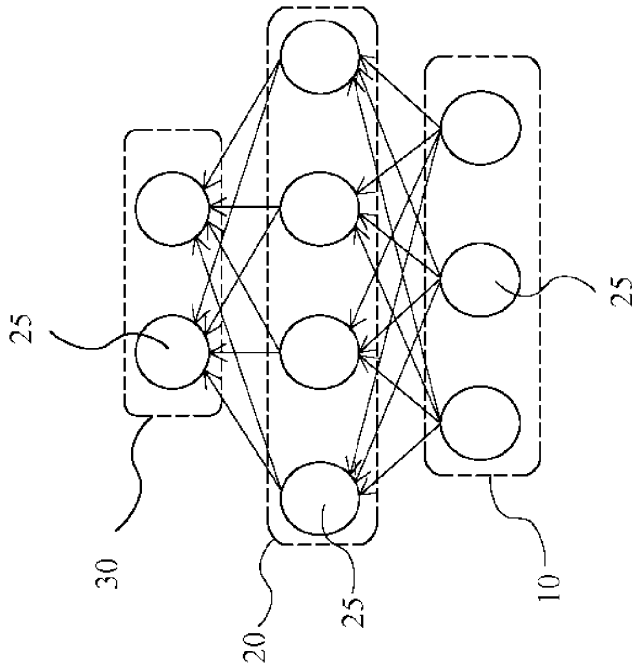


Fig. 2a

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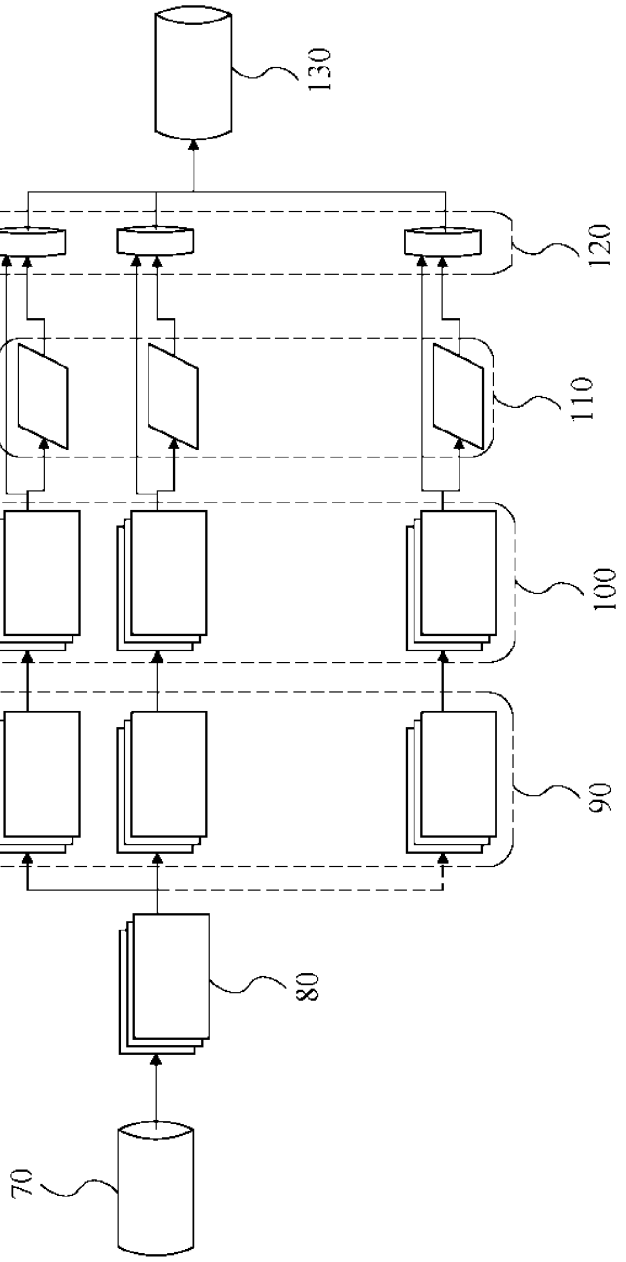


Fig. 3

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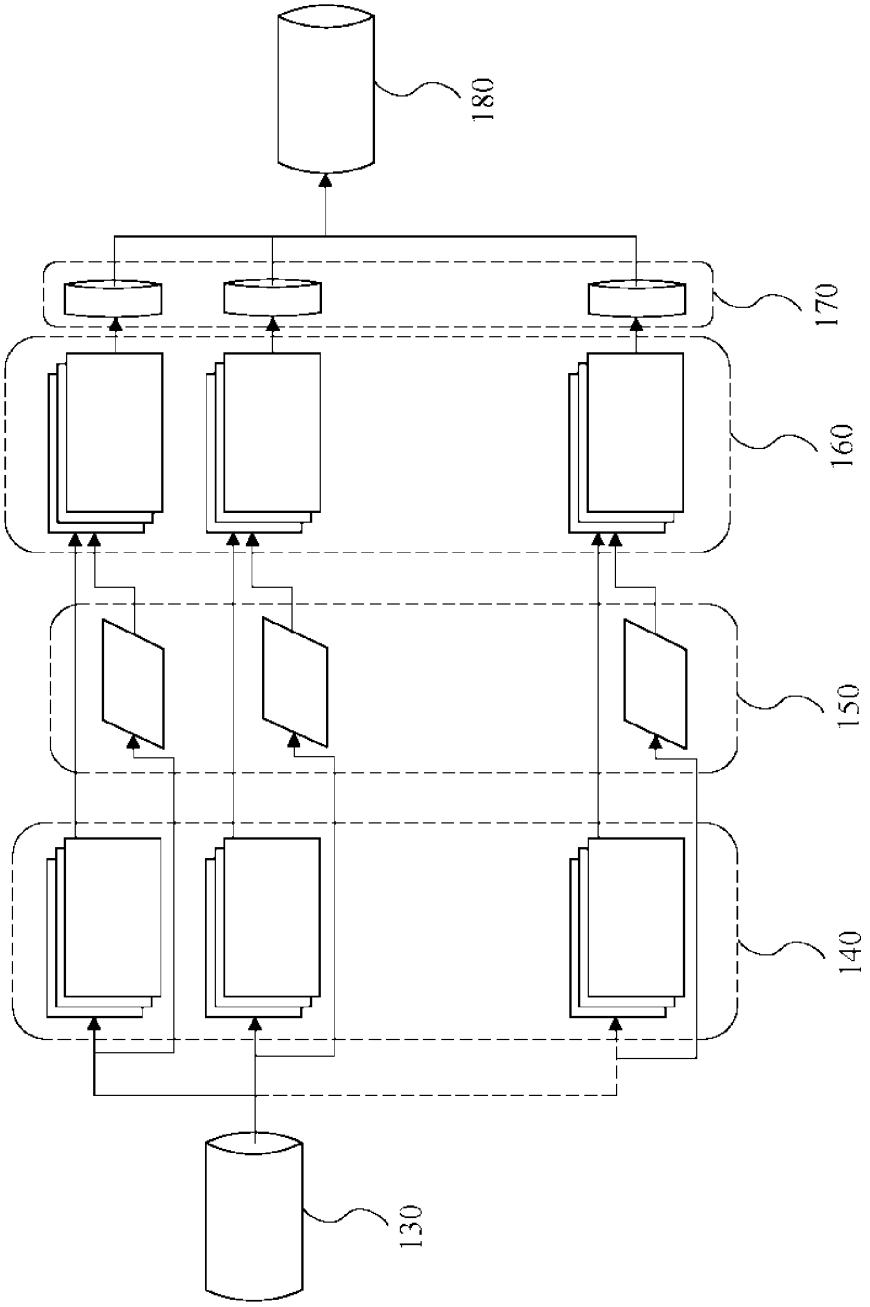


Fig. 4

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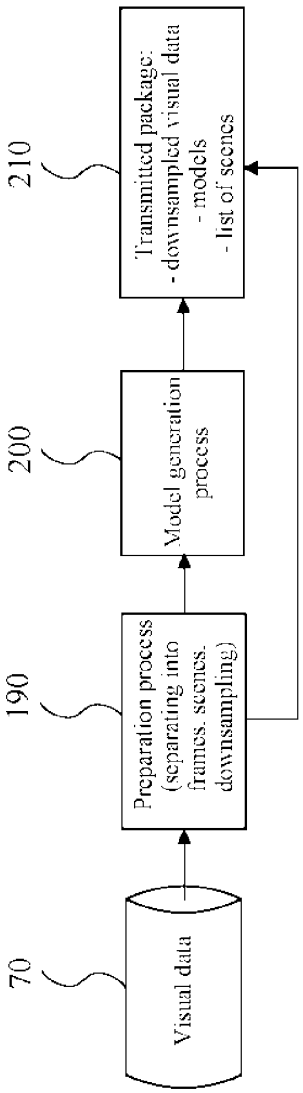


Fig. 5

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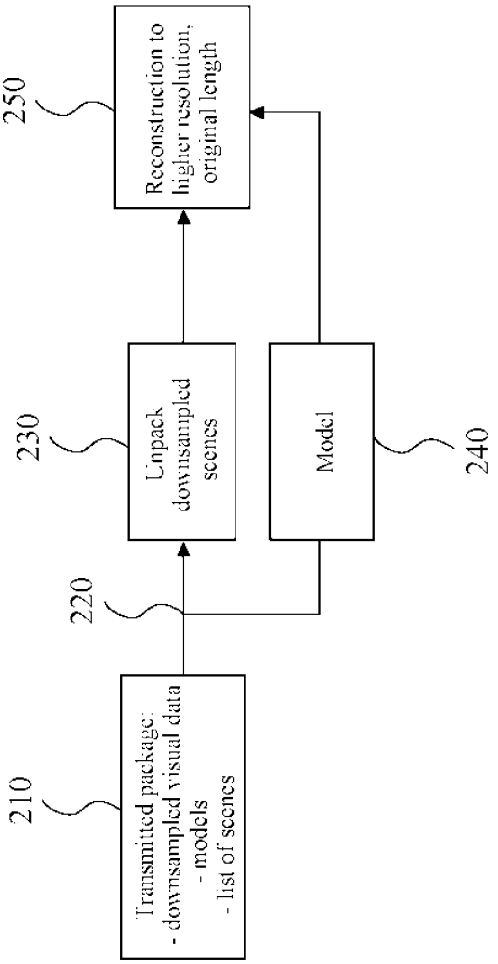


Fig. 6

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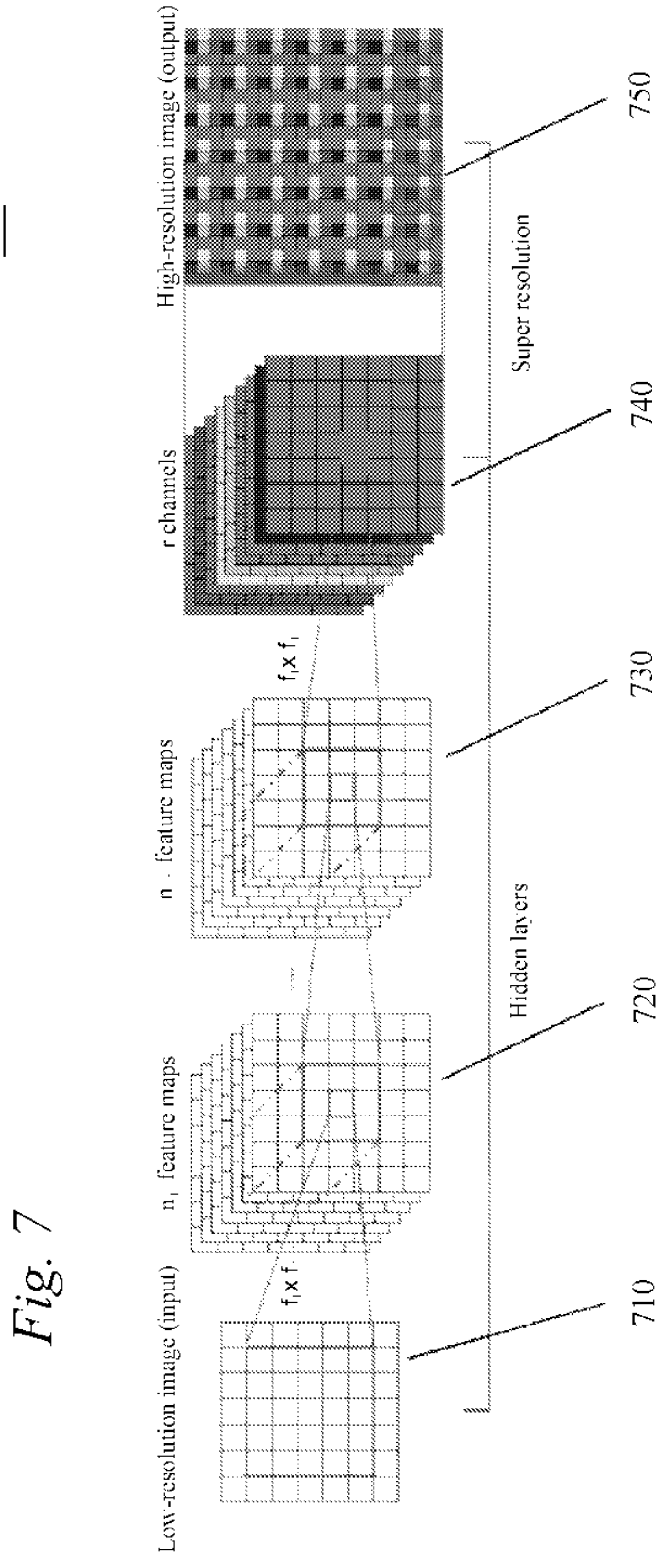


Fig. 7

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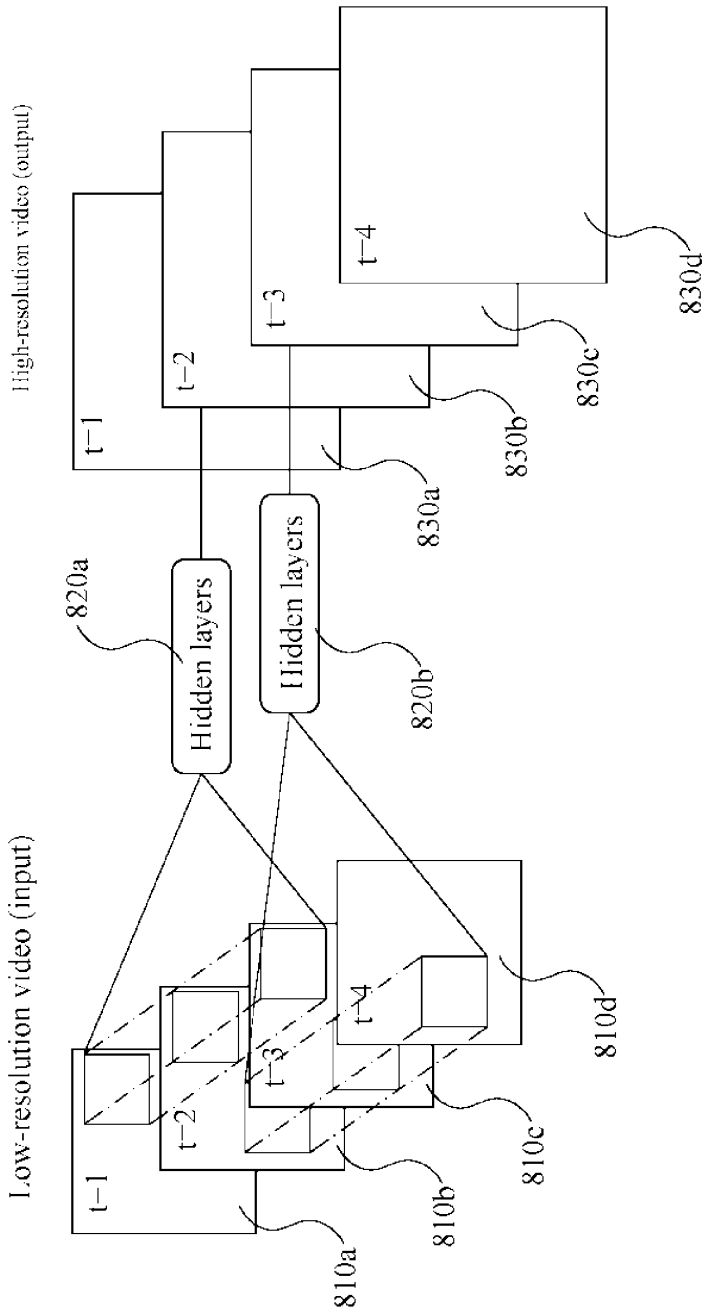


Fig. 8

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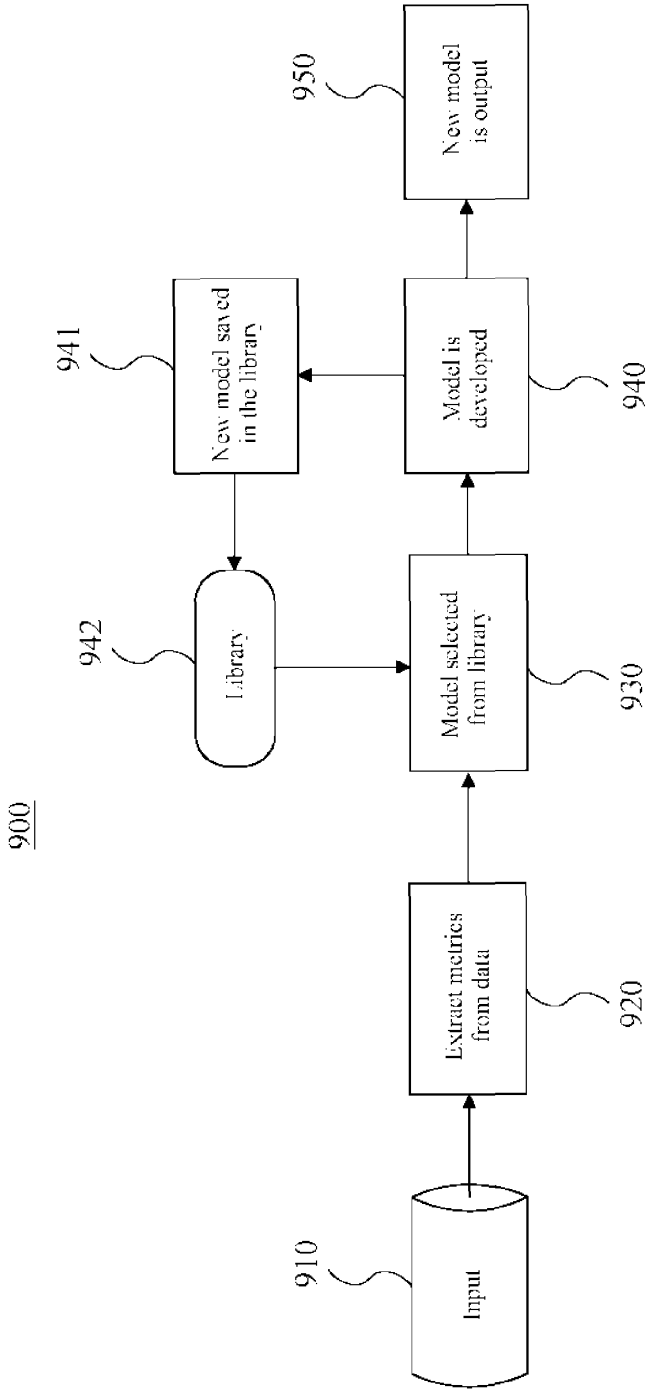
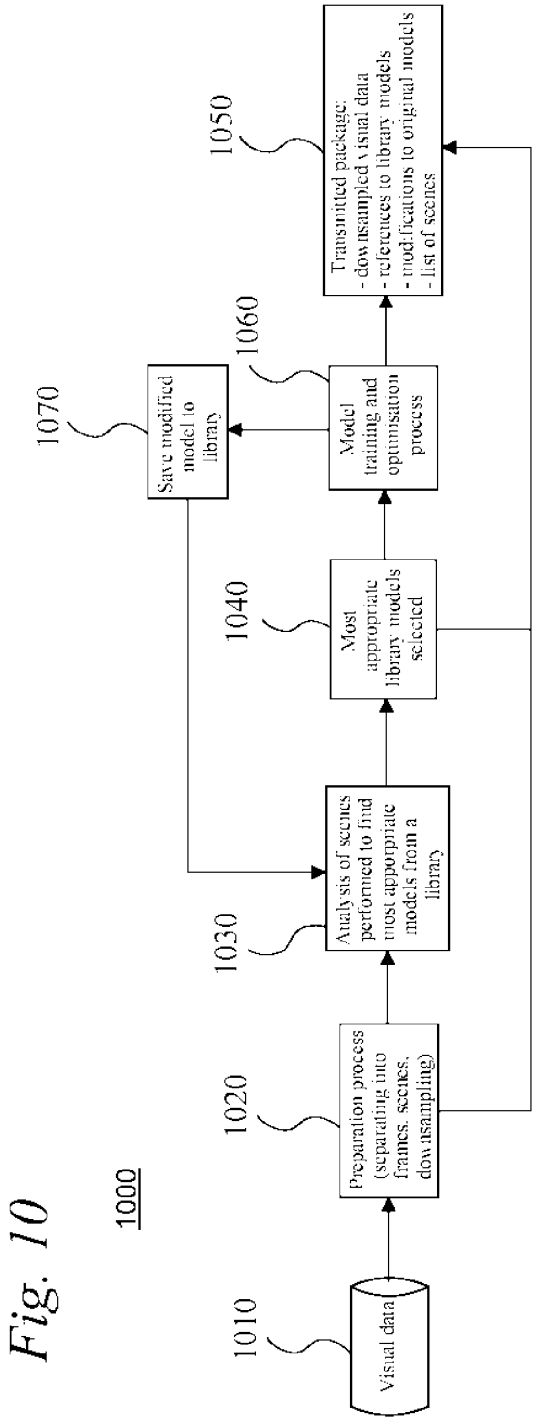


