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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
62/232,222	09/24/2015		130	OUST-M01-PRV		

CONFIRMATION NO. 3195

FILING RECEIPT

129794
Run8 Patent Group, LLC
268 Bush Street #2712
San Francisco, CA 94104-3503

OC000000077954744

Date Mailed: 10/09/2015

Receipt is acknowledged of this provisional patent application. It will not be examined for patentability and will become abandoned not later than twelve months after its filing date. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Angus Pacala, San Francisco, CA;
Mark Frichtl, San Francisco, CA;

Applicant(s)

Ouster, Inc., San Francisco, CA;

Power of Attorney:
Peter Miller--69351

Permission to Access - A proper **Authorization to Permit Access to Application by Participating Offices** (PTO/SB/39 or its equivalent) has been received by the USPTO.

If Required, Foreign Filing License Granted: 10/08/2015

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 62/232,222**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No
**** SMALL ENTITY ****
Title

OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

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This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	OUST-M01-PRV
	Application Number	
Title of Invention	OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Angus		Pacala	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	San Francisco	State/Province	CA	Country of Residence i	US

Mailing Address of Inventor:

Address 1	2959 Mission St.		
Address 2			
City	San Francisco	**State/Province**	CA
Postal Code	94110	**Country** i	US

Inventor 2 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Mark		Frichtl	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	San Francisco	State/Province	CA	Country of Residence i	US

Mailing Address of Inventor:

Address 1	2959 Mission St.		
Address 2			
City	San Francscio	**State/Province**	CA
Postal Code	94110	**Country** i	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	OUST-M01-PRV
	Application Number	
Title of Invention	OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD	

☐ **An Address is being provided for the correspondence Information of this application.**			
Customer Number	129794		
Email Address	docketing@r8pg.com	Add Email	Remove Email

Application Information:

Title of the Invention	OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD		
Attorney Docket Number	OUST-M01-PRV	**Small Entity Status Claimed**	☒
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)		**Suggested Figure for Publication (if any)**	

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)
☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	129794		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the application number blank.

Prior Application Status			Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button. Add

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	OUST-M01-PRV
	Application Number	
Title of Invention	OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD	

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(d). When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX) [i]the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(h)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Remove

Application Number	Country [i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Authorization to Permit Access:

☒ Authorization to Permit Access to the Instant Application by the Participating Offices

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	OUST-M01-PRV
	Application Number	
Title of Invention	OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD	

If checked, the undersigned hereby grants the USPTO authority to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the instant patent application is filed access to the instant patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the instant patent application is filed to have access to the instant patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the instant patent application with respect to: 1) the instant patent application-as-filed; 2) any foreign application to which the instant patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the instant patent application; and 3) any U.S. application-as-filed from which benefit is sought in the instant patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date of filing this Authorization.

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1 Remove

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

(•) Assignee	( ) Legal Representative under 35 U.S.C. 117	( ) Joint Inventor
( ) Person to whom the inventor is obligated to assign.	( ) Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor :

If the Applicant is an Organization check here. [X]

Organization Name	Ouster, Inc.		
Mailing Address Information:			
Address 1	2959 Mission St.		
Address 2			
City	San Francisco	**State/Province**	CA
Country [i]	US	Postal Code	94110
Phone Number		Fax Number	

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	OUST-M01-PRV
	Application Number	
Title of Invention	OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD	

Email Address	

Additional Applicant Data may be generated within this form by selecting the Add button. Add

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not subsitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication . An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

Remove

If the Assignee or Non-Applicant Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1			
Address 2			
City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button. Add

Signature:

Remove

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

Signature	/Peter Miller/			Date (YYYY-MM-DD)	2015-09-24
First Name	Peter	Last Name	Miller	Registration