Fig. 9

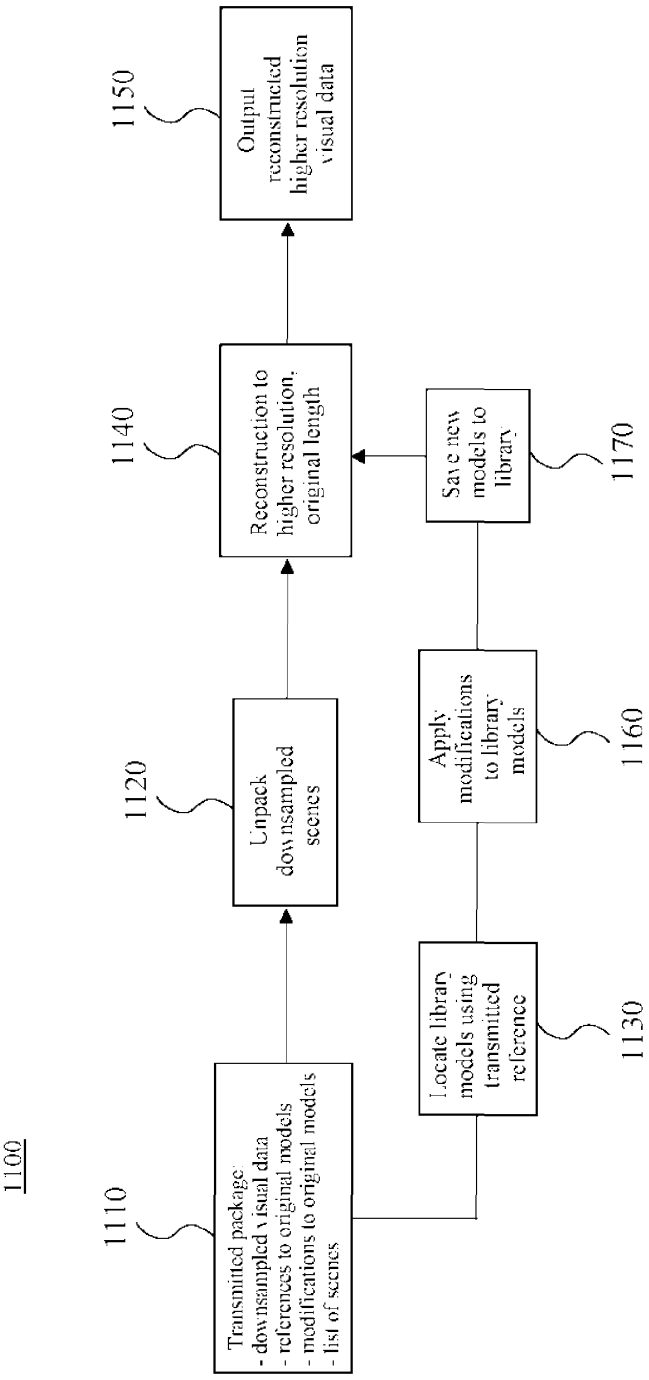
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Fig. 10



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Fig. 11



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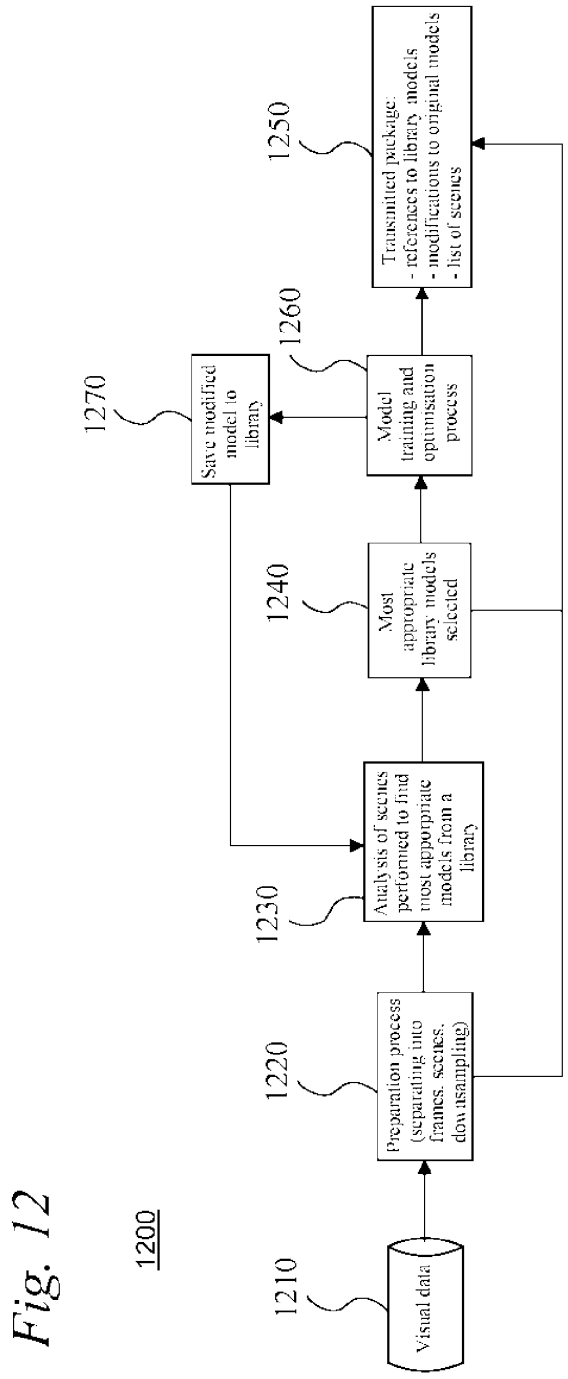
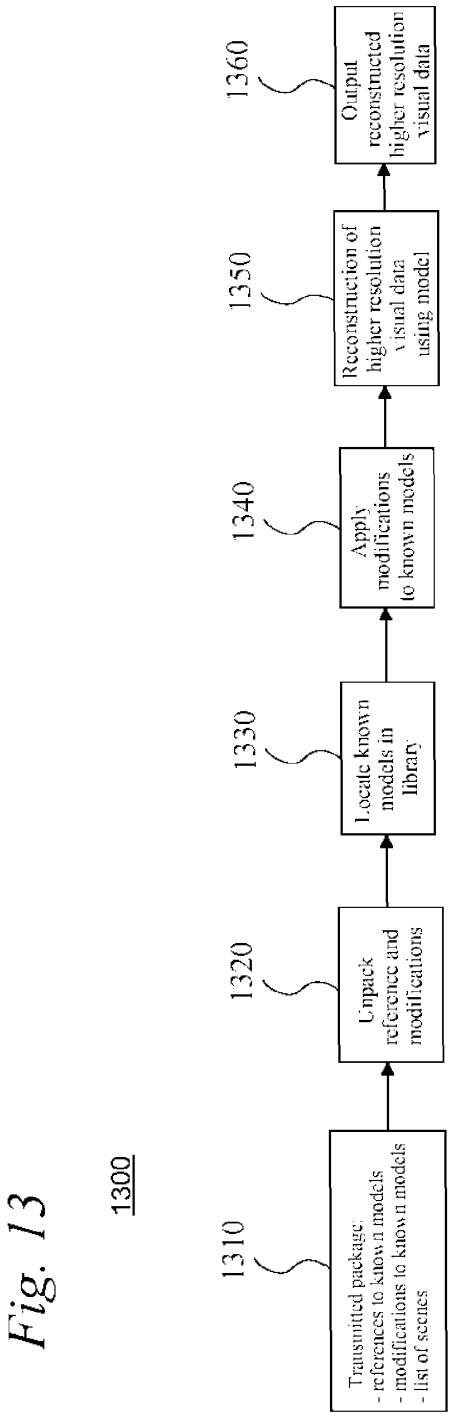


Fig. 12

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Fig. 13



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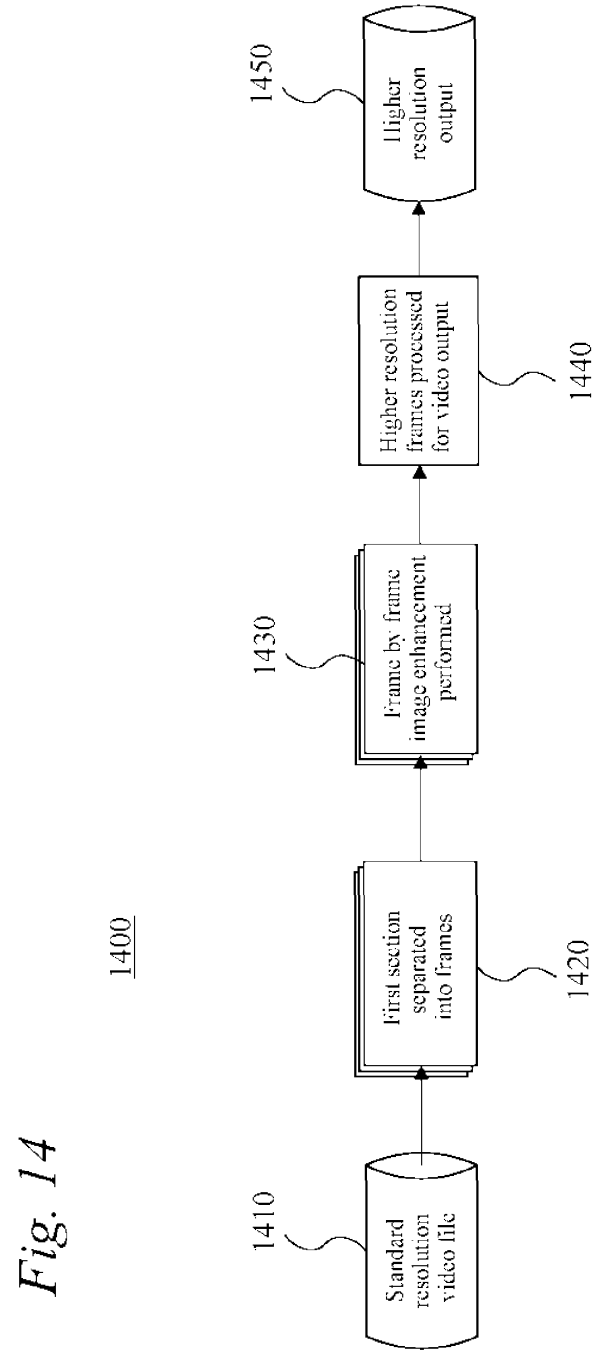
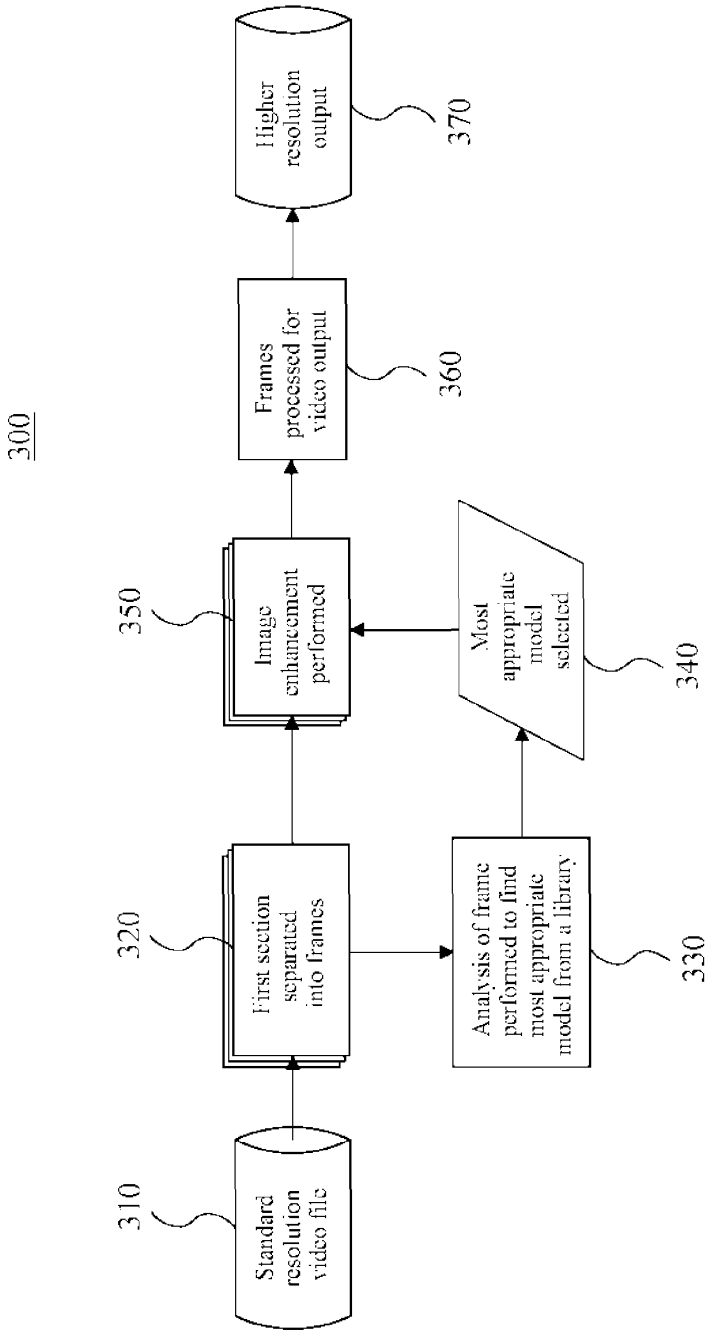


Fig. 14

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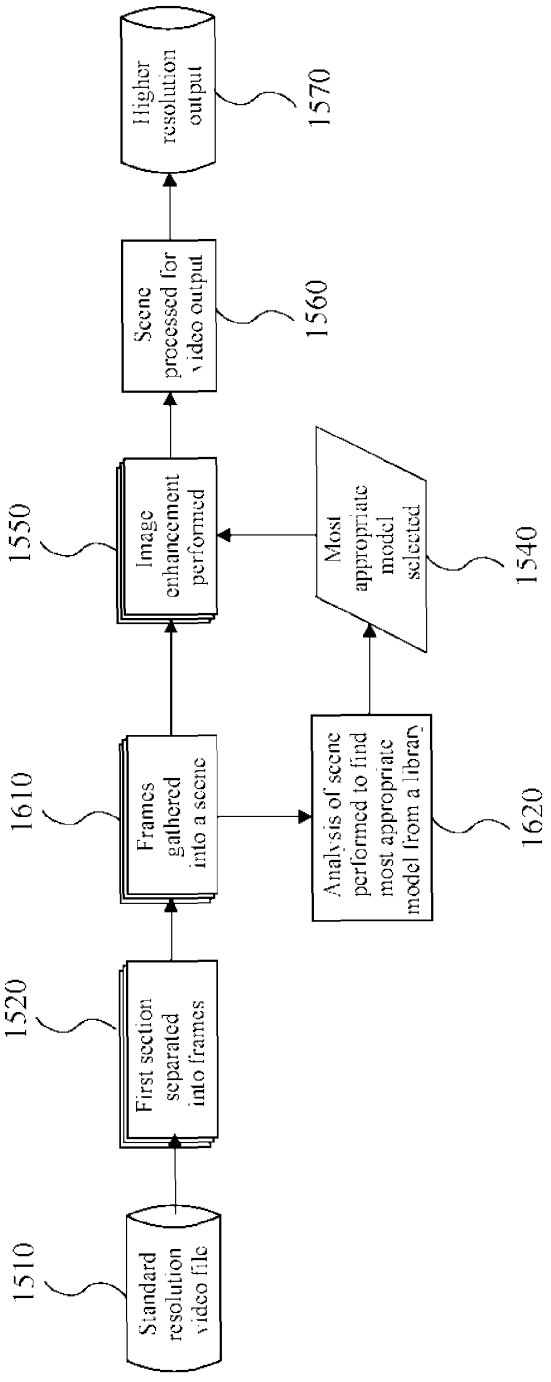
Fig. 15



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Fig. 16



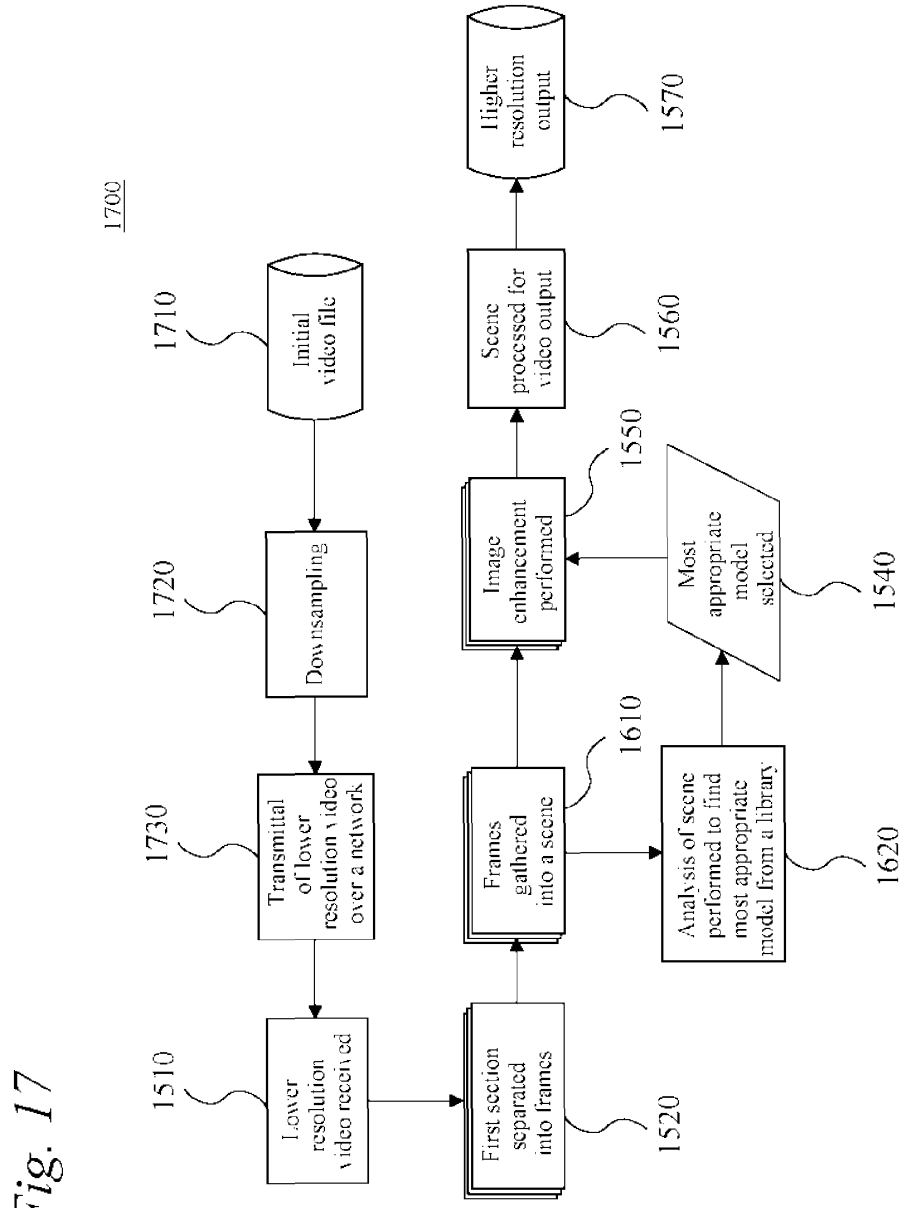


Fig. 17

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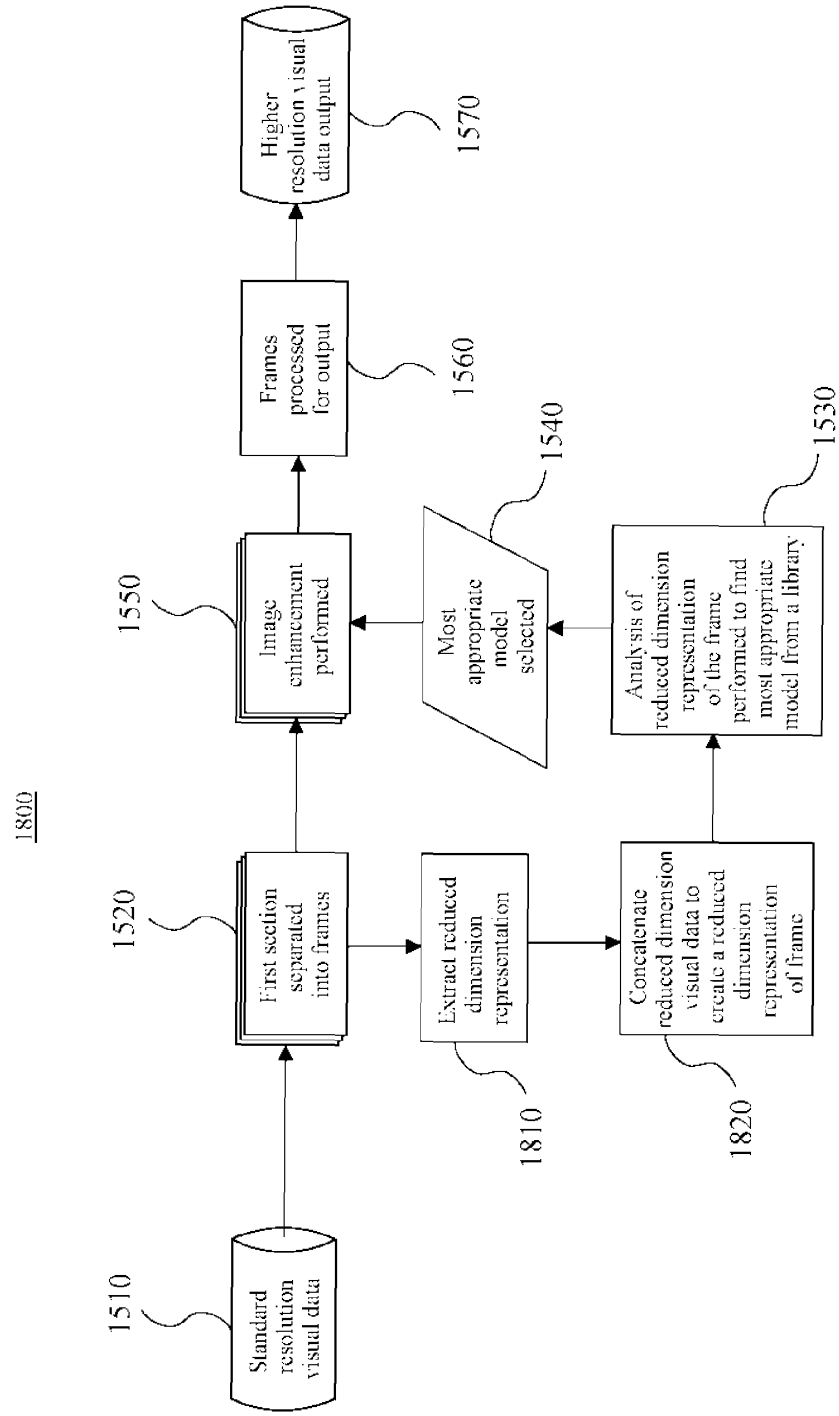


Fig. 18

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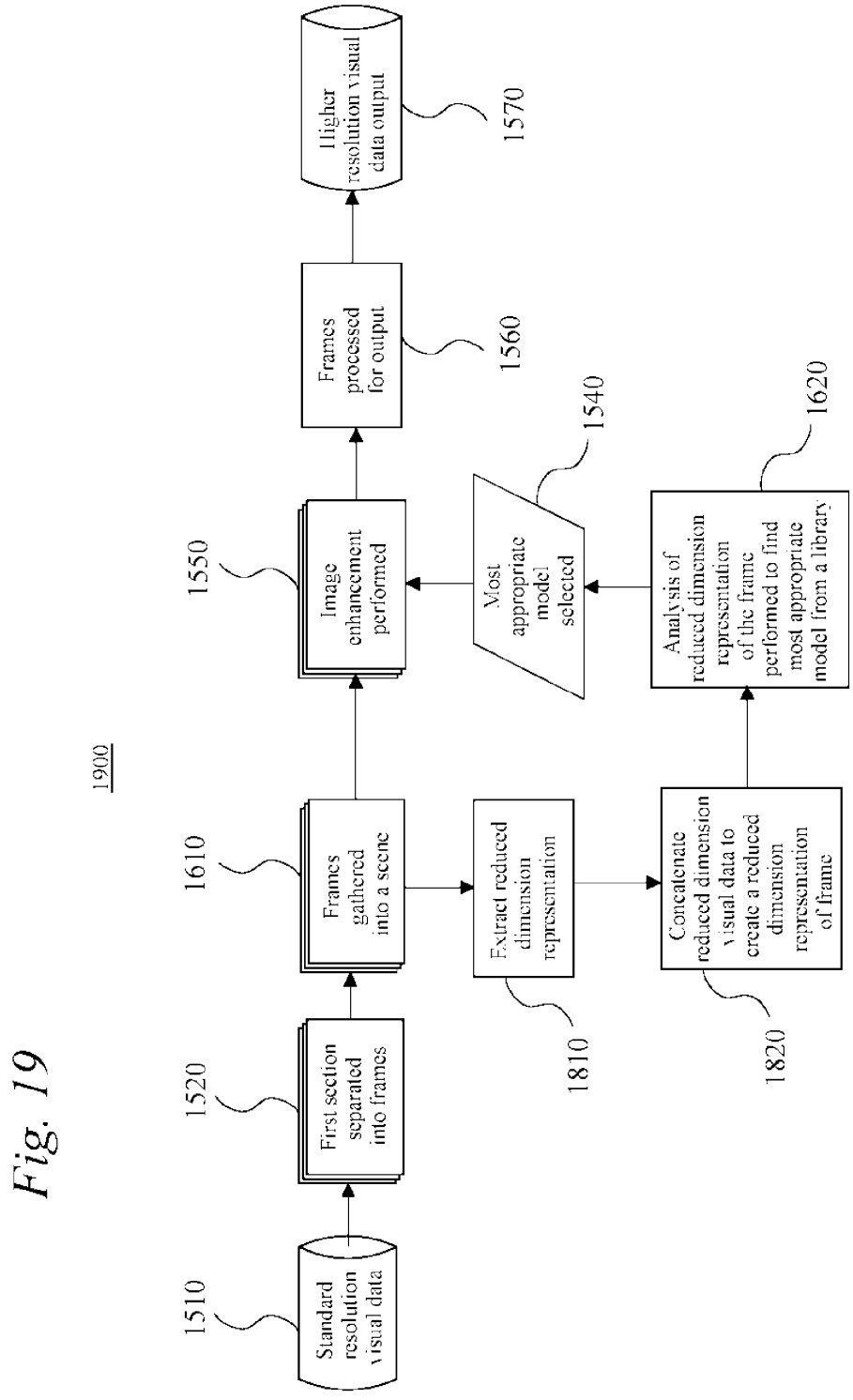
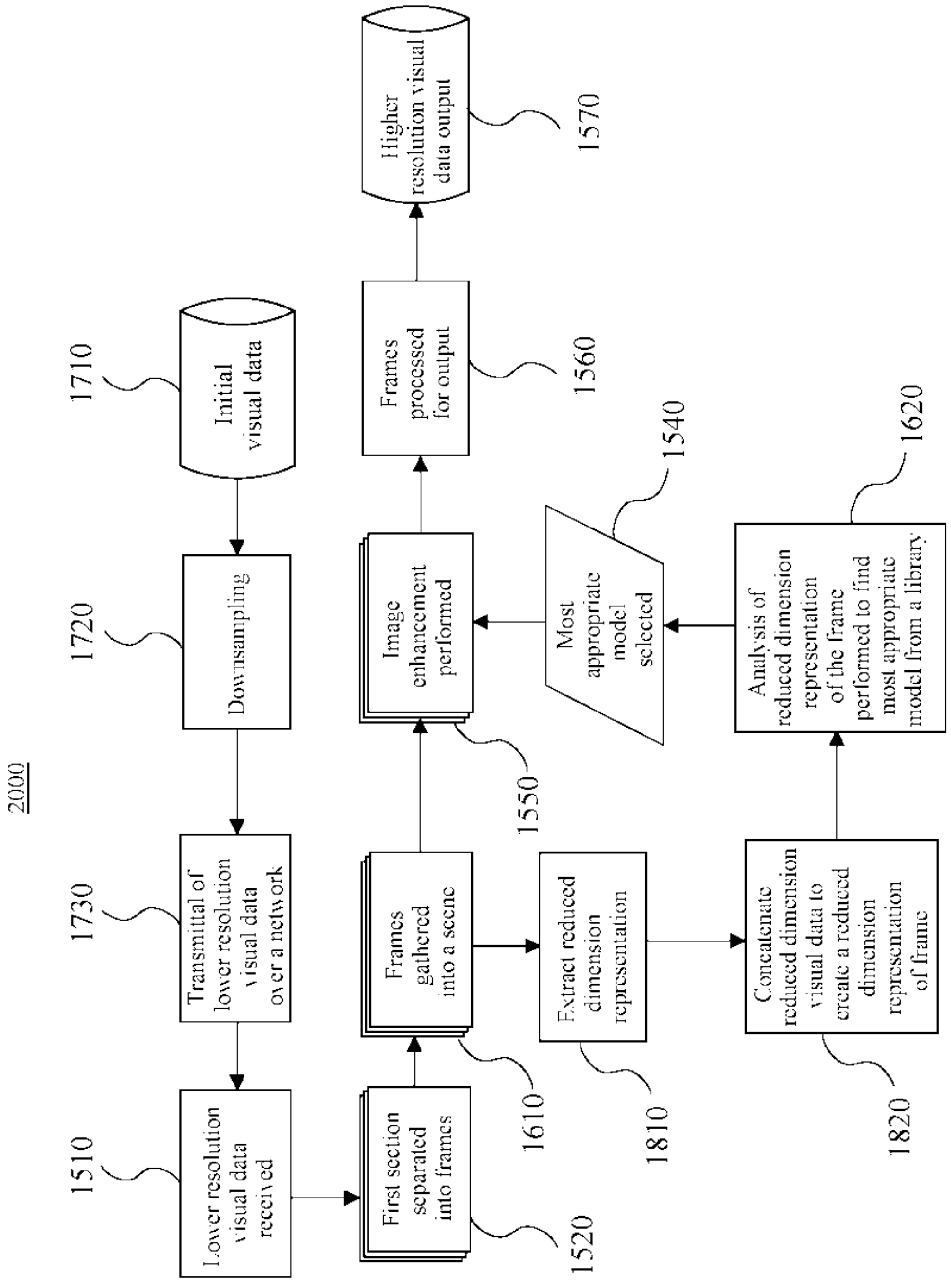


Fig. 19

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Microsoft Corporation v. RealD Spark, LLC
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Fig. 20



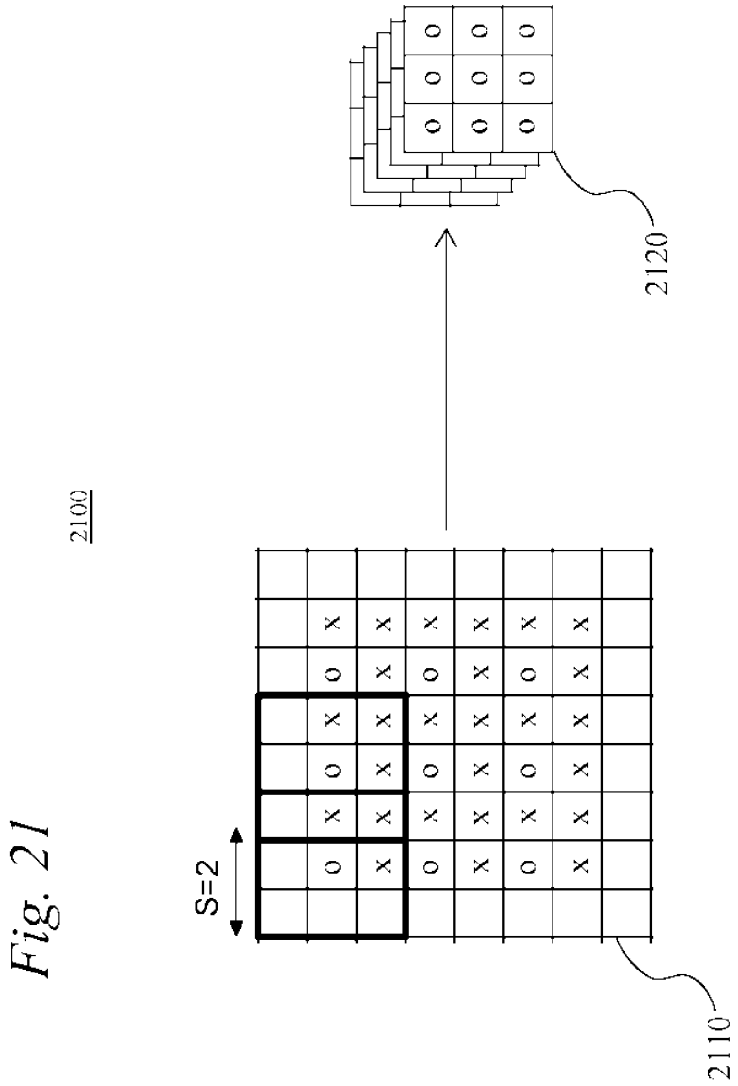


Fig. 21

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

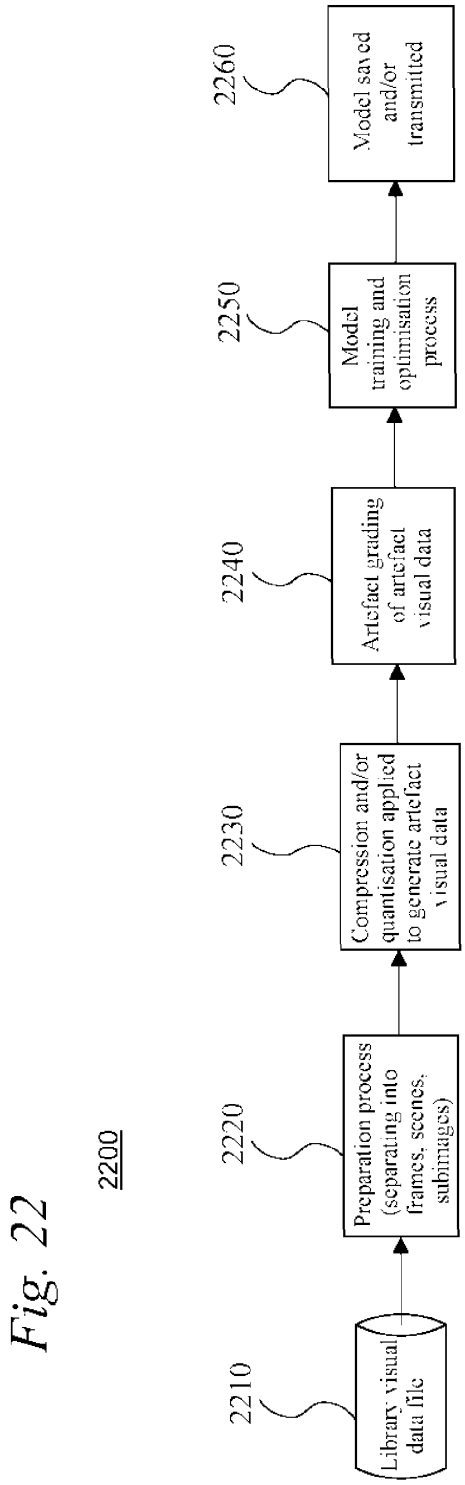


Fig. 22

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

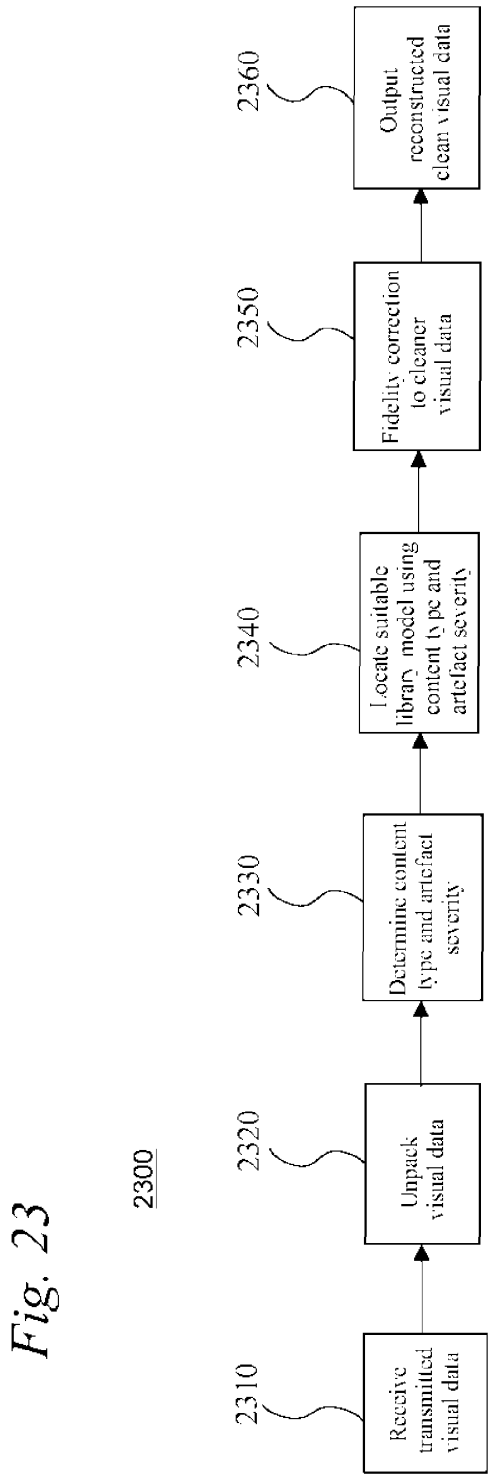
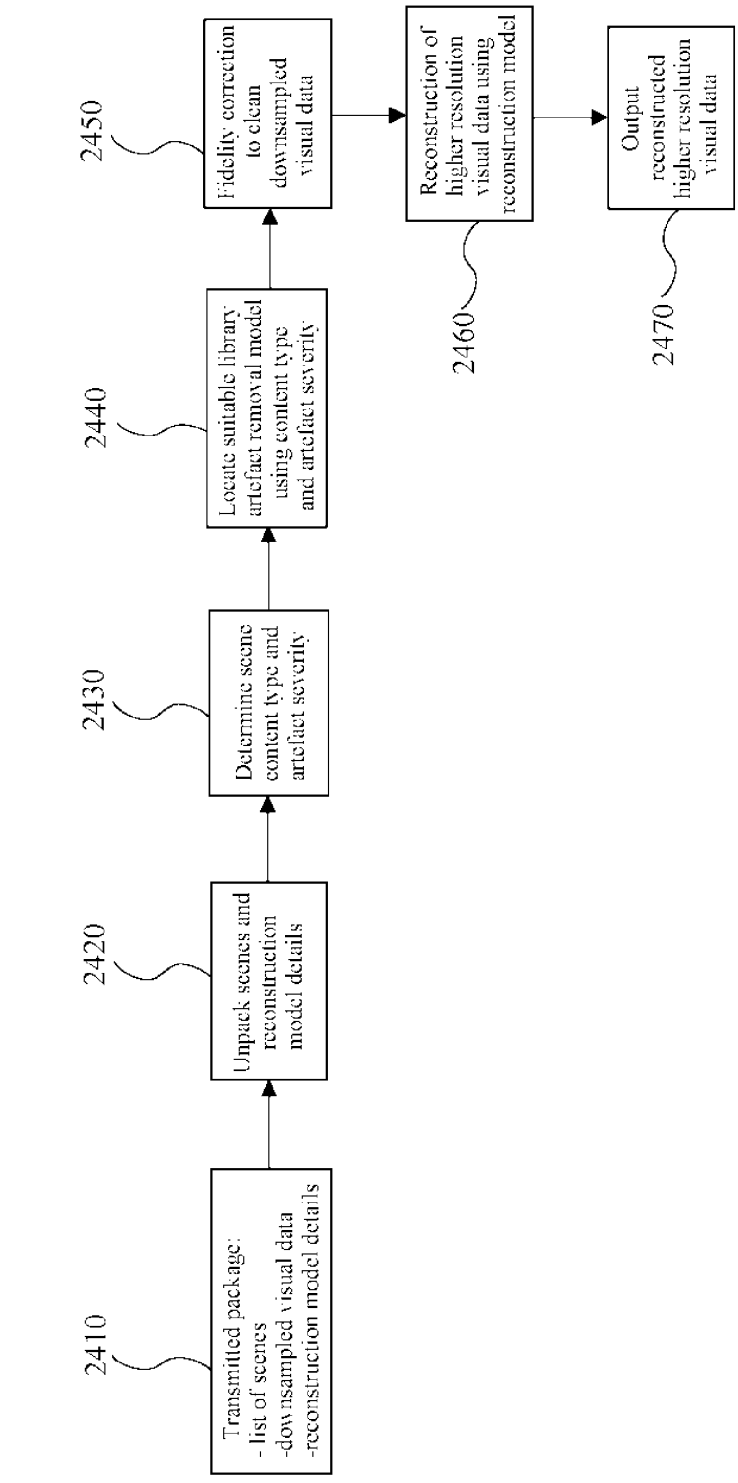


Fig. 23

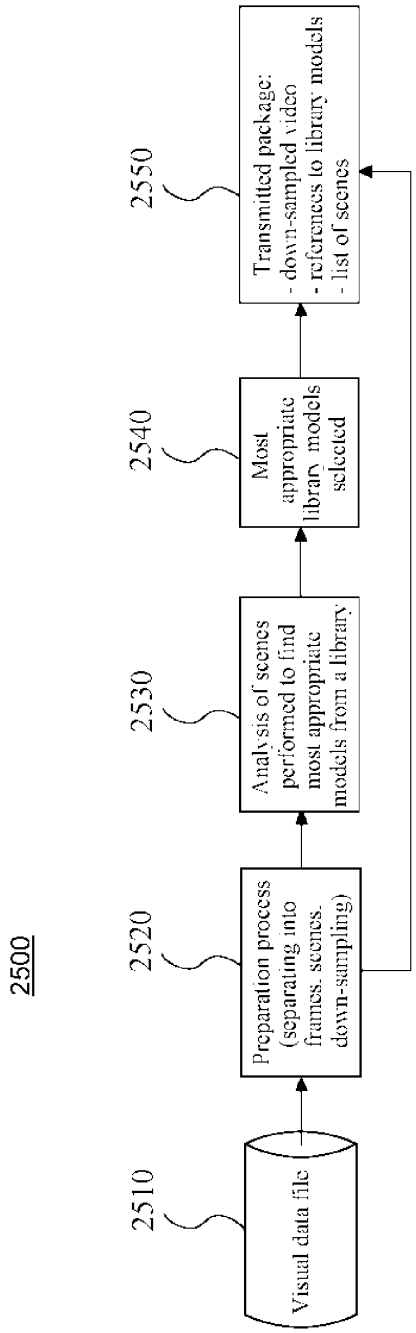
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Fig. 24



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Fig. 25



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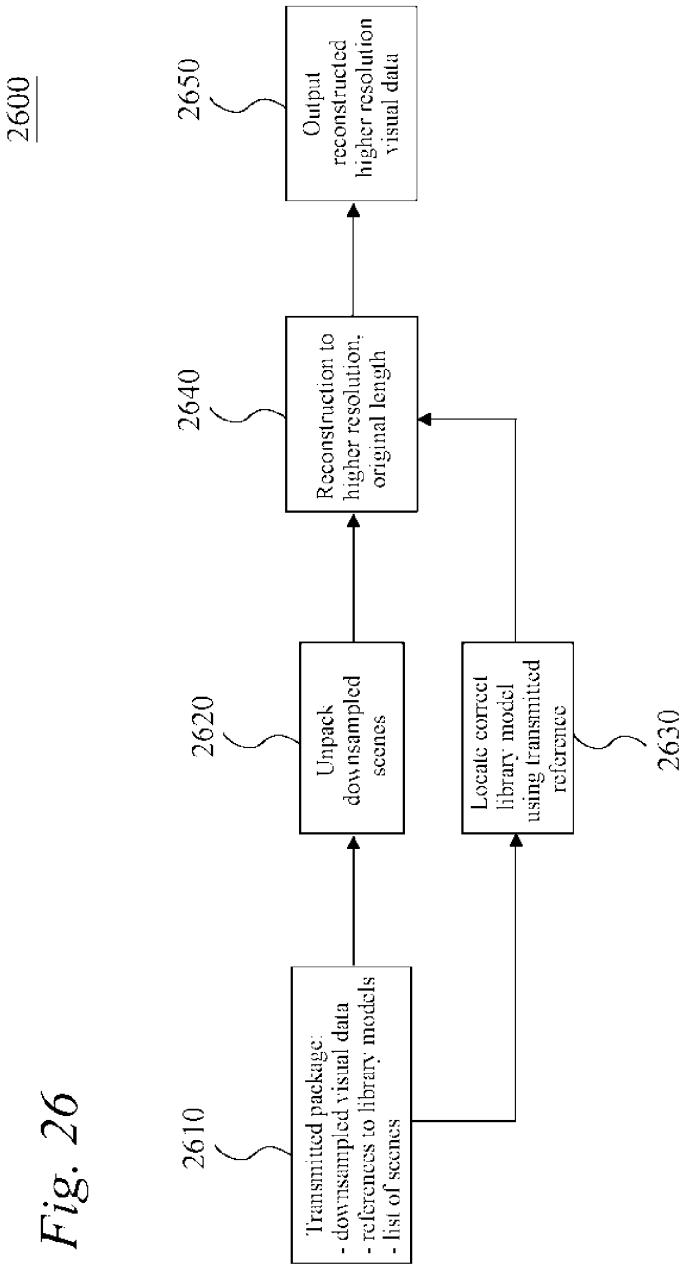


Fig. 26

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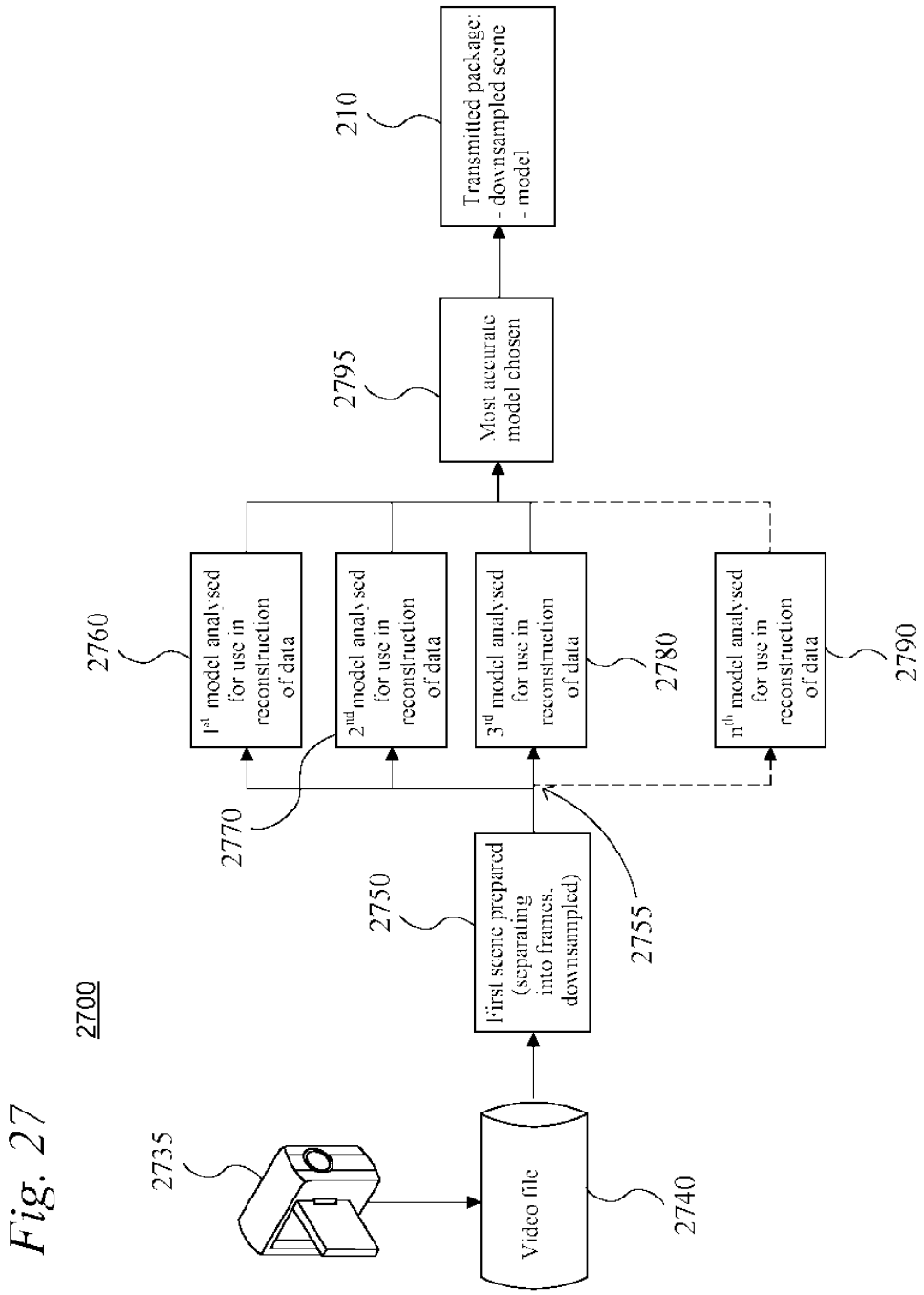


Fig. 27

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/050426

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N19/117 H04N19/177
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DONG CHAO ET AL: "Learning a Deep Convolutional Network for Image Super-Resolution", 6 September 2014 (2014-09-06), CORRECT SYSTEM DESIGN; [LECTURE NOTES IN COMPUTER SCIENCE; LECT.NOTES COMPUTER], SPRINGER INTERNATIONAL PUBLISHING, CHAM, PAGE(S) 184 - 199, XP047296566, ISSN: 0302-9743 ISBN: 978-3-642-24570-1	1-7,9, 10,12, 15,16, 32-48
Y	the whole document	8,11,13, 14,17-31

Y	US 2013/128111 A1 (CORRAL-SOTO EDUARDO R [CA]) 23 May 2013 (2013-05-23) paragraph [0027] - paragraph [0029]	8

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 May 2016	13/05/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Willems, Brigitte

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Form PCT/ISA/210 (second sheet) (April 2005)

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IPR2023-01046 - U.S. Patent No. 10,740,985

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/200757 A1 (PICA ALBERTA [US] ET AL) 15 September 2005 (2005-09-15) paragraph [0020] - paragraph [0035]; figures 1-3	11,13, 14,17-31
A	SHUYUAN YANG ET AL: "Single-Image Super-Resolution Reconstruction via Learned Geometric Dictionaries and Clustered Sparse Coding", IEEE TRANSACTIONS ON IMAGE PROCESSING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 21, no. 9, 1 September 2012 (2012-09-01), pages 4016-4028, XP011492170, ISSN: 1057-7149, DOI: 10.1109/TIP.2012.2201491 the whole document	1-39

4

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2016/050426

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013128111 A1	23-05-2013	NONE	
US 2005200757 A1	15-09-2005	US 2005200757 A1	15-09-2005
		WO 2005072337 A2	11-08-2005

Form PCT/ISA/210 (patent family annex) (April 2005)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY
(Chapter I of the Patent Cooperation Treaty)

(PCT Rule 44*bis*)

Applicant's or agent's file reference R15100420	**FOR FURTHER ACTION**	See item 4 below
International application No. PCT/RU2016/000118	International filing date *(day/month/year)* 03 March 2016 (03.03.2016)	Priority date *(day/month/year)* 20 March 2015 (20.03.2015)
International Patent Classification (8th edition unless older edition indicated) See relevant information in Form PCT/ISA/237		
Applicant AUTONOMOUS NON-PROFIT ORGANIZATION FOR HIGHER EDUCATION "SKOLKOVO INSTITUTE OF SCIENCE AND TECHNOLOGY"		

1. This international preliminary report on patentability (Chapter I) is issued by the International Bureau on behalf of the International Searching Authority under Rule 44 *bis*.1(a).

2. This REPORT consists of a total of 10 sheets, including this cover sheet.

   In the attached sheets, any reference to the written opinion of the International Searching Authority should be read as a reference to the international preliminary report on patentability (Chapter I) instead.

3. This report contains indications relating to the following items:

☒	Box No. I	Basis of the report
☐	Box No. II	Priority
☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
☐	Box No. IV	Lack of unity of invention
☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
☐	Box No. VI	Certain documents cited
☐	Box No. VII	Certain defects in the international application
☒	Box No. VIII	Certain observations on the international application

4. The International Bureau will communicate this report to designated Offices in accordance with Rules 44*bis*.3(c) and 93*bis*.1 but not, except where the applicant makes an express request under Article 23(2), before the expiration of 30 months from the priority date (Rule 44*bis* .2).

	Date of issuance of this report 26 September 2017 (26.09.2017)
The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No. +41 22 338 82 70	Authorized officer Athina Nickitas-Etienne e-mail: pct.team4@wipo.int

Form PCT/IB/373 (January 2004)

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To:

see form PCT/ISA/220

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY
(PCT Rule 43*bis*.1)

Date of mailing
(day/month/year) see form PCT/ISA/210 (second sheet)

Applicant's or agent's file reference
see form PCT/ISA/220

FOR FURTHER ACTION
See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/RU2016/000118	03.03.2016	20.03.2015

International Patent Classification (IPC) or both national classification and IPC
INV. G06K9/00 G06F3/01 G06T11/60 G06T15/04

Applicant
AUTONOMOUS NON-PROFIT ORGANIZATION FOR HIGHER...

1. This opinion contains indications relating to the following items:

- ☑ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☑ Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the international application
- ☒ Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will usually be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

Name and mailing address of the ISA:	Date of completion of this opinion	Authorized Officer
European Patent Office P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk - Pays Bas Tel. +31 70 340 - 2040 Fax: +31 70 340 - 3016	see form PCT/ISA/210	Neubüser, Bernhard Telephone No. +31 70 340-0

Form PCT/ISA/237 (Cover Sheet) (January 2015)

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Box No. I Basis of the opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☑ the international application in the language in which it was filed.

   ☐ a translation of the international application into , which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1 (b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing:

   a. ☐ forming part of the international application as filed:

      ☐ in the form of an Annex C/ST.25 text file.

      ☐ on paper or in the form of an image file.

   b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.

   c. ☐ furnished subsequent to the international filing date for the purposes of international search only:

      ☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).

      ☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that forming part of the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

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Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	3, 11
	No:	Claims	1, 2, 4-10, 12, 13
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-13
Industrial applicability (IA)	Yes:	Claims	1-13
	No:	Claims	

2. Citations and explanations

see separate sheet

Box No. VIII Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

see separate sheet

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Re item VIII

1 Articles 5 and 6 PCT, interpretation of the claims and the description.

1.1 Claim 1 lacks several essential features, and therefore is not supported by the description, contrary to the requirements of Article 6 PCT.

1.1.1 The method disclosed in the present application merely is capable of correcting *one fixed displacement offset* of the gaze direction, cf. D1, p. 3, last paragraph:

> "Furthermore, while random forests in [16] are trained for a specific angle of gaze redirection, our architecture allows the redirection angle to be specified as an input, and to change continuously in a certain range.".

Note that the authors of D1 comprise the inventors of the present patent application, and note furthermore, that reference [16] in D1 refers to D2, an scientific article of the inventors comprising the disclosure of the present application.

This set-up necessitates that the predictor is trained with training data as indicated on p. 7 of the description of the present application, namely wherein for all learning pairs *the difference in gaze direction is equal*.

This essential features is however lacking in claim 1.

1.2 Contrary to the requirements of Article 5 PCT the disclosure of the invention lacks clarity.

1.2.1 According to p. 7:

> 3). To provide a possibility of machine learning a predetermined set of pairs of images $(\mathbf{I}_j, \rho)$ is required fulfilling the following requirements: each pair of images represents a face of the same person, in the same position of a head and equal conditions of visualization, differing only by gaze direction of this person (Fig. 1).

It is unclear how the notation (I_j,ρ) relates to a set of pairs of training images. Is "j" indexing the different pairs of images? Why does ρ not have an index? The symbol "ρ" does seem to be used elsewhere in the present application.

1.2.2 According to p. 8:

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Further, images are brought to equal size. For each pair of images matching to the right eye, focusing is made on points (f_1, g_1), (f_2, g_2)... (f_N, g_N), matching to this eye in the image I^j. In article [1] number of points N is 6. It is obvious that it is not a fixed parameter. Further, axes-aligned rectangles B^j bounding points of each eye are determined, and a characteristic radius δ is defined as $\sqrt{Square(B^j)}$.

Which images are brought to equal size? What are the points (f_i, g_i) (i = 1...N)? Note that reference [1] does not mention any points (f_i, g_i), nor wording like focus point. Rather [1] mentions *landmark points.* There are however 66 landmark points in [1]. It is unclear what it means that the named points are *matching to this eye in the image I*. It is furthermore unclear what *square(B')* may be.

From the first paragraph of p. 9 or the last paragraph of p. 11, it is apparent that the points (f_i, g_i) (i = 1...N) lie on the *eye outline*. It remains unclear which points are concretely meant. Also the last paragraph of p. 11 refers to *square(B')* without any explanation of the intended meaning of this expression.

1.2.3 It is unclear what the meaning of the first paragraph of p. 13 is:

channel is compared to the threshold value as follows . The test of the second type (the test for position of pixel with respect to the characteristic point) is determined

$$i \in \{1, ..N\}$$

by the number of the feature point and the threshold value τ, and within the frames of this test either $x - f_i$ or $y - g_i$ is compared to threshold value

$$y - g_i \gtrless \frac{\alpha}{\tau}$$

τ as follows: $x - f_i \gtrless \frac{\alpha}{\tau}$ τ or τ.

1.3 Contrary to the requirements of Article 5 PCT the disclosure of the invention is not sufficiently complete.

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1.3.1 The paragraph bridging p. 8 to p. 9 appears to be a headline, indicating that the following passage will explain how the learning/training of the predictor works. This passage however does not contain enabling disclosure for the predictor learning/training. Rather, it can merely be understood that learning/ training samples of the following form are used:

$$\{(x,y), I, \{f_i,g_i \mid i= 1 \ldots N\}, O(x,y)\}.$$

The entrusted Examiner has furthermore difficulty to understand why the whole input image I is part of a training sample, while only a single pixel of the output image O, at location (x,y) is part of the sample.

Enabling disclosure for the predictor learning/training should have explained

i) which parameters of the machine learning algorithm exist,

ii) how these parameters are modified during the training/learning, in dependence on the training/learning data.

1.3.2 Although the passage p. 12 - p. 13, according to its heading, relates to the *use of the predictor*, it also represents *implicit disclosure* regarding the training of the predictor for the the specific choice that it uses a randomnized decision tree.

According to the disclosure on p. 12 the interior (i.e. non-leave) nodes of the randomnized decision tree correspond to tests. There are two types of tests.

The first type of test is called an appearance test and is determined by an offset (dx, dy) in one of the (color) channels {R,G,B} and a threshold value τ.

So, it appears that the answer to i) of the previous item is that for the first type of test the parameters are: (dx, dy), a choice c of the color channel, and a threshold value.

Although the wording "`[...], and within the frames of this test a difference of two values of pixels in this color channel is compared to the threshold value`" lacks linguistic clarity, and, contrary to the announcement "as follows" not explanations follow, it appears that the test is

$$I_c(x+d_x,y+d_y) - O_c(x,y) < \tau,$$

where $I_c(x+d_x,y+d_y)$ is the color channel c for $c \in \{R,G,B\}$, of the pixel with coordinates $(x+d_x,y+d_y)$ of image I, and $O_c(x,y)$ is the color channel c for the pixel with coordinates (x,y) of image O.

It remains however obscure what the answer to ii) above is.

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Based on a substantial amount of guessing, for the second type of test, called "test for position of pixel with respect to the characteristic point", the first paragraph of p. 13 may be interpreted to mean that the parameters, in the sense of i) above, are the index i, $i \in \{1,...,N\}$, the choice of x- or y-coordinate, and the threshold value τ.

If the x-coordinate is chosen then the test is:

$$x - f_i < \tau,$$

if the y-coordinate is chosen the test is:

$$y - g_i < \tau.$$

Again, it is (completely) obscure, how these parameters are determined based on the training/learning data. It is furthermore obscure how the type of the test is chosen.

1.4 It follows from the arguments in item 1.3 above, that only a predictor structured as a randomnized decision tree with the parameters mentioned in loc. cit. could possibly be supported by the description in the sense of Article 6 PCT. Also for this reason, claim 1 is insufficiently supported by the description as it lacks essential features.

Furthermore, claim 2 does not have any support from the description, Article 6 PCT.

1.5 According to p. 13, see last paragraph independently learned/trained decision trees may be summed together. It is unclear how such a summation is to be implemented. Different trees may have different numbers of leaf nodes. Which (pairs of) leaf nodes are combined?

1.6 The entrusted Examiner is of the opinion that the above deficiencies cannot be remedied by an amendment which does not excess beyond the contents of the application as filed.

It is noted that the teaching in D2, see section 3.2 entitled "learning" clearly exceeds the teaching of the present application regarding the learning/training of the predictor.

1.7 Claim 4 is not clear, Article 6 PCT. "The characteristic points" does not appear to have an antecedent in claim 1.

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Re item V

Assessment according to Article 33 PCT

2 The subject-matter of claim 1 is known.

2.1 Document D3 discloses (references in parenthesis applying to this document):

A method for correcting user's gaze direction in [an] image (see title). Furthermore:

"[0098] Eye-lea[r]ning is performed using a plurality of eye image pairs to transform the eye outline, and the eye outline is transformed based on the eye-learning More specifically, an eye gazing at the display unit 116 of the mobile terminal 100 (i.e., an eye gazing at a lower side) and an eye gazing at the camera 150 of the mobile terminal 100 (i.e., an eye gazing at the front side) are captured with respect to the same person, and the mobile terminal 100 learns the manner in which an eye shape is transformed in the two images."

As is apparent from §[0100] a displacement vector field is learnt from training data, the displacement vector field relating eye outline points from in a pair of images (of the same person) where the images differ in gaze direction. Inside the eye (and in between the outline points texture warping is applied to extend the mapping from the eye outline to the whole eye region.

It is implied that the generated transformation is saved.

The subject-matter of claim 1 therefore lacks novelty in the meaning of Article 33(2) PCT.

2.2 Furthermore, the subject-matter of claim 1 also lacks novelty in view of D4. The teaching of D4 largely agrees with that of D3, the main difference being a artificial neural networks are you as predictors for the displacement of the feature points on the eye contour/outline, see title, abstract, and section 2.3.

3 The additional subject-matter of claim 2 is known from D4.

4 The additional subject-matter of claim 3 is obvious to a skilled person. Decision trees are commonly known alternative for artificial neural networks.

5 As far as understood, the additional subject-matter of claim 4 is known from D4.

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6 The additional subject-matter of claim 5, apart from pertaining to common general knowledge, is known from D4: Section 2.3 discloses normalization of feature point coordinates.

7 Since claim 6 exhaustively lists potentially used storage technologies, the additional matter of claim 6 is implicitly disclosed in D3 or D4.

8 The additional subject-matter of claim 7 is known from D4, see section 3.

9 The additional subject-matter of claim 8 is known from D4: Evidently, the ANN is used as trained.

10 Similar to the situation in claim 6 the additional subject-matter of claim 9 is implied in D3 or D4.

11 The additional subject-matter of claim 10 is known from D4.

12 The additional subject-matter of claim 11 is obvious to a skilled person. Decision trees are commonly known alternative for artificial neural networks.

13 The predictor disclosed in D4 meets the requirements listed in claim 12. Therefore, the additional subject-matter of claim 12 is known from D4.

14 It appears that the additional subject-matter of claim 13 is implied by D4. The normalization of the coordinates of the feature points appears to have the effect mentioned. The additional subject-matter of claim 13 is therefore known from D4.

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PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION**	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
R15100420		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/RU2016/000118	3 March 2016 (03-03-2016)	20 March 2015 (20-03-2015)
Applicant		
AUTONOMOUS NON-PROFIT ORGANIZATION FOR HIGHER...		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 4 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of:
      [X] the international application in the language in which it was filed
      [ ] a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))
   b. [ ] This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).
   c. [ ] With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. [ ] **Certain claims were found unsearchable** (See Box No. II)

3. [ ] **Unity of invention is lacking** (see Box No III)

4. With regard to the **title**,
   [X] the text is approved as submitted by the applicant
   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,
   [X] the text is approved as submitted by the applicant
   [ ] the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority

6. With regard to the **drawings**,
   a. the figure of the **drawings** to be published with the abstract is Figure No. 2
      [ ] as suggested by the applicant
      [X] as selected by this Authority, because the applicant failed to suggest a figure
      [ ] as selected by this Authority, because this figure better characterizes the invention
   b. [ ] none of the figures is to be published with the abstract

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

INTERNATIONAL SEARCH REPORT

International application No
PCT/RU2016/000118

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K9/00 G06F3/01 G06T11/60 G06T15/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06K G06F G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
T	Yaroslav Ganin ET AL: "DeepWarp: Photorealistic Image Resynthesis for Gaze Manipulation", , 25 July 2016 (2016-07-25), XP055295123, Retrieved from the Internet: URL:http://arxiv.org/pdf/1607.07215v2.pdf [retrieved on 2016-08-15] the whole document ----- -/--	1-13

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 August 2016	25/08/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Neubüser, Bernhard

Form PCT/ISA/210 (second sheet) (April 2005)

Microsoft Exhibit 1002 - Page 272
Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

INTERNATIONAL SEARCH REPORT

International application No
PCT/RU2016/000118

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
T	KONONENKO DANIIL ET AL: "Learning to look up: Realtime monocular gaze correction using machine learning", 2015 IEEE CONFERENCE ON COMPUTER VISION AND PATTERN RECOGNITION (CVPR), IEEE, 7 June 2015 (2015-06-07), pages 4667-4675, XP032793924, DOI: 10.1109/CVPR.2015.7299098 [retrieved on 2015-10-14] the whole document -----	1-13
X	US 2014/016871 A1 (SON BYUNG-JUN [KR] ET AL) 16 January 2014 (2014-01-16) paragraph [0098] - paragraph [0115] -----	1
X	YIP B: "Face and Eye Rectification in Video Conference Using Artificial Neural Network", IEEE INTERNATIONAL CONFERENCE ON MULTIMEDIA AND EXPO, 2005. ICME 2005. AMSTERDAM, THE NETHERLANDS, 06-08 JULY 2005, IEEE, PISCATAWAY, NJ, USA, 6 July 2005 (2005-07-06), pages 690-693, XP010844250, DOI: 10.1109/ICME.2005.1521517 ISBN: 978-0-7803-9331-8 the whole document -----	1-13

1

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

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IPR2023-01046 - U.S. Patent No. 10,740,985

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/RU2016/000118

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014016871 A1	16-01-2014	KR 20140010541 A	27-01-2014
		US 2014016871 A1	16-01-2014
		US 2015339512 A1	26-11-2015

Form PCT/ISA/210 (patent family annex) (April 2005)

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To:

see form PCT/ISA/220

PCT

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing
(day/month/year) see form PCT/ISA/210 (second sheet)

Applicant's or agent's file reference
see form PCT/ISA/220

FOR FURTHER ACTION
See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/RU2016/000118	03.03.2016	20.03.2015

International Patent Classification (IPC) or both national classification and IPC
INV. G06K9/00 G06F3/01 G06T11/60 G06T15/04

Applicant
AUTONOMOUS NON-PROFIT ORGANIZATION FOR HIGHER...

1. This opinion contains indications relating to the following items:

- ☑ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☑ Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the international application
- ☒ Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will usually be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

Name and mailing address of the ISA:	Date of completion of this opinion	Authorized Officer
European Patent Office P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk - Pays Bas Tel. +31 70 340 - 2040 Fax: +31 70 340 - 3016	see form PCT/ISA/210	Neubüser, Bernhard Telephone No. +31 70 340-0

Form PCT/ISA/237 (Cover Sheet) (January 2015)

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IPR2023-01046 - U.S. Patent No. 10,740,985

Box No. I Basis of the opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☑ the international application in the language in which it was filed.

   ☐ a translation of the international application into , which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1 (b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing:

   a. ☐ forming part of the international application as filed:

      ☐ in the form of an Annex C/ST.25 text file.

      ☐ on paper or in the form of an image file.

   b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.

   c. ☐ furnished subsequent to the international filing date for the purposes of international search only:

      ☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).

      ☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that forming part of the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

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Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	3, 11
	No:	Claims	1, 2, 4-10, 12, 13
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-13
Industrial applicability (IA)	Yes:	Claims	1-13
	No:	Claims	

2. Citations and explanations

see separate sheet

Box No. VIII Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

see separate sheet

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Re item VIII

1 Articles 5 and 6 PCT, interpretation of the claims and the description.

1.1 Claim 1 lacks several essential features, and therefore is not supported by the description, contrary to the requirements of Article 6 PCT.

1.1.1 The method disclosed in the present application merely is capable of correcting *one fixed displacement offset* of the gaze direction, cf. D1, p. 3, last paragraph:

> "Furthermore, while random forests in [16] are trained for a specific angle of gaze redirection, our architecture allows the redirection angle to be specified as an input, and to change continuously in a certain range.".

Note that the authors of D1 comprise the inventors of the present patent application, and note furthermore, that reference [16] in D1 refers to D2, an scientific article of the inventors comprising the disclosure of the present application.

This set-up necessitates that the predictor is trained with training data as indicated on p. 7 of the description of the present application, namely wherein for all learning pairs *the difference in gaze direction is equal.*

This essential features is however lacking in claim 1.

1.2 Contrary to the requirements of Article 5 PCT the disclosure of the invention lacks clarity.

1.2.1 According to p. 7:

> 3). To provide a possibility of machine learning a predetermined set of pairs of images $(\mathbf{I}_j, \rho)$ is required fulfilling the following requirements: each pair of images represents a face of the same person, in the same position of a head and equal conditions of visualization, differing only by gaze direction of this person (Fig. 1).

It is unclear how the notation (I_j,ρ) relates to a set of pairs of training images. Is "j" indexing the different pairs of images? Why does ρ not have an index? The symbol "ρ" does seem to be used elsewhere in the present application.

1.2.2 According to p. 8:

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Further, images are brought to equal size. For each pair of images matching to the right eye, focusing is made on points (f_1, g_1), (f_2, g_2)... (f_N, g_N), matching to this eye in the image I^j. In article [1] number of points N is 6. It is obvious that it is not a fixed parameter. Further, axes-aligned rectangles B^j bounding points of each eye are determined, and a characteristic radius Δ is defined as $\sqrt{Square(B^j)}$.

Which images are brought to equal size? What are the points (f_i, g_i) (i = 1...N)? Note that reference [1] does not mention any points (f_i, g_i), nor wording like focus point. Rather [1] mentions *landmark points*. There are however 66 landmark points in [1]. It is unclear what it means that the named points are *matching to this eye in the image I*. It is furthermore unclear what *square(B')* may be.

From the first paragraph of p. 9 or the last paragraph of p. 11, it is apparent that the points (f_i, g_i) (i = 1...N) lie on the *eye outline*. It remains unclear which points are concretely meant. Also the last paragraph of p. 11 refers to *square(B')* without any explanation of the intended meaning of this expression.

1.2.3 It is unclear what the meaning of the first paragraph of p. 13 is:

channel is compared to the threshold value as follows . The test of the second type (the test for position of pixel with respect to the characteristic point) is determined

$$i \in \{1, \ldots N\}$$

by the number of the feature point and the threshold value τ, and within the frames of this test either $x - f_i$ or $y - g_i$ is compared to threshold value

$$y - g_i > \frac{\alpha}{\tau}$$

τ as follows: $x - f_i > \frac{\alpha}{\tau}$ τ or τ.

1.3 Contrary to the requirements of Article 5 PCT the disclosure of the invention is not sufficiently complete.

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1.3.1 The paragraph bridging p. 8 to p. 9 appears to be a headline, indicating that the following passage will explain how the learning/training of the predictor works. This passage however does not contain enabling disclosure for the predictor learning/training. Rather, it can merely be understood that learning/ training samples of the following form are used:

$$(x,y), I, \{f_i,g_i \mid i= 1 \ldots N\}, O(x,y)).$$

The entrusted Examiner has furthermore difficulty to understand why the whole input image I is part of a training sample, while only a single pixel of the output image O, at location (x,y) is part of the sample.

Enabling disclosure for the predictor learning/training should have explained

i) which parameters of the machine learning algorithm exist,

ii) how these parameters are modified during the training/learning, in dependence on the training/learning data.

1.3.2 Although the passage p. 12 - p. 13, according to its heading, relates to the *use of the predictor*, it also represents *implicit disclosure* regarding the training of the predictor for the the specific choice that it uses a randomnized decision tree.

According to the disclosure on p. 12 the interior (i.e. non-leave) nodes of the randomnized decision tree correspond to tests. There are two types of tests.

The first type of test is called an appearance test and is determined by an offset (dx, dy) in one of the (color) channels {R,G,B} and a threshold value τ.

So, it appears that the answer to i) of the previous item is that for the first type of test the parameters are: (dx, dy), a choice c of the color channel, and a threshold value.

Although the wording "`(...), and within the frames of this test a difference of two values of pixels in this color channel is compared to the threshold value`" lacks linguistic clarity, and, contrary to the announcement "as follows" not explanations follow, it appears that the test is

$$I_c(x+d_x,y+d_y) - O_c(x,y) < \tau,$$

where $I_c(x+d_x,y+d_y)$ is the color channel c for $c \in \{R,G,B\}$, of the pixel with coordinates $(x+d_x,y+d_y)$ of image I, and $O_c(x,y)$ is the color channel c for the pixel with coordinates (x,y) of image O.

It remains however obscure what the answer to ii) above is.

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Based on a substantial amount of guessing, for the second type of test, called "test for position of pixel with respect to the characteristic point", the first paragraph of p. 13 may be interpreted to mean that the parameters, in the sense of i) above, are the index i, $i \in \{1,...,N\}$, the choice of x- or y-coordinate, and the threshold value τ.

If the x-coordinate is chosen then the test is:

$$x - f_i < \tau,$$

if the y-coordinate is chosen the test is:

$$y - g_i < \tau.$$

Again, it is (completely) obscure, how these parameters are determined based on the training/learning data. It is furthermore obscure how the type of the test is chosen.

1.4 It follows from the arguments in item 1.3 above, that only a predictor structured as a randomnized decision tree with the parameters mentioned in loc. cit. could possibly be supported by the description in the sense of Article 6 PCT. Also for this reason, claim 1 is insufficiently supported by the description as it lacks essential features.

Furthermore, claim 2 does not have any support from the description, Article 6 PCT.

1.5 According to p. 13, see last paragraph independently learned/trained decision trees may be summed together. It is unclear how such a summation is to be implemented. Different trees may have different numbers of leaf nodes. Which (pairs of) leaf nodes are combined?

1.6 The entrusted Examiner is of the opinion that the above deficiencies cannot be remedied by an amendment which does not excess beyond the contents of the application as filed.

It is noted that the teaching in D2, see section 3.2 entitled "learning" clearly exceeds the teaching of the present application regarding the learning/training of the predictor.

1.7 Claim 4 is not clear, Article 6 PCT. "The characteristic points" does not appear to have an antecedent in claim 1.

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Re item V

Assessment according to Article 33 PCT

2 The subject-matter of claim 1 is known.

2.1 Document D3 discloses (references in parenthesis applying to this document):

A method for correcting user's gaze direction in [an] image (see title). Furthermore:

"[0098] Eye-lea[r]ning is perfoomed using a plurality of eye image pairs to transform the eye outline, and the eye outline is transformed based on the eye-learning More specifically, an eye gazing at the display unit 116 of the mobile terminal 100 (i.e., an eye gazing at a lower side) and an eye gazing at the camera 150 of the mobile terminal 100 (i.e., an eye gazing at the front side) are captured with respect to the same person, and the mobile terminal 100 learns the manner in which an eye shape is transformed in the two images."

As is apparent from §[0100] a displacement vector field is learnt from training data, the displacement vector field relating eye outline points from in a pair of images (of the same person) where the images differ in gaze direction. Inside the eye (and in between the outline points texture warping is applied to extend the mapping from the eye outline to the whole eye region.

It is implied that the generated transformation is saved.

The subject-matter of claim 1 therefore lacks novelty in the meaning of Article 33(2) PCT.

2.2 Furthermore, the subject-matter of claim 1 also lacks novelty in view of D4. The teaching of D4 largely agrees with that of D3, the main difference being a artificial neural networks are you as predictors for the displacement of the feature points on the eye contour/outline, see title, abstract, and section 2.3.

3 The additional subject-matter of claim 2 is known from D4.

4 The additional subject-matter of claim 3 is obvious to a skilled person. Decision trees are commonly known alternative for artificial neural networks.

5 As far as understood, the additional subject-matter of claim 4 is known from D4.

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6 The additional subject-matter of claim 5, apart from pertaining to common general knowledge, is known from D4: Section 2.3 discloses normalization of feature point coordinates.

7 Since claim 6 exhaustively lists potentially used storage technologies, the additional matter of claim 6 is implicitly disclosed in D3 or D4.

8 The additional subject-matter of claim 7 is known from D4, see section 3.

9 The additional subject-matter of claim 8 is known from D4: Evidently, the ANN is used as trained.

10 Similar to the situation in claim 6 the additional subject-matter of claim 9 is implied in D3 or D4.

11 The additional subject-matter of claim 10 is known from D4.

12 The additional subject-matter of claim 11 is obvious to a skilled person. Decision trees are commonly known alternative for artificial neural networks.

13 The predictor disclosed in D4 meets the requirements listed in claim 12. Therefore, the additional subject-matter of claim 12 is known from D4.

14 It appears that the additional subject-matter of claim 13 is implied by D4. The normalization of the coordinates of the feature points appears to have the effect mentioned. The additional subject-matter of claim 13 is therefore known from D4.

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
LOWRY, PENNY L.

5700 FLATIRON PARKWAY BOULDER CO 80301 USA

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)* 18 April 2017 (18.04.2017)
Applicant's or agent's file reference 388002	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. **PCT/US2017/012203**	International filing date *(day/month/year)* **04 January 2017 (04.01.2017)**

Applicant

REALD SPARK, LLC

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

Filing of amendments and statement under Article 19:

The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46).

When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

How? Directly to the International Bureau of WIPO preferably through ePCT or on paper to, 34 chemin des Colombettes 1211 Geneva 20, Switzerland. Facsimile No.: +41 22 338 82 70

For more detailed instructions, see *PCT Applicant's Guide*, International Phase, paragraphs 9.004 . 9-011.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to any protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

☐ the protest together with the decision thereon has been transmitted to the International Bureau together with any request to forward the texts of both the protest and the decision thereon to the designated Offices.

☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

The applicant may submit comments on an informal basis on the written opinion of the International Searching Authority to the International Bureau. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established. Following the expiration of 30 months from the priority date, these comments will also be made available to the public.

Shortly after the expiration of **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau before the completion of the technical preparations for international publication (Rules 90*bis*.1 and 90*bis*.3).

Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices. In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months. For details about the applicable time limits, Office by Office, see www.wipo.int/pct/en/texts/time_limits.html and the *PCT Applicant's Guide*, National Chapters.

Within **19 months** from the priority date, the applicant may request that a supplementary international search be carried out by an International Searching Authority, that offers this service (Rule 45*bis*.1). The procedure for requesting supplementary international search is described in the *PCT Applicant's Guide*, International Phase, paragraphs 8.006-8.032.

Name and mailing address of the ISA/KR International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea	Authorized officer COMMISSIONER
Facsimile No. 82-42-481-8578	Telephone No. 82-42-481-5875

Form PCT/ISA/220 (July 2014)

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

* Attention

Copies of the documents cited in the international search report can be searched in the following Korean Intellectual Property Office English website for six months(expire date : **2017.10.18**) from the date of mailing of the international search report.

http://www.kipo.go.kr/en/ => PCT Services => PCT Services

ID : PCT international application number
PW : **9Y822634**

Inquiries related to PCT International Search Report or Written Opinion prepared by KIPO as an International Searching Authority can be answered not only by KIPO but also through IPKC (Intellectual Property Korea Center), located in Vienna, VA, which functions as a PCT Help Desk for PCT applicants.

Homepage: http://www.ipkcenter.com

Email: ipkc@ipkcenter.com

Notes to Form PCT/ISA/220 (July 2014)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 388002	FOR FURTHER ACTION	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. **PCT/US2017/012203**	International filing date *(day/month/year)* **04 January 2017 (04.01.2017)**	(Earliest) Priority Date *(day/month/year)* 05 January 2016 (05.01.2016)

Applicant

REALD SPARK, LLC

This International search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of **4** sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of :
      ☒ the international application in the language in which it was filed
      ☐ a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))
   b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).
   c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.
2. ☒ **Certain claims were found unsearchable** (See Box No. II)
3. ☐ **Unity of invention is lacking** (See Box No. III)
4. With regard to the **title,**
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established by this Authority to read as follows:
5. With regard to the **abstract,**
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. With regard to the drawings,
   a. the figure of the **drawings** to be published with the abstract is Figure No. **2**
      ☒ as suggested by the applicant.
      ☐ as selected by this Authority, because the applicant failed to suggest a figure.
      ☐ as selected by this Authority, because this figure better characterizes the invention.
   b. ☐ none of the figures is to be published with the abstract.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/012203

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 15
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claim 15 is not clear, contrary to the requirement of PCT Article 6, because it refers to a claim which does not comply with PCT Rule 6.4(a).

3. ☒ Claims Nos.: 9-14,19
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
☐ No protest accompanied the payment of additional search fees.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/012203

A. CLASSIFICATION OF SUBJECT MATTER

H04N 13/04(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04N 13/04; G06K 9/00; G06K 9/60; G06T 7/20; A61B 3/14; H04N 7/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: gaze, camera, multi-view, vector, reference

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015-0339512 A1 (SAMSUNG ELECTRONICS CO., LTD. et al.) 26 November 2015 See paragraphs [0062], [0096]-[0098]; claims 1-11; and figures 1-22.	1-7,16-18
Y		8
Y	US 8942434 B1 (KENNETH M. KARAKOTSIOS et al.) 27 January 2015 See column 4, line 33-column 8, line 38; claims 1-5; and figures 1-11.	8
A	US 2014-0267584 A1 (FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.) 18 September 2014 See paragraphs [0026]-[0054]; claims 1-11; and figures 1-7.	1-8,16-18
A	US 2012-0219180 A1 (MEHRA SUMAT) 30 August 2012 See paragraphs [0096]-[0107]; claims 1-12; and figures 1A-5B.	1-8,16-18
A	JP 2007-100256 A (EYEMATIC INTERFACES INC.) 26 April 2007 See paragraphs [0012]-[0031]; claim 1; and figures 1-5.	1-8,16-18

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 April 2017 (17.04.2017)	**18 April 2017 (18.04.2017)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
AHN, Jeong Hwan
Telephone No. +82-42-481-8633

Form PCT/ISA/210 (second sheet) (January 2015)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2017/012203

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015-0339512 A1	26/11/2015	KR 10-2014-0010541 A	27/01/2014
		US 2014-0016871 A1	16/01/2014
		US 9111171 B2	18/08/2015
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US 8942434 B1	27/01/2015	None	
US 2014-0267584 A1	18/09/2014	US 9521362 B2	13/12/2016
		WO 2013-079607 A1	06/06/2013
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JP 2007-109255 A	26/04/2007	AU 1999-34904 A1	01/11/1999
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		CA 2326816 A1	21/10/1999
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		EP 1580684 B1	31/12/2008
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		US 2002-0015512 A1	07/02/2002
		US 2002-0031253 A1	14/03/2002
		US 2002-0067362 A1	06/06/2002
		US 2002-0118196 A1	29/08/2002
		US 2003-0007666 A1	09/01/2003
		US 2003-0031381 A1	13/02/2003
		US 6272231 B1	07/08/2001
		US 6301370 B1	09/10/2001
		US 6580811 B2	17/06/2003
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		US 6940454 B2	06/09/2005
		US 7050624 B2	23/05/2006
		US 7060655 B2	23/05/2006
		WO 99-53427 A1	21/10/1999
		WO 99-53430 A1	21/10/1999
		WO 99-53443 A1	21/10/1999

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PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To:
LOWRY, PENNY L.

5700 FLATIRON PARKWAY BOULDER CO 80301 USA

PCT

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43bis.1)

Date of mailing *(day/month/year)*	**18 April 2017 (18.04.2017)**
Applicant's or agent's file reference 388002	**FOR FURTHER ACTION** See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US2017/012203	**04 January 2017 (04.01.2017)**	05 January 2016 (05.01.2016)

International Patent Classification (IPC) or both national classification and IPC

H04N 13/04(2006.01)i

Applicant
REALD SPARK, LLC

1. This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☒ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement under Rule 43bis.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☒ Box No. VII Certain defects in the international application
- ☐ Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1bis(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.
For further options, see Form PCT/ISA/220.

Name and mailing address of the ISA/KR	Date of completion of this opinion	Authorized officer
International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea Facsimile No. +82-42-481-8578	17 April 2017 (17.04.2017)	AHN, Jeong Hwan Telephone No. +82-42-481-8633

Form PCT/ISA/237 (cover sheet) (January 2015)

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US2017/012203

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of :

   ☒ the international application in the language in which it was filed

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing:

   a. ☐ forming part of the international application as filed:
      ☐ in the form of an Annex C/ST.25 text file.
      ☐ on paper or in the form of an image file.

   b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.

   c. ☐ furnished subsequent to the international filing date for the purposes of international search only:
      ☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).
      ☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that forming part of the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US2017/012203

Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non obvious), or to be industrially applicable have not been examined in respect of:

☐ the entire international application

☒ claims Nos. 9-15,19

because:

☐ the said international application, or the said claims Nos. _____
relate to the following subject matter which does not require an international search *(specify)*:

☒ the description, claims or drawings *(indicate particular elements below)* or said claims Nos. 15
are so unclear that no meaningful opinion could be formed *(specify)*:

Claim 15 is not clear, contrary to the requirement of PCT Article 6, because it refers to a claim which does not comply with PCT Rule 6.4(a).

☐ the claims, or said claims Nos. _____ are so inadequately supported by the description that no meaningful opinion could be formed *(specify)*:

☒ no international search report has been established for said claims Nos. 9-15,19

☐ a meaningful opinion could not be formed without the sequence listing; the applicant did not, within the prescribed time limit:

☐ furnish a sequence listing in the form of an Annex C/ST.25 text file, and such listing was not available to the International Searching Authority in the form and manner acceptable to it; or the sequence listing furnished did not comply with the standard provided for in Annex C of the Administrative Instructions.

☐ furnish a sequence listing on paper or in the form of an image file complying with the standard provided for in Annex C of the Administrative Instructions, and such listing was not available to the International Searching Authority in the form and manner acceptable to it; or the sequence listing furnished did not comply with the standard provided for in Annex C of the Administrative Instructions.

☐ pay the required late furnishing fee for the furnishing of a sequence listing in response to an invitation under Rule 13*ter*.1(a) or (b).

☐ See Supplemental Box for further details.

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
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Box No. V Reasoned statement under Rule 43bis.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	1-8,16-18	YES
	Claims	NONE	NO
Inventive step (IS)	Claims	NONE	YES
	Claims	1-8,16-18	NO
Industrial applicability (IA)	Claims	1-8,16-18	YES
	Claims	NONE	NO

2. Citations and explanations :

Reference is made to the following documents:

D1: US 2015-0339512 A1 (SAMSUNG ELECTRONICS CO., LTD. et al.) 26 November 2015
D2: US 8942434 B1 (KENNETH M. KARAKOTSIOS et al.) 27 January 2015

1. Novelty and Inventive Step

1.1. Independent Claim 1

D1, which is considered to be the closest prior art to the subject matter of claim 1, discloses a method of correcting a gaze of a user in an image, the method comprising:
providing a controller (160) that detects a face gaze direction (or an angle of a face) and/or a gradient of a face, and determines whether the detected facial image gazes at a front side, a left side, a right side, an upper side, a lower side, or a diagonal side (a top-left side, a top-right side, a bottom-left side, or a bottom-right side) (see paragraph [0097] and figure 1 in D1); and
detecting first eye outer points by extracting eye model shape parameters of the first eye outer points associated with eigen vectors of the eye model, and limiting a range of each of the extracted eye model shape parameters (see claim 3 in D1).

Claim 1 differs from D1 in deriving a displacement vector field representing a transformation of an image patch, using a derived feature vector to look up reference data comprising reference displacement vector fields associated with possible values of the feature vector, and adjusting each image of multi-view images by transforming image patches containing the left and right eyes of a head in accordance with the derived displacement vector field.

Continued on Supplemental Box

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WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US2017/012203

Box No. VII Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

Claims 9-14 and 19 do not comply with PCT Rule 6.4(a) because multiple dependent claims should not serve as a basis for any other multiple dependent claim.

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Supplemental Box

In case the space in any of the preceding boxes is not sufficient.
Continuation of : Box No. V

However, the difference can be easily conceived from the features of D1 considering providing a controller (160) that transforms (or modifies) the first eye outline in a camera gaze direction corresponding to a gaze at the camera (150), wherein the controller (160) changes eye outer points of an eye region in a user image in a predetermined reference camera gaze direction, and wherein the controller (160) transforms eye outer points defining an eye outline, based on a difference between a face gaze direction of a user in a current image (i.e., an angle or a gradient of a face) and the predetermined reference camera gaze direction (i.e., an angle or a gradient of a face) (see paragraph [0096] and figure 1 in D1), and shifting each first eye outer point to a location obtained by adding a coordinate of each first eye outer point to an average displacement between an eye gazing at a lower side and an eye gazing at a front side (see claim 5 in D1). Accordingly, claim 1 would have been obvious over D1. Therefore, claim 1 lacks an inventive step under PCT Article 33(3).

1.2. Dependent Claims 2-7

The additional feature of claim 2 can be easily conceived from the features of D1 considering that a controller (160) changes eye outer points of an eye region in a user image in a predetermined reference camera gaze direction, wherein the controller (160) transforms eye outer points defining an eye outline, based on a difference between a face gaze direction of a user in a current image (i.e., an angle or a gradient of a face) and the predetermined reference camera gaze direction (see paragraph [0096] and figure 1 in D1).

The additional features of claims 3-4 are merely variations of the disclosures of D1 considering providing a controller (160) that transforms (or modifies) the first eye outline in a camera gaze direction corresponding to a gaze at the camera (150), wherein the controller (160) changes eye outer points of an eye region in a user image in a predetermined reference camera gaze direction, and wherein the controller (160) transforms eye outer points defining an eye outline, based on a difference between a face gaze direction of a user in a current image (i.e., an angle or a gradient of a face) and the predetermined reference camera gaze direction (i.e., an angle or a gradient of a face) (see paragraph [0096] and figure 1 in D1), detecting the first eye outer points by extracting eye model shape parameters of the first eye outer points associated with eigen vectors of the eye model, and limiting a range of each of the extracted eye model shape parameters (see claim 3 in D1), and shifting each first eye outer point to a location obtained by adding a coordinate of each first eye outer point to an average

Continued on The Next Page

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Supplemental Box

In case the space in any of the preceding boxes is not sufficient.
Continuation of : Previous Page

displacement between an eye gazing at a lower side and an eye gazing at a front side (see claim 5 in D1).

The additional feature of claim 5 is merely a variation of the disclosure of D1 considering that eye-leaning is performed using a plurality of eye image pairs to transform the eye outline, and the eye outline is transformed based on the eye-learning (see paragraph [0098] in D1), and that the second eye outer points correspond to a direction corresponding to a gaze facing straight onto a camera of a device (see claim 4 in D1).

The additional feature of claim 6 is merely a variation of the disclosure of D1 considering performing eye-leaning using a plurality of eye image pairs to transform the eye outline, and the eye outline is transformed based on the eye-learning (see paragraph [0098] in D1), and detecting first eye outer points by extracting eye model shape parameters of the first eye outer points associated with eigen vectors of the eye model, and limiting a range of each of the extracted eye model shape parameters (see claim 3 in D1).

The additional feature of claim 7 can be easily conceived from the features of D1 considering providing a controller (160) that transforms (or modifies) the first eye outline in a camera gaze direction corresponding to a gaze at the camera (150), wherein the controller (160) changes eye outer points of an eye region in a user image in a predetermined reference camera gaze direction, and wherein the controller (160) transforms eye outer points defining an eye outline, based on a difference between a face gaze direction of a user in a current image (i.e., an angle or a gradient of a face) and the predetermined reference camera gaze direction (i.e., an angle or a gradient of a face) (see paragraph [0096] and figure 1 in D1), and shifting each first eye outer point to a location obtained by adding a coordinate of each first eye outer point to an average displacement between an eye gazing at a lower side and an eye gazing at a front side (see claim 5 in D1).

Accordingly, claims 2-7 would have been obvious over D1. Therefore, claims 2-7 lack an inventive step under PCT Article 33(3).

1.3. Dependent Claim 8

The additional feature of claim 8 can be easily conceived from the features of D2 considering

Continued on The Next Page

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Supplemental Box

In case the space in any of the preceding boxes is not sufficient.
Continuation of : Previous Page

that the computer-implemented method comprises determining a first estimated pupil location using a first pupil location determination algorithm, the first pupil determination algorithm returning a first confidence value corresponding to the first estimated pupil location (see claim 4 in D2), and that the first estimated pupil location and the second estimated pupil location corresponds to at least one of a pixel location, a vector, or an estimated set of coordinates (see claim 5 in D2). Accordingly, claim 8 would have been obvious over D1 in view of D2. Therefore, claim 8 lacks an inventive step under PCT Article 33(3).

1.4. Independent Claim 16

Claim 16 relates to a device, but it shares the same technical features as claim 1. Accordingly, since the same reasoning as in claim 1 applies to claim 16, claim 16 would have been obvious over D1. Therefore, claim 16 lacks an inventive step under PCT Article 33(3).

1.5. Dependent Claims 17-18

The additional feature of claim 17 can be easily conceived from the feature of D1 considering a camera for capturing an original image (see claim 11 in D1).

The additional feature of claim 18 can be easily conceived from the feature of D1 considering that a controller (160) performs a video call with a partner mobile terminal using the communication unit (140), the user interface (110), and the camera (150), and performs a gaze correction processing with respect to an original user image input from the camera (150), and transmits, to the partner mobile terminal through the communication unit (140), a gaze-corrected user image and a voice signal of the user received through the microphone (114) (see paragraph [0062] and figure 1 in D1).

Accordingly, claims 17-18 would have been obvious over D1. Therefore, claims 17-18 lack an inventive step under PCT Article 33(3).

2. Industrial Applicability

Claims 1-8 and 16-18 are industrially applicable under PCT Article 33(4).

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Electronic Patent Application Fee Transmittal

Application Number:	16057566
Filing Date:	07-Aug-2018
Title of Invention:	Adjusting a digital representation of a head region
First Named Inventor/Applicant Name:	Eric Sommerlade
Filer:	Charles C. Yang/Kristal Veliz
Attorney Docket Number:	409001

Filed as Small Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
SUBMISSION- INFORMATION DISCLOSURE STMT	2806	1	120	120
		Total in USD ($)		**120**

Electronic Acknowledgement Receipt

EFS ID:	38782224
Application Number:	16057566
International Application Number:	
Confirmation Number:	5211
Title of Invention:	Adjusting a digital representation of a head region
First Named Inventor/Applicant Name:	Eric Sommerlade
Customer Number:	145234
Filer:	Charles C. Yang/Kristal Veliz
Filer Authorized By:	Charles C. Yang
Attorney Docket Number:	409001
Receipt Date:	05-MAR-2020
Filing Date:	07-AUG-2018
Time Stamp:	15:45:11
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	DA
Payment was successfully received in RAM	$120
RAM confirmation Number	E202035F45325640
Deposit Account	
Authorized User	
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Information Disclosure Statement (IDS) Form (SB08)	20200305_409001_Supp_IDS_cross_cite_388_411.pdf	1082724 c9e85a6c46a991013f671513443f7bb7dd1dd54b	no	8
Warnings:					
Information:					
2	Foreign Reference	JP-2007109255A.pdf	5551865 1b57115094cb3fd8e87f7202113d06edc4089020	no	23
Warnings:					
Information:					
3	Foreign Reference	WO2011148366.pdf	9962152 00096e0ec4b94d743fd5e40cb805bf4bc2d3704b	no	52
Warnings:					
Information:					
4	Foreign Reference	WO2016-132148.pdf	4080845 9994470b745c14abdbd765ff6e660dcbc0045e76	no	142
Warnings:					
Information:					
5	Non Patent Literature	EP17736268_8_European_search_report.pdf	1658161 f45caae65c44c0bd8a986c00f9254ed59491a59c	no	11
Warnings:					
Information:					
6	Non Patent Literature	GANIN_DeepWarp_Photorealistic_2016.pdf	9814778 e93cb0b76d40db77fddaa66da690d44214e7e315	no	18
Warnings:					
Information:					

7	Non Patent Literature	GIGER_Gaze_Correction_Single_Webcam_IEEE_ICME_2014.pdf	4720124 650c75708c747121f0e59e47d96230077344fb18	no	6
Warnings:					
Information:					
8	Non Patent Literature	411001_WO2016153389-IPRP.pdf	1590080 59368f17fcb017bcae3fb7f1984771ba789eae7f	no	10
Warnings:					
Information:					
9	Non Patent Literature	411001-WO2016153389-ISR-WO.pdf	2661642 72f62f6f6d19cb2d910ddb7bfb076558bdaed762	no	13
Warnings:					
Information:					
10	Non Patent Literature	PCTUS2017-12203-ISR-WO.pdf	5470037 2af56905a2914e50768bb0ad26acca48aae7c07e	no	14
Warnings:					
Information:					
11	Non Patent Literature	REN_ET_EL_Face_Alignment_at_3000_2014.pdf	4791208 16fe0b715745b929f41c20058c22163f551e337e	no	8
Warnings:					
Information:					
12	Non Patent Literature	SMITH_Gaze_locking_passive_eye_ACM_2013.pdf	8296383 269d3a0166b5bf1b8b71f08b5be9a61282e9fb11	no	10
Warnings:					
Information:					
13	Non Patent Literature	XIONG_Supervised_Descent_Method_IEEE_2013.pdf	6709581 8db9d51d8e98e3f18a720a8e77fff3a9b662a991	no	8
Warnings:					
Information:					

14	Non Patent Literature	YANG_Multi-Scale_Recognition_With_ICCV_2015_paper.pdf	1313624 646e4300be68e90b46f128d87008cbc422a59b57	no	9
Warnings:					
Information:					
15	Non Patent Literature	YIP_Face_and_Eye_Rectification_ICME_2005.pdf	2805659 45f26d8f02bd39cdd142d2645607d91e8a01ad43	no	4
Warnings:					
Information:					
16	Fee Worksheet (SB06)	fee-info.pdf	30544 e28f116cd862d5ff0dc9f9221fc803e74d6cd7d5	no	2
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		Total Files Size (in bytes):	70539407		

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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

Applicant:	RealD Spark, LLC	§	**Group Art Unit:**	2618
		§		
Appl. No.:	16/057,566	§	**Examiner:**	Pringle-Parker, Jason A
		§		
Filed:	August 7, 2018	§	**Atty. Docket No.:**	409001
		§		
		§	**Confirmation No.:**	5211

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

CERTIFICATE OF FILING ELECTRONICALLY VIA EFS 37 CFR 1.8

I HEREBY CERTIFY THAT I HAVE A REASONABLE BASIS FOR BELIEF THAT THIS CORRESPONDENCE IS BEING SUBMITTED TO THE UNITED STATES PATENT AND TRADEMARK OFFICE VIA EFS (ELECTRONICALLY) ON THE DATE INDICATED BELOW, AND IS ADDRESSED TO:
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/Penny L Lowry/
Penny L. Lowry, Reg. No. 57186

DATE OF SUBMISSION: FEBRUARY 21, 2020
ELECTRONIC FILING (EFS)

RESPONSE TO NON-FINAL OFFICE ACTION

Applicant respectfully requests reconsideration of the present application in view of this submission, which is filed in response to the non-final office action mailed November 22, 2019 ("Office Action"). Applicant notes that because the three-month deadline for filing a response expires on February 22, 2020, this response is timely filed.

The **Listing of Claims** begins on page **2** of this paper.

Remarks begin on page **10** of this paper.

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IPR2023-01046 - U.S. Patent No. 10,740,985

LISTING OF CLAIMS

The listing of claims will replace all prior versions, and listings, of claims in the application.

1. (Currently amended) A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the first reference data comprise first editing instructions for a range of possible configurations of the target feature and first selection instructions for selecting editing instructions for a particular input patch from the first editing instructions based on the configuration of the target feature of the input patch; and

wherein the second reference data comprise second editing instructions for a range of possible configurations of the target feature and second selection instructions for selecting editing instructions for a particular input patch from the second image editing instructions based on the configuration of the target feature of the input patch.

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2. (Canceled)

3. (Currently amended) The method of claim 1 ~~claim 2~~, wherein the configuration of the target feature of each input patch is represented by a feature vector derived from plural local descriptors of the input patch, and the first and second selection instructions define how the feature vector is used to select editing instructions for the input patch.

4. (Currently amended) The method of claim 1 ~~claim 2~~, wherein the editing instructions comprise a displacement vector field defining how the input patch is to be transformed.

5. (Currently amended) The method of claim 1 ~~claim 2~~, wherein the editing instructions comprise a filter field, a brightness adjustment field, or a texture blending field.

6. (Currently amended) The method of claim 1 ~~claim 2~~, wherein:

a first editing algorithm is used by the first machine learning algorithm to define how the first editing instructions are to be applied to an input patch to derive an output patch; and

a second editing algorithm is used by the second machine learning algorithm to define how the second editing instructions are to be applied to an input patch to derive an output patch.

7. (Original) The method of claim 6, wherein:

the second editing instructions are principle component analysis components of a principle component analysis of the first editing instructions; and

the second image editing algorithm is configured to transform the second editing instructions into the first editing instructions by inverse principle component analysis transform.

8. (Original) The method of claim 6, wherein:

the second editing instructions are wavelet components of the first editing instructions; and

the second editing algorithm is configured to transform the second editing instructions into the first editing instructions by inverse wavelet transform.

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9. (Currently amended) The method of claim 1 ~~claim 2~~, wherein the first selection instructions for the first reference data are able to select between a larger number of alternative editing instructions than the second selection instructions for the second reference data.

10. (Previously presented) The method of claim 1, wherein the first machine learning algorithm is of a different machine learning algorithm type than the second machine learning algorithm.

11. (Previously presented) The method of claim 1, wherein the first machine learning algorithm comprises one or more of the following: a neural network; a support vector machine; and a generative adversarial network (GAN).

12. (Previously presented) The method of claim 1, wherein the second machine learning algorithm comprises one or more of the following: a regression forest; regression ferns, cluster centres, a lookup table, and separable filter banks.

13. (Canceled)

14. (Previously presented) The method of claim 1, wherein the target feature comprises one or more of the following: an eye region comprising at least part of an eye, a nose region comprising at least part of a nose, a mouth region comprising at least part of a mouth, a chin region comprising at least part of a chin, a neck region comprising at least part of a neck, and a hair region comprising hair.

15-17. (Canceled)

18. (Previously presented) A method of adjusting a digital representation of a head region, the method comprising

receiving a digital representation of a head region; and

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using reference data comprising editing instructions to adjust the digital representation of the head region, wherein the reference data comprises the second reference data generated by the method of claim 1.

19-26. (Canceled)

27. (Currently amended) A method of training a machine learning algorithm to adjust a digital representation of a head region, the method comprising:

receiving training data comprising a set of input digital representations of a head region;

training a first machine learning algorithm using the training data to perform an adjustment of a digital representation of a head region;

using the trained first machine learning algorithm to generate first reference data, the first reference data comprising an adjusted digital representation of the head region for each of at least a subset of the input digital representations, each adjusted digital representation being obtained by performed the adjustment that the first machine learning algorithm was trained to perform; and

training a second machine learning algorithm using at least a subset of the training data used to train the first machine learning algorithm and the first reference data to perform the same adjustment of a digital representation of a head region as the first machine learning algorithm,

wherein the adjustment of the digital representation comprises converting from a two-dimensional digital representation to a three-dimensional digital representation, and

wherein the training of the first machine learning algorithm comprises iteratively using a rendering process to generate a two-dimensional digital representation from a three-dimensional digital representation generated by the first machine learning algorithm and comparing the generated digital representation with a corresponding digital representation in the training data.

28-31. (Canceled)

32. (Currently amended) A non-transitory computer readable storage medium storing a computer program ~~according to claim 31~~ capable of execution by a processor and arranged on execution to cause the processor to perform a method according to claim 1.

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33. (Currently amended) A device for generating reference data for adjusting a digital representation of a head region, the device comprising a data processing unit arranged to:

receive training data comprising:

a set of input patches, each input patch comprising information about a target feature of a digital representation of the head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target portion of the digital representation of the head region after adjustment of the digital representation of the head region;

use a first machine learning algorithm to generate first reference data using the training data; and

use a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data output by the first machine learning algorithm,

wherein the first reference data comprises editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the second reference data comprises editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region, and

wherein the second editing instructions in the second reference data are provided in a compressed representation.

34-36. (Canceled)

37. (New) A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

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a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the first machine learning algorithm comprises a first neural network and the second machine learning algorithm comprises a second neural network, and wherein the second neural network comprises fewer layers and/or smaller convolution fields than the first neural network.

38. (New) A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital

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representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the target feature comprises an eye region comprising at least part of an eye and the adjustment of the digital representation of the head region comprises adjusting a gaze direction, and/or

wherein the target feature comprises a nose region comprising at least part of a nose and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the nose, and/or

wherein the target feature comprises a chin region comprising at least part of a chin and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the chin, and/or

wherein the target feature comprises a neck region comprising at least part of a neck and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the neck, and/or

wherein the target feature comprises a hair region comprising hair and the adjustment of the digital representation of the head region comprises adjusting a color of the hair.

39. (New) A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

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using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the second editing instructions in the second reference data are provided in a compressed representation, and

wherein the compressed representation comprises one or more of the following: a principle component analysis representation; a wavelet representation; Fourier and/or discrete cosine transform components; cluster centers.

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REMARKS

Claims 1-36 were originally filed in this application. Claims 4-6, 9-16, 18-19, 22, 30-31, and 36 were previously amended to remove multiple dependencies and to correct minor typographical errors, and claims 19-24 and 35-36 were previously withdrawn. Claims 1, 3-6, 9, 27, and 32-33 are currently amended. Claims 2, 13, 15-17, 19-26, 28-31, and 34-36 are currently canceled. New claims 37-39 are currently added. No new matter has been added.

Allowable Subject Matter

Applicant thanks the Examiner for indicating allowable subject matter in Item 3 of the Office Action. This response is intended to accept such allowable subject matter.

Claim 1 has been amended to include the limitations of allowable claim 2, and claim 2 has been canceled. Claims 3-6 and 9 have been amended to depend from claim 1.

Claim 27 has been amended to include the limitations of allowable claim 29 and intervening claim 28, and claims 28-29 have been canceled.

Claim 33 has been amended to include the limitations of allowable claim 34, and claim 34 has been canceled.

Newly added claim 37 is equivalent to original claim 1 amended to include the limitations of allowable claim 13, and claim 13 has been canceled.

Newly added claim 38 is equivalent to original claim 1 amended to include the limitations of allowable claim 15, and claim 15 has been canceled.

Newly added claim 39 is equivalent to original claim 1 amended to include the limitations of allowable claim 17 and intervening claim 16, and claims 16-17 have been canceled.

Rejections under 35 USC 112

Item 5 of the Office Action rejects claim 26, asserting that claim 26 is indefinite. Without agreeing with this assertion and to accept allowable subject matter, Applicant has canceled claim 26.

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Rejections under 35 USC 101

Items 7-8 of the Office Action rejects claims 31 and 32, asserting that these claims are directed to non-statutory subject matter. Without agreeing with this assertion and to accept allowable subject matter, Applicant has amended claim 32 to recite a "non-transitory computer readable storage medium…" and to include the limitations of claim 31, and has canceled claim 31. Applicant therefore respectfully requests that this rejection be withdrawn.

Rejections under 35 USC 103

Item 10 of the Office Action rejects claims 1, 10-11, 14, 18, 25, 27-28, and 30-33, asserting that these claims are unpatentable over U.S. Patent Publ. No. 2016-0125227 ("Soare") in view of U.S. Patent Publ. No. 2010-0030578 ("Siddique"). Without agreeing with this assertion and to accept allowable subject matter, Applicant has amended claim 1 to include the limitations of allowable claim 2, has amended claim 27 to include the limitations of allowable claim 29 and intervening claim 28, has amended claim 33 to include the limitations of allowable claim 34, and has canceled claims 25, 28, and 30-31. In view of these amendments and because claims 10-11, 14, 18, and 32 each depend from amended allowable claim 1, Applicant respectfully requests that these rejections be withdrawn.

Item 11 of the Office Action rejects claim 12, asserting that this claim is unpatentable over Soare and Siddique in view of U.S. Patent Publ. No. 2007-0244606 ("Zhang"). Without agreeing with this assertion and to accept allowable subject matter, because claim 12 depends from amended allowable claim 1, Applicant respectfully requests that this rejection be withdrawn.

Item 12 of the Office Action rejects claim 16, asserting that this claim is unpatentable over Soare and Siddique in view of U.S. Patent Publ. No. 2002-0013691 ("Warnes"). Without agreeing with this assertion and to accept allowable subject matter, Applicant has canceled claim 16.

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Conclusion

Applicant thanks the Examiner for time spent reviewing the present application. Should the Examiner have any questions or comments regarding this matter, the Examiner is invited to contact Applicant's attorney at the number below. If it is determined that additional fees are due, or if an overcharge has occurred, please charge or credit Deposit Account No. 50-6262, referencing Attorney Docket No. 409001.

Respectfully submitted,

Date: February 21, 2020

/Penny L Lowry/
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Tel: (303) 500-6030

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IPR2023-01046 - U.S. Patent No. 10,740,985

Electronic Acknowledgement Receipt

EFS ID:	38656787
Application Number:	16057566
International Application Number:	
Confirmation Number:	5211
Title of Invention:	Adjusting a digital representation of a head region
First Named Inventor/Applicant Name:	Eric Sommerlade
Customer Number:	145234
Filer:	Penny Lea Lowry/Stefan Bump
Filer Authorized By:	Penny Lea Lowry
Attorney Docket Number:	409001
Receipt Date:	21-FEB-2020
Filing Date:	07-AUG-2018
Time Stamp:	14:43:30
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		409001_response_NFOA.pdf	122587 963c83c07cf5cce4ff2b7b6cca241f5453893441	yes	12

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Amendment/Req. Reconsideration-After Non-Final Reject	1	1
	Claims	2	9
	Applicant Arguments/Remarks Made in an Amendment	10	12
Warnings:			
Information:			
	Total Files Size (in bytes):	122587	

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PTO/SB/06 (09-11)
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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 16/057,566	Filing Date 08/07/2018	☐ To be Mailed

ENTITY: ☐ LARGE ☑ SMALL ☐ MICRO

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA		RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A		N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A		N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*		x $50 =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*		x $230 =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).				
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))					
* If the difference in column 1 is less than zero, enter "0" in column 2.				TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1)		(Column 2)	(Column 3)			
AMENDMENT	02/21/2020	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA		RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 19	Minus	** 36	= 0		x $50 =	0
	Independent (37 CFR 1.16(h))	* 6	Minus	*** 6	= 0		x $230 =	0
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	0

		(Column 1)		(Column 2)	(Column 3)			
AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA		RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=		x $0 =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=		x $0 =	
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.	LIE
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".	/ALLYSON PURNELL/
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".	
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.	

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/057,566	08/07/2018	Eric Sommerlade	409001	5211

145234 7590 11/22/2019

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EXAMINER	
PRINGLE-PARKER, JASON A	

ART UNIT	PAPER NUMBER
2618	

NOTIFICATION DATE	DELIVERY MODE
11/22/2019	ELECTRONIC

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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):

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IPR2023-01046 - U.S. Patent No. 10,740,985

Office Action Summary	Application No. 16/057,566	Applicant(s) Sommerlade et al.	
	Examiner JASON A PRINGLE-PARKER	Art Unit 2618	AIA (FITF) Status Yes

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

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTHS FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☑ Responsive to communication(s) filed on 10/15/19.

☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2a)☐ This action is **FINAL.** 2b) ☑ This action is non-final.

3)☐ 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.

4)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims*

5) ☑ Claim(s) 1-36 is/are pending in the application.

5a) Of the above claim(s) 19-24 and 35-36 is/are withdrawn from consideration.

6) ☐ Claim(s) _____ is/are allowed.

7) ☑ Claim(s) 1,10-12,14,16,18,25,27-28 and 30-33 is/are rejected.

8) ☑ Claim(s) 2-9,13,15,17,29 and 34 is/are objected to.

9) ☐ Claim(s) _____ are subject to restriction and/or election requirement

* If any claims have been determined allowable, 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.**

Application Papers

10)☐ The specification is objected to by the Examiner.

11)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

Priority under 35 U.S.C. § 119

12)☐ 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)).

** See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☑ Notice of References Cited (PTO-892)

2) ☑ Information Disclosure Statement(s) (PTO/SB/08a and/or PTO/SB/08b) Paper No(s)/Mail Date _____.

3) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date _____.

4) ☐ Other: _____.

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Notice of Pre-AIA or AIA Status

1. The present application, filed on or after March 16, 2013, is being examined under the first inventor to file provisions of the AIA.

DETAILED ACTION

Election/Restrictions

2. Claims 19-24, 35-36 withdrawn from further consideration pursuant to 37 CFR 1.142(b) as being drawn to a nonelected inventions, there being no allowable generic or linking claim. Election was made **without** traverse in the reply filed on 10/15/19.

Allowable Subject Matter

3. Claims 2-9, 13, 15, 17, 29, 34 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.

Claim Rejections - 35 USC § 112

4. The following is a quotation of 35 U.S.C. 112(b):

> (b) CONCLUSION.—The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the inventor or a joint inventor regards as the invention.

The following is a quotation of 35 U.S.C. 112 (pre-AIA), second paragraph:

> The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention.

5. The term " at or near " in claim 26 “wherein the updating of the second machine learning algorithm is performed at or near input data frame rate” is a relative term which renders the claim indefinite. The term "at or near " is not defined by the claim, the specification does not provide a standard for ascertaining the requisite degree, and one of ordinary skill in the art would not be reasonably apprised of the scope of the invention.

Claim Rejections - 35 USC § 101

6. 35 U.S.C. 101 reads as follows:

> Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title.

7. Claim 32 is rejected under 35 U.S.C. 101 because the claimed invention is directed to non-statutory subject matter. The claim is directed to a computer readable medium. The claim remains silent regarding the transitory nature of the computer readable medium. Thus interpretation of medium allows for non-eligibly patentable subject matter such as the mentioned propagation medium, data structure. Such propagation media (carrier waves, signals...) do not fall into one of the eligible statutory classes of invention (process, machine, article of manufacture, or composition of matter) Therefore, the claim is rejected as being nonstatutory. Applicant is advised that a claim drawn to such a computer readable medium that covers both transitory and non-transitory embodiments may be corrected by amending to narrow the claim to cover only statutory embodiments to avoid a rejection under 35 USC 101 by adding the limitation **"non-transitory"** to the claim. Other terms that exclude the signal embodiments may be acceptable upon review.

8. Claim 31 is rejected under 35 U.S.C. 101 because the claimed invention is directed to non-statutory subject matter. The claim is directed to a product that does not have a physical or tangible form, such as information (often referred to as "data per se") or a computer program per se (often referred to as "software per se").

Claim Rejections - 35 USC § 103

9. The following is a quotation of 35 U.S.C. 103 which forms the basis for all obviousness rejections set forth in this Office action:

> A patent for a claimed invention may not be obtained, notwithstanding that the claimed invention is not identically disclosed as set forth in section 102, if the differences between the claimed invention and the prior art are such that the claimed

invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art to which the claimed invention pertains. Patentability shall not be negated by the manner in which the invention was made.

10. Claim(s) 1, 10-11, 14, 18, 25, 27-28, 30-33 is/are rejected under 35 U.S.C. 103 as being unpatentable over Soare U.S. Patent/PG Publication 20160125227 in view of Siddique U.S. Patent/PG Publication 20100030578.

Regarding claim 1:

A method of generating reference data for adjusting a digital representation of a head region, the method comprising: **(Soare Abstract: An eyebrow shaping method includes providing an image of a face.)**.

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch **(Soare [0079] In FIG. 6A, there is a system and method comprising providing a frontal image of a person's face, including a base of the person's nose, tip end of the chin, cheeks, nostrils, eyes including irises, supraorbital margins, ears, and eyebrows and integrating features of the features of FIGS. 1-5 into the face.)**

and a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region **(Soare: [0091] The method and system comprising the steps of opening an App on a computer device. In substantially real-time the user uses the App using a camera to generate facial measurements using a facial measurement engine. Measurements give the user in real time data about a custom application of cosmetics on their individual face using the camera)** since there is input of the original face, and output of the face with superimposed outlines.

using a first ~~machine learning~~ algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region and using a second ~~machine learning~~ algorithm to generate second reference data using the same training data as the first ~~machine learning~~ algorithm and the first reference data generated by the first ~~machine learning~~ algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region **(Soare Fig. 9-10 and [0088] At a next stage anyone or more of the images from FIGS. 1A, 2A, 3A, 4A, 5A or 6A can be overlaid on the facial image. There is continual feedback and comparison of the facial image after makeup and/or contouring is applied to the face of the user with the ideal image as shown in FIGS. 1A, 2A, 3A, 4A, 5A or 6A on the screen. When there is a satisfactory or acceptable result the user can move)** since there is a superimposed outline of Fig. 1A on the face showing editing instructions, and once the makeup is acceptable, it moves to superimposing Fig. 2A which takes the original face input (training data) and the output from "acceptable" (first machine learning algorithm), and uses that for further editing.

Soare does not expressly disclose machine learning algorithms. In a related field of endeavor, Siddique teaches:

machine learning algorithm **(Siddique [0117]: Furthermore, the movements of the original character can be extracted, in exemplary embodiment, either manually or using machine learning algorithms (for example: pose tracking and pose recover techniques) and then applied to the user model.)**

Therefore, it would have been obvious before the effective filing date of the claimed invention to use a machine learning algorithm as taught by Siddique. The motivation for doing so would have been that machine learning algorithms are efficient, don't require human intervention, and can continually improve. Therefore it would have been obvious to combine Siddique with Soare to obtain the invention.

Regarding claim 10:

The method of claim 1, has all of its limitations taught by Soare in view of Siddique. Soare further teaches *wherein the first ~~machine learning~~ algorithm is of a different ~~machine learning~~ algorithm type than the second machine learning algorithm* **(Soares Fig. 9: first algorithm superimposes Fig 1A, second superimposes Fig. 2A, so at the very least there is a minor difference in the algorithm in that it uses/displays different data)**.

Regarding claim 11:

The method of claim 1, has all of its limitations taught by Soare in view of Siddique. Siddique further teaches *wherein the first machine learning algorithm comprises one or more of the following:*

a neural network a support vector machine and a generative adversarial network (GAN) Soare does not expressly disclose machine learning algorithms. In a related field of endeavor, Siddique teaches: **(Siddique [0124]: This can be accomplished using a variety of machine learning algorithms such as neural networks or support vector machines.)**

Therefore, it would have been obvious before the effective filing date of the claimed invention to use a machine learning algorithm as taught by Siddique. The motivation for doing so would have been that machine learning algorithms are efficient, don't require human intervention, and can continually improve. Further, this is a simple substitution of algorithm types. Therefore it would have been obvious to combine Siddique with Soare to obtain the invention.

Regarding claim 14:

The method of claim 1, has all of its limitations taught by Soare in view of Siddique. Soare further teaches *wherein the target feature comprises one or more of the following:*

an eye region comprising at least part of an eye, a nose region comprising at least part of a nose, a mouth region comprising at least part of a mouth, a chin region comprising at least part of a chin, a neck region comprising at least part of a neck, and a hair region comprising hair **(Soare Abstract: An eyebrow shaping method includes providing an image of a face.)(Soare [0030] A method comprises providing a frontal image of a person's face, including a base of the person's nose, tip end of the chin, cheeks, nostrils, eyes including irises, supraorbital margins, ears, and eyebrows. A first distance extends in length from a point at the base of the nose to the tip end of the chin; forming a first guide line on a cheek at a radius substantially equal to the first distance; the first guide line being user to demarcate a first limit for the application of contouring on the cheek.)**

Regarding claim 18:

A method of adjusting a digital representation of a head region, the method comprising receiving a digital representation of a head region **(Soare Abstract: An eyebrow shaping method includes providing an image of a face.)**.

and using reference data comprising editing instructions to adjust the digital representation of the head region, **(Soare: [0091] The method and system comprising the steps of opening an App on a computer device. In substantially real-time the user uses the App using a camera to generate facial measurements using a facial measurement engine. Measurements give the user in real time data about a custom application of cosmetics on their individual face using the camera)** *wherein the reference data comprises the second reference data generated by the method of claim 1* **(See claim 1 rejection).**

Regarding claim 25:

A method of training a machine learning algorithm to adjust a digital representation of a head region, comprising: **(Soare Abstract: An eyebrow shaping method includes providing an image of a face.)**.

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch **(Soare [0079] In FIG. 6A, there is a system and method comprising providing a frontal image of a person's face, including a base of the person's nose, tip end of the chin, cheeks, nostrils, eyes including irises, supraorbital margins, ears, and eyebrows and integrating features of the features of FIGS. 1-5 into the face.)**

and first reference data generated by a pre-trained first ~~machine learning~~ algorithm, the first reference data comprising a set of editing instructions in one-to-one correspondence with the input patches, each editing instruction being for adjusting the digital representation of the head region updating a pre-trained second ~~machine learning~~ algorithm trained to generate second reference data, where the input for the updating comprises the training data and the generated first reference data, the second reference data comprising editing instructions for adjusting the digital representation of the head region **(Soare Fig. 9-10 and [0088] At a next stage anyone or more of the images from FIGS. 1A, 2A, 3A, 4A, 5A or 6A can be overlaid on the facial image. There is continual feedback and comparison of the facial image after makeup and/or contouring is applied to the face of the user with the ideal image as shown in FIGS. 1A, 2A, 3A, 4A, 5A or 6A on the screen. When there is a satisfactory or acceptable result the user can move)** since there is a superimposed outline of Fig. 1A on the face showing editing instructions, and once the makeup is acceptable, it moves to superimposing Fig. 2A which takes the original face input (training data) and the output from "acceptable" (first machine learning algorithm), and uses that for further editing.

Soare does not expressly disclose machine learning algorithms. In a related field of endeavor, Siddique teaches:

machine learning algorithm **(Siddique [0117]: Furthermore, the movements of the original character can be extracted, in exemplary embodiment, either manually or**

using machine learning algorithms (for example: pose tracking and pose recover techniques) and then applied to the user model.)

Therefore, it would have been obvious before the effective filing date of the claimed invention to use a machine learning algorithm as taught by Siddique. The motivation for doing so would have been that machine learning algorithms are efficient, don't require human intervention, and can continually improve. Therefore it would have been obvious to combine Siddique with Soare to obtain the invention.

Regarding claim 27:

A method of training a machine learning algorithm to adjust a digital representation of a head region, the method comprising: **(Soare Abstract: An eyebrow shaping method includes providing an image of a face.)**.

receiving training data comprising a set of input digital representations of a head region **(Soare [0079] In FIG. 6A, there is a system and method comprising providing a frontal image of a person's face, including a base of the person's nose, tip end of the chin, cheeks, nostrils, eyes including irises, supraorbital margins, ears, and eyebrows and integrating features of the features of FIGS. 1-5 into the face.)**

training a first ~~machine learning~~ algorithm using the training data to perform an adjustment of a digital representation of a head region using the trained first ~~machine learning~~ algorithm to generate first reference data, the first reference data comprising an adjusted digital representation of the head region for each of at least a subset of the input digital representations, each adjusted digital representation being obtained by performed the adjustment that the first ~~machine learning~~ algorithm was trained to perform and training a second ~~machine learning~~ algorithm using at least a subset of the training data used to train the first ~~machine learning~~ algorithm and the first reference data to perform the same adjustment of a digital representation of a head region as the first ~~machine learning~~ algorithm **(Soare Fig. 9-10 and [0088] At a next stage anyone or more of the images from FIGS. 1A, 2A, 3A, 4A, 5A or 6A can be overlaid on the facial image. There is continual feedback and comparison of the facial image after makeup**

and/or contouring is applied to the face of the user with the ideal image as shown in FIGS. 1A, 2A, 3A, 4A, 5A or 6A on the screen. When there is a satisfactory or acceptable result the user can move) since there is a superimposed outline of Fig. 1A on the face showing editing instructions, and once the makeup is acceptable, it moves to superimposing Fig. 2A which takes the original face input (training data) and the output from "acceptable" (first machine learning algorithm), and uses that for further editing.

Soare does not expressly disclose machine learning algorithms. In a related field of endeavor, Siddique teaches:

machine learning algorithm **(Siddique [0117]: Furthermore, the movements of the original character can be extracted, in exemplary embodiment, either manually or using machine learning algorithms (for example: pose tracking and pose recover techniques) and then applied to the user model.)**

Therefore, it would have been obvious before the effective filing date of the claimed invention to use a machine learning algorithm as taught by Siddique. The motivation for doing so would have been that machine learning algorithms are efficient, don't require human intervention, and can continually improve. Therefore it would have been obvious to combine Siddique with Soare to obtain the invention.

Regarding claim 28:

The method of claim 27, has all of its limitations taught by Soare in view of Siddique. Soare does not expressly disclose 2D to 3D. In a related field of endeavor, Siddique teaches:

wherein the adjustment of the digital representation comprises converting from a two-dimensional digital representation to a three-dimensional digital representation

(Siddique [0098]: The three-dimensional models are herein referred to as user models or character models, and are created based on information provided by the user. This information includes, but is not limited to, any combination of: images; movies; measurements; outlines of feet, hands, and other body parts;

moulds/imprints including those of feet, hands, ears, and other body parts; scans such as laser scans; skin tone, race, gender, weight, hair type etc.; high resolution scans and images of the eyes; motion capture data (mocap).)

Therefore, it would have been obvious before the effective filing date of the claimed invention to use 2D to 3D conversion as taught by Siddique. The rationale for doing so would have been that it combines prior art elements according to known methods to yield predictable results, where Siddique allows for the creation of 3D models from 2D information, and Soare is using 2D information of a users face, where if it were 3D it would better show the contours for applying makeup, by making the information more accurate to the 3D shape of a human face. Therefore it would have been obvious to combine Siddique with Soare to obtain the invention.

Regarding claim 30:

The method of claim 25, has all of its limitations taught by Soare in view of Siddique. Soare further teaches *further comprising receiving a further digital representation of the head region and using the updated or trained second machining learning algorithm to adjust the further digital representation* **(Soare Fig. 9: superimposing, comparison, and application is repeated for 1A, 2A, 3A, 4A, 5A, 6A)** since the head region is updated and adjusted repeatedly.

Regarding claim 31:

The claim is a/an program version of claim 1 where the program performs the method. As such it is rejected under the same teachings.

Regarding claim 32:

The claim is a/an medium version of claim 1 where the medium stores and performs the method. As such it is rejected under the same teachings.

Regarding claim 33:

The claim is a/an device version of claim 1 where the device stores and performs the method. As such it is rejected under the same teachings.

11. Claim(s) 12 is/are rejected under 35 U.S.C. 103 as being unpatentable over Soare U.S. Patent/PG Publication 20160125227 in view of Siddique U.S. Patent/PG Publication 20100030578 and Zhang U.S. Patent/PG Publication 20070244606.

Regarding claim 12:

The method of claim 1, has all of its limitations taught by Soare in view of Siddique. Soare does not expressly disclose machine learning algorithms. In a related field of endeavor, Zhang teaches:

wherein the second machine learning algorithm comprises one or more of the following:

a regression forest, regression ferns, cluster centres, a lookup table, and separable filter banks **(Zhang [0027]: Depending on the machine/learning method used, which can include, but is not limited to, decision trees, artificial neural networks, Bayes learning, hidden Markov models, Bayesian belief networks, case based reasoning, genetic algorithms, etc., the learned DWE can be a set of rules, a look-up table, or a numerical function, depending on the algorithm used. Using this design method, a driver workload estimator is established.)**.

Therefore, it would have been obvious before the effective filing date of the claimed invention to use lookup tables as taught by Zhang. The rationale for doing so would have been that it combines prior art elements according to known methods to yield predictable results since an algorithm such as a machine learning algorithm can include countless types of storage and classification forms, which do not change the function of the algorithm. Therefore it would have been obvious to combine Zhang with Soare to obtain the invention.

12. Claim(s) 16 is/are rejected under 35 U.S.C. 103 as being unpatentable over Soare U.S. Patent/PG Publication 20160125227 in view of Siddique U.S. Patent/PG Publication 20100030578 and Warnes U.S. Patent/PG Publication 20020013691.

Regarding claim 16:

The method of claim 1, has all of its limitations taught by Soare in view of Siddique. Soare does not expressly disclose compression. In a related field of endeavor, Warnes teaches:

wherein the second editing instructions in the second reference data are provided in a compressed representation **(Warnes: [0009] Compressing the instruction set of a RISC processor (particularly in the case of an embedded applications such as consumer electronics) is important for reasons relating to memory and die space limitations, as well as others. A number of varying compression techniques have been proposed to reduce instruction set size.)**.

Therefore, it would have been obvious before the effective filing date of the claimed invention to use compression as taught by Warnes. The motivation for doing so would have been to reduce data size (Warnes [0009]). Therefore it would have been obvious to combine Warnes with Soare to obtain the invention.

Conclusion

13. For the prior art referenced and the prior art considered pertinent to Applicant's disclosure but not relied upon, see PTO-892 "Notice of References Cited".

Any inquiry concerning this communication or earlier communications from the examiner should be directed to JASON PRINGLE-PARKER whose telephone number is (571)272-5690 and e-mail is jason.pringle-parker@uspto.gov. The examiner can normally be reached on 8:30am-5:00pm est Monday-Friday. If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Barry Drennan can be reached on (571) 270-7262. 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.

/JASON A PRINGLE-PARKER/

Primary Examiner, Art Unit 2618

Notice of References Cited	Application/Control No. 16/057,566	Applicant(s)/Patent Under Reexamination Sommerlade et al.	
	Examiner JASON A PRINGLE-PARKER	Art Unit 2618	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	CPC Classification	US Classification
*	A	US-20130076853-A1	03-2013	DIAO; Jie	H04N7/15	348/14.08
*	B	US-20120223956-A1	09-2012	SAITO; Mari	A45D44/005	345/582
*	C	US-9378574-B2	06-2016	Kim; Jin Seo	G06T19/00	1/1
*	D	US-6283858-B1	09-2001	Hayes, Jr.; Carl Douglas	G06K9/00268	345/418
*	E	US-20070019882-A1	01-2007	Tanaka; Shoji	G06T17/20	382/276
*	F	US-9224248-B2	12-2015	Ye; Zhou	G06T19/20	1/1
*	G	US-9986812-B2	06-2018	Yamanashi; Tomofumi	A45D44/005	1/1
*	H	US-20160125227-A1	05-2016	Soare; Anastasia	G06K9/00248	382/118
*	I	US-20100030578-A1	02-2010	Siddique; M.A. Sami	G06Q10/0637	705/3
*	J	US-20070244606-A1	10-2007	Zhang; Yilu	B60T8/17551	701/1
*	K	US-20130163659-A1	06-2013	Sites; Richard L.	H04N19/13	375/240.02
*	L	US-20020013691-A1	01-2002	Warnes, Peter	G06F9/30156	703/22
	M					

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	CPC Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

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Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/057,566	Sommerlade et al.
	Examiner	Art Unit
	JASON A PRINGLE-PARKER	2618

CPC - Searched*		
Symbol	Date	Examiner

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner

* 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
Inventor	11/19/2019	JP
EAST	11/19/2019	JP

Interference Search			
US Class/CPC Symbol	US Subclass/CPC Group	Date	Examiner

/JASON A PRINGLE-PARKER/ Primary Examiner, Art Unit 2618	

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EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
S1	1	"16057566"	US-PGPUB; USPAT	OR	ON	2019/11/08 10:41
S2	16	((("SOMMERLADE") near3 ("Eric")) OR (("NEOPHYTOU") near3 ("Alexandros"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2019/11/08 10:41
S3	16	((("SOMMERLADE") near3 ("Eric")) OR (("NEOPHYTOU") near3 ("Alexandros"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2019/11/08 10:41
S4	697	real ADJ2 time SAME (eye OR gaze) SAME (meeting OR conferenc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 11:09
S5	35	real ADJ2 time SAME (eye OR gaze) WITH (chang$4 OR adjust$4 OR modify$4) SAME (meeting OR conferenc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 11:10
S6	1214	(head OR face) AND input ADJ2 patch	US-PGPUB; USPAT	OR	ON	2019/11/08 11:43
S7	169	(head OR face) AND input ADJ2 patch SAME output ADJ2 patch	US-PGPUB; USPAT	OR	ON	2019/11/08 11:43
S8	0	("2017/0195662").URPN.	USPAT	OR	ON	2019/11/08 11:44
S9	14	("2013/0076853").URPN.	USPAT	OR	ON	2019/11/08 11:47
S10	29	("2012/0223956").URPN.	USPAT	OR	ON	2019/11/08 11:57
S11	4	("20050147955" | "20060239591" | "20120223956" | "7392204").PN. OR ("9378574").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 11:59
S12	5014	real ADJ2 time SAME (cosmetic OR make ADJ2 up)	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 11:59
S13	1280	real ADJ2 time WITH (cosmetic OR make ADJ2 up)	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 11:59
S14	304	S13 AND ((G06F17/5009 OR G06F16/54 OR G06F9/5072 OR G06F3/011 OR G06F16/258 OR G06F3/04817 OR	US-PGPUB; USPAT;	OR	ON	2019/11/08 12:00

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		G06F3/0482 OR G06F11/1441 OR G06F11/1474 OR G06F16/164 OR G06F16/168 OR G06F16/25 OR G06F16/29 OR G06F16/444 OR G06F17/11 OR G06F17/50 OR G06F17/5036 OR G06F1/3265 OR G06F2009/4557 OR G06F2009/45591 OR G06F2009/45595 OR G06F2201/805 OR G06F2201/85 OR G06F2217/78 OR G06F3/013 OR G06F3/015 OR G06F3/016 OR G06F3/04812 OR G06F3/04815 OR G06F3/0484 OR G06F3/04842 OR G06F3/04845 OR G06F3/04847 OR G06F3/0485 OR G06F3/0487 OR G06F3/12 OR G06F8/30 OR G06F8/38 OR G06F9/453 OR G06F9/45558 OR G06F9/4856 OR G06F9/505 OR G06F9/5077 OR G06F9/5083 OR G06F9/5088 OR G06F9/541 OR G06F9/547 OR G06T19/20 OR G06T2207/30201 OR G06T13/40 OR G06T15/005 OR G06T15/04 OR G06T17/10 OR G06T17/20 OR G06T11/60 OR G06T19/006 OR G06T2210/16 OR G06T7/11 OR G06T7/90 OR G06T17/205 OR G06T1/0007 OR G06T19/00 OR G06T19/003 OR G06T2207/10024 OR G06T2215/16 OR G06T3/40 OR G06T7/251 OR G06T7/73 OR G06T11/00 OR G06T11/001 OR G06T11/40 OR G06T15/02 OR G06T15/10 OR G06T15/80 OR G06T17/00 OR G06T17/05 OR G06T2200/24 OR G06T2207/10016 OR G06T2207/10021 OR G06T2207/20081 OR G06T2207/20221 OR G06T2207/30088 OR G06T2210/32 OR G06T2210/36 OR G06T2219/2004 OR G06T2219/2016 OR G06T7/0012 OR G06T7/0014 OR G06T7/174 OR G06T7/40 OR G06T7/55 OR G06T7/75).CPC.)	USOCR			
S15	2	"20160125227"	US-PGPUB; USPAT	OR	ON	2019/11/08 12:17
S16	41	real ADJ2 time WITH (cosmetic OR make ADJ2 up) AND machine ADJ2 learning AND (neural ADJ2 network OR vector ADJ2 machine OR adversarial)	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 12:47
S17	6738	compressed ADJ2 representation	US-PGPUB; USPAT	OR	ON	2019/11/08 13:59
S18	1	regression ADJ2 fern WITH cluster ADJ2 centre	US-PGPUB; USPAT	OR	ON	2019/11/08 14:01
S19	4	regression ADJ2 fern	US-PGPUB; USPAT	OR	ON	2019/11/08 14:01
S20	182	machine ADJ2 learning WITH look ADJ2 up ADJ2 table	US-PGPUB; USPAT; USOCR	OR	ON	2019/11/08 14:04
S21	38768	compress$4 WITH instructions	US-PGPUB;	OR	ON	2019/11/08 14:15

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			USPAT			
S22	6045	S21 AND ((G06F3/067 OR G06F3/0659 OR G06F3/0631 OR G06F3/0653 OR G06F12/1408 OR G06F3/0608 OR G06F3/061 OR G06F3/0619 OR G06F3/064 OR G06F3/0647 OR G06F3/0665 OR G06F3/0673 OR G06F3/0679 OR G06F3/0683 OR G06F3/0689 OR G06F9/3887 OR G06F9/4401 OR G06F9/5072 OR G06F11/141 OR G06F11/3414 OR G06F12/0862 OR G06F12/0893 OR G06F12/10 OR G06F12/109 OR G06F13/161 OR G06F13/1668 OR G06F13/1694 OR G06F13/4022 OR G06F13/4068 OR G06F13/409 OR G06F13/42 OR G06F13/4282 OR G06F15/8061 OR G06F16/182 OR G06F16/9014 OR G06F17/16 OR G06F1/183 OR G06F21/602 OR G06F2207/4824 OR G06F2209/5019 OR G06F2209/5022 OR G06F2212/1008 OR G06F2212/1024 OR G06F2212/1041 OR G06F2212/1044 OR G06F2212/152 OR G06F2212/202 OR G06F2212/401 OR G06F2212/402 OR G06F2212/7207 OR G06F3/0482 OR G06F3/0604 OR G06F3/0611 OR G06F3/0613 OR G06F3/0616 OR G06F3/0625 OR G06F3/0629 OR G06F3/0638 OR G06F3/0643 OR G06F3/0644 OR G06F3/065 OR G06F3/0655 OR G06F3/0658 OR G06F3/0664 OR G06F3/0688 OR G06F8/65 OR G06F9/30021 OR G06F9/30036 OR G06F9/466 OR G06F9/5016 OR G06F9/5044 OR G06F9/505 OR G06F9/5077 OR G06F9/544 OR G06F11/10 OR G06F11/1469 OR G06F11/3664 OR G06F11/3688 OR G06F11/3692 OR G06F16/221 OR G06F16/2282 OR G06F16/2322 OR G06F16/24578 OR G06F16/252 OR G06F16/258 OR G06F16/27 OR G06F16/285 OR G06F16/743 OR G06F16/904 OR G06F16/9577 OR G06F17/18 OR G06F17/2247 OR G06F17/2252 OR G06F17/2288 OR G06F17/5036 OR G06F1/20 OR G06F1/3231 OR G06F2009/45579 OR G06F2009/45583 OR G06F21/36 OR G06F21/60 OR G06F21/604 OR G06F21/606 OR G06F21/6245 OR G06F21/6272 OR G06F21/629 OR G06F2201/805 OR G06F2212/1052 OR G06F3/0605 OR G06F3/0626 OR G06F3/0634 OR G06F3/0635 OR G06F3/0641 OR G06F3/0652 OR G06F3/0661 OR G06F3/0685 OR G06F7/483 OR G06F7/4876 OR G06F8/4441 OR G06F8/61 OR G06F8/654 OR G06F8/658 OR G06F8/71 OR G06F9/30025 OR G06F9/30032 OR G06F9/3004 OR G06F9/30043 OR	US-PGPUB; USPAT	OR	ON	2019/11/08 14:16

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		G06F9/30072 OR G06F9/30079 OR G06F9/30087 OR G06F9/30181 OR G06F9/3834 OR G06F9/3857 OR G06F9/45558 OR G06F9/50 OR G06F9/5027 OR G06F9/52 OR G06T9/00 OR G06T1/0007 OR G06T1/60 OR G06T2207/10036 OR G06T2207/20021 OR G06T2207/20024 OR G06T7/223).CPC.)				
S23	2979	compress$4 WITH instructions SAME (reduc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 14:28
S24	1596	compress$4 WITH instructions WITH (reduc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 14:29
S25	324	compress$4 ADJ4 instructions WITH (reduc$4)	US-PGPUB; USPAT	OR	ON	2019/11/08 14:29
S26	1	compress$4 ADJ4 instructions WITH (reduc$4) AND machine ADJ2 learning	US-PGPUB; USPAT	OR	ON	2019/11/08 14:30

EAST Search History (Interference)

< This search history is empty>

11/19/2019 9:40:03 AM
C:\Users\jparker4\Documents\EAST\Workspaces\16\16057566.wsp

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

PTO/SB/08a (02-18)
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U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT
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Application Number	16057566
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First Named Inventor	Eric Sommerlade
Art Unit	2618
Examiner Name	PRINGLE-PARKER, JASON A
Attorney Docket Number	409001

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	Attorney Docket Number	409001

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	Attorney Docket Number	409001

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	Examiner Name	PRINGLE-PARKER, JASON A
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Microsoft Corporation v. RealD Spark, LLC
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	Application Number	16057566
	Filing Date	2018-08-07
	First Named Inventor	Eric Sommerlade
	Art Unit	2618
	Examiner Name	PRINGLE-PARKER, JASON A
	Attorney Docket Number	409001

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	Art Unit	2618
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	Attorney Docket Number	409001

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IPR2023-01046 - U.S. Patent No. 10,740,985

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	Examiner Name	PRINGLE-PARKER, JASON A
	Attorney Docket Number	409001

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
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	First Named Inventor	Eric Sommerlade
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	Examiner Name	PRINGLE-PARKER, JASON A
	Attorney Docket Number	409001

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

INFORMATION DISCLOSURE STATEMENT BY APPLICANT
(Not for submission under 37 CFR 1.99)

Application Number	16057566
Filing Date	2018-08-07
First Named Inventor	Eric Sommerlade
Art Unit	2618
Examiner Name	PRINGLE-PARKER, JASON A
Attorney Docket Number	409001

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Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
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	First Named Inventor	Eric Sommerlade
	Art Unit	2618
	Examiner Name	PRINGLE-PARKER, JASON A
	Attorney Docket Number	409001

EXAMINER SIGNATURE			
Examiner Signature	/JASON A PRINGLE-PARKER/	Date Considered	11/19/2019

*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.

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Microsoft Exhibit 1002 - Page 375
Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

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	First Named Inventor	Eric Sommerlade
	Art Unit	2618
	Examiner Name	PRINGLE-PARKER, JASON A
	Attorney Docket Number	409001

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	/Brian E. Harris/	Date (YYYY-MM-DD)	2019-03-08
Name/Print	Brian E. Harris	Registration Number	48383

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.**

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Microsoft Exhibit 1002 - Page 376
Microsoft Corporation v. RealD Spark, LLC
IPR2023-01046 - U.S. Patent No. 10,740,985

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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.

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IPR2023-01046 - U.S. Patent No. 10,740,985

Bibliographic Data

Application No: 16/057,566

Foreign Priority claimed: ○ Yes ◉ No

35 USC 119 (a-d) conditions met: ☐ Yes ☑ No ☐ Met After Allowance

Verified and Acknowledged: /JASON A PRINGLE-PARKER/ (Examiner's Signature) | (Initials)

Title: Adjusting a digital representation of a head region

FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
08/07/2018	345	2618	409001
RULE			

APPLICANTS

RealD Spark, LLC, Beverly Hills, CA,

INVENTORS

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Alexandros Neophytou Oxford, UNITED KINGDOM

CONTINUING DATA

This application has PRO of 62543587 08/10/2017

This application has PRO of 62542661 08/08/2017

FOREIGN APPLICATIONS

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08/24/2018

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FILING FEE RECEIVED

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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
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	Attorney Docket Number	409001

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	1	International search report and written opinion of international searching authority for PCT application PCT/US2018/045648 mailed October 16, 2018	

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[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.

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IPR2023-01046 - U.S. Patent No. 10,740,985

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	16057566
	Filing Date	2018-08-07
	First Named Inventor	Eric Sommerlade
	Art Unit	2618
	Examiner Name	PRINGLE-PARKER, JASON A.
	Attorney Docket Number	409001

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	/Brian E. Harris/	Date (YYYY-MM-DD)	2019-03-08
Name/Print	Brian E. Harris	Registration Number	48383

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.**

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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:

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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.

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s):	RealD Spark, LLC	§	**Art Unit:**	2618
		§		
Serial No.:	16/057,566	§	**Examiner:**	Pringle-Parker, Jason A
		§		
Filed:	August 7, 2018	§	**Atty. Docket No.:**	409001
		§		
		§	**Confirmation No.:**	5211

Submitted via EFS

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

CERTIFICATE OF FILING ELECTRONICALLY VIA EFS 37 CFR 1.8

I HEREBY CERTIFY THAT I HAVE A REASONABLE BASIS FOR BELIEF THAT THIS CORRESPONDENCE IS BEING SUBMITTED TO THE UNITED STATES PATENT AND TRADEMARK OFFICE VIA EFS (ELECTRONICALLY) ON THE DATE INDICATED BELOW, AND IS ADDRESSED TO:
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/Penny L Lowry/
Penny L. Lowry, Reg. No. 57186
DATE OF SUBMISSION: OCTOBER 15, 2019
ELECTRONIC FILING (EFS)

RESPONSE TO ELECTION/RESTRICTION REQUIREMENT

This communication is in response to the Restriction Requirement set forth in the office action mailed August 15, 2019 ("Office Action"). Applicant notes that because the two-month deadline for filing a response expires on October 15, 2019, this response is timely filed.

Listing of Claims begins on page **2** of this filing; and

Remarks begin on page **11** of this filing.

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Electronic Acknowledgement Receipt

EFS ID:	37461444
Application Number:	16057566
International Application Number:	
Confirmation Number:	5211
Title of Invention:	Adjusting a digital representation of a head region
First Named Inventor/Applicant Name:	Eric Sommerlade
Customer Number:	145234
Filer:	Penny Lea Lowry/Stefan Bump
Filer Authorized By:	Penny Lea Lowry
Attorney Docket Number:	409001
Receipt Date:	15-OCT-2019
Filing Date:	07-AUG-2018
Time Stamp:	15:47:45
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		409001_Restriction_Response.pdf	119245 fe1ed9fc721ed3df510c352d0f54dc84746c1f19	yes	11

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Applicant Arguments/Remarks Made in an Amendment	11	11
	Claims	2	10
	Preliminary Amendment	1	1
Warnings:			
Information:			
	Total Files Size (in bytes):	119245	

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.

REMARKS

Claims 1-36 were originally filed in this application. Claims 4-6, 9-16, 18-19, 22, 30-31, and 36 were previously amended to remove multiple dependencies and to correct minor typographical errors. Claims 19-24 and 35-36 are currently withdrawn.

Restriction Requirement

The Office Action sets forth a restriction requirement. Without agreeing with this restriction requirement and to advance prosecution, Applicant elects, without traverse, Examiner's designated Group I (claims 1-18 and 25-34). Accordingly, Applicant withdraws from examination claims 19-24 and 35-36.

Conclusion

If the Examiner has any questions regarding this response or the application in general, the Examiner is invited to contact Applicant's attorney at the below-listed telephone number. Applicant does not believe that any fees are due with the filing of this document; however, if it is determined that any additional fees are due, or if an overcharge had occurred, please charge or credit deposit account no. 50-6262, referencing Attorney Docket No. 409001.

Respectfully submitted,

/Penny L Lowry/

Date: October 15, 2019

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RealD Inc.
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LISTING OF CLAIMS

The listing of claims will replace all prior versions, and listings, of claims in the application.

1. (Original) A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region.

2. (Original) The method of claim 1, wherein:

the first reference data comprise first editing instructions for a range of possible configurations of the target feature and first selection instructions for selecting editing instructions for a particular input patch from the first editing instructions based on the configuration of the target feature of the input patch; and

the second reference data comprise second editing instructions for a range of possible configurations of the target feature and second selection instructions for selecting editing

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instructions for a particular input patch from the second image editing instructions based on the configuration of the target feature of the input patch.

3. (Original) The method of claim 2, wherein the configuration of the target feature of each input patch is represented by a feature vector derived from plural local descriptors of the input patch, and the first and second selection instructions define how the feature vector is used to select editing instructions for the input patch.

4. (Previously presented) The method of claim 2, wherein the editing instructions comprise a displacement vector field defining how the input patch is to be transformed.

5. (Previously presented) The method of claim 2, wherein the editing instructions comprise a filter field, a brightness adjustment field, or a texture blending field.

6. (Previously presented) The method of claim 2, wherein:

a first editing algorithm is used by the first machine learning algorithm to define how the first editing instructions are to be applied to an input patch to derive an output patch; and

a second editing algorithm is used by the second machine learning algorithm to define how the second editing instructions are to be applied to an input patch to derive an output patch.

7. (Original) The method of claim 6, wherein:

the second editing instructions are principle component analysis components of a principle component analysis of the first editing instructions; and

the second image editing algorithm is configured to transform the second editing instructions into the first editing instructions by inverse principle component analysis transform.

8. (Original) The method of claim 6, wherein:

the second editing instructions are wavelet components of the first editing instructions; and

the second editing algorithm is configured to transform the second editing instructions into the first editing instructions by inverse wavelet transform.

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9. (Previously presented) The method of claim 2, wherein the first selection instructions for the first reference data are able to select between a larger number of alternative editing instructions than the second selection instructions for the second reference data.

10. (Previously presented) The method of claim 1, wherein the first machine learning algorithm is of a different machine learning algorithm type than the second machine learning algorithm.

11. (Previously presented) The method of claim 1, wherein the first machine learning algorithm comprises one or more of the following: a neural network; a support vector machine; and a generative adversarial network (GAN).

12. (Previously presented) The method of claim 1, wherein the second machine learning algorithm comprises one or more of the following: a regression forest; regression ferns, cluster centres, a lookup table, and separable filter banks.

13. (Previously presented) The method of claim 1, wherein the first machine learning algorithm comprises a first neural network and the second machine learning algorithm comprises a second neural network, wherein the second neural network comprises fewer layers and/or smaller convolution fields than the first neural network.

14. (Previously presented) The method of claim 1, wherein the target feature comprises one or more of the following: an eye region comprising at least part of an eye, a nose region comprising at least part of a nose, a mouth region comprising at least part of a mouth, a chin region comprising at least part of a chin, a neck region comprising at least part of a neck, and a hair region comprising hair.

15. (Previously presented) The method of claim 1, wherein:

the target feature comprises an eye region comprising at least part of an eye and the adjustment of the digital representation of the head region comprises adjusting a gaze direction;

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the target feature comprises a nose region comprising at least part of a nose and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the nose;

the target feature comprises a chin region comprising at least part of a chin and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the chin;

the target feature comprises a neck region comprising at least part of a neck and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the neck; and/or

the target feature comprises a hair region comprising hair and the adjustment of the digital representation of the head region comprises adjusting a color of the hair.

16. (Previously presented) The method of claim 1, wherein the second editing instructions in the second reference data are provided in a compressed representation.

17. (Original) The method of claim 16, wherein the compressed representation comprises one or more of the following: a principle component analysis representation; a wavelet representation; Fourier and/or discrete cosine transform components; cluster centers.

18. (Previously presented) A method of adjusting a digital representation of a head region, the method comprising

receiving a digital representation of a head region; and

using reference data comprising editing instructions to adjust the digital representation of the head region, wherein the reference data comprises the second reference data generated by the method of claim 1.

19. (Withdrawn) A method of adjusting a digital representation of a head region, the method comprising:

identifying a target patch in the digital representation of the head region, the target patch comprising a target feature of the digital representation of the head region;

deriving a feature vector from plural local descriptors of the target patch;

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using the feature vector to select editing instructions from reference data, the reference data comprising editing instructions for a range of possible values of the feature vector; and

applying the selected editing instructions to the target patch to adjust the digital representation of the head region, wherein:

the reference data comprises the second reference data generated by the method of claim 1.

20. (Withdrawn) A method of adjusting a digital representation of a head region, the method comprising:

identifying a target patch in the digital representation of the head region, the target patch comprising a target feature of the digital representation of the head region;

deriving a feature vector from plural local descriptors of the target patch;

using the feature vector to select editing instructions from reference data, the reference data comprising editing instructions for a range of possible values of the feature vector; and

applying the selected editing instructions to the target patch to adjust the digital representation of the head region, wherein:

the editing instructions in the reference data are provided in a compressed representation.

21. (Withdrawn) The method of claim 20, wherein the compressed representation comprises one or more of the following: a principle component analysis representation; a wavelet representation; Fourier and/or discrete cosine transform components; cluster centres.

22. (Withdrawn) The method of claim 18, wherein a plurality of the digital representations of the head region are received and adjusted, each digital representation being captured from the head region at a different point in time, and the method further comprises updating the second machine learning algorithm using editing instructions generated by the first machine learning algorithm using one or more of the received and adjusted digital representations.

23. (Withdrawn) The method of claim 22, wherein the updating of the second machine learning algorithm is performed at or near input data frame rate.

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24. (Withdrawn) The method of claim 23, wherein only a subset of the received and adjusted digital representations are used to update the second machine learning algorithm.

25. (Original) A method of training a machine learning algorithm to adjust a digital representation of a head region, comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

first reference data generated by a pre-trained first machine learning algorithm, the first reference data comprising a set of editing instructions in one-to-one correspondence with the input patches, each editing instruction being for adjusting the digital representation of the head region;

updating a pre-trained second machine learning algorithm trained to generate second reference data, where the input for the updating comprises the training data and the generated first reference data, the second reference data comprising editing instructions for adjusting the digital representation of the head region.

26. (Original) The method of claim 25, wherein the updating of the second machine learning algorithm is performed at or near input data frame rate.

27. (Original) A method of training a machine learning algorithm to adjust a digital representation of a head region, the method comprising:

receiving training data comprising a set of input digital representations of a head region;

training a first machine learning algorithm using the training data to perform an adjustment of a digital representation of a head region;

using the trained first machine learning algorithm to generate first reference data, the first reference data comprising an adjusted digital representation of the head region for each of at least a subset of the input digital representations, each adjusted digital representation being obtained by performed the adjustment that the first machine learning algorithm was trained to perform; and

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training a second machine learning algorithm using at least a subset of the training data used to train the first machine learning algorithm and the first reference data to perform the same adjustment of a digital representation of a head region as the first machine learning algorithm.

28. (Original) The method of claim 27, wherein the adjustment of the digital representation comprises converting from a two-dimensional digital representation to a three-dimensional digital representation.

29. (Original) The method of claim 28, wherein the training of the first machine learning algorithm comprises iteratively using a rendering process to generate a two-dimensional digital representation from a three-dimensional digital representation generated by the first machine learning algorithm and comparing the generated digital representation with a corresponding digital representation in the training data.

30. (Previously presented) The method of claim 25, further comprising receiving a further digital representation of the head region and using the updated or trained second machining learning algorithm to adjust the further digital representation.

31. (Previously presented) A computer program capable of execution by a processor and arranged on execution to cause the processor to perform a method according to claim 1.

32. (Original) A computer readable storage medium storing a computer program according to claim 31.

33. (Original) A device for generating reference data for adjusting a digital representation of a head region, the device comprising a data processing unit arranged to:

receive training data comprising:

a set of input patches, each input patch comprising information about a target feature of a digital representation of the head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

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a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target portion of the digital representation of the head region after adjustment of the digital representation of the head region;

use a first machine learning algorithm to generate first reference data using the training data; and

use a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data output by the first machine learning algorithm.

34. (Original) The device of claim 33, wherein:

the first reference data comprises editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region;

the second reference data comprises editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region;

the second editing instructions in the second reference data are provided in a compressed representation.

35. (Withdrawn) A device for adjusting a digital representation of a head region, the device comprising a data processing unit arranged to process the digital representation of the head region by:

identifying a target patch in the digital representation of the head region, the target patch comprising information about a target feature of the digital representation of the head region;

deriving a feature vector from plural local descriptors of the target patch;

using the feature vector to select editing instructions from reference data, the reference data comprising editing instructions for a range of possible values of the feature vector; and

applying the selected editing instructions to the target patch to adjust the digital representation of the head region, wherein:

the editing instructions in the reference data are provided in a compressed representation.

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36. (Withdrawn) The device of claim 35, further comprising a telecommunications interface arranged to transmit the adjusted digital representation over a telecommunications network to a destination device to allow display of the head region thereon.

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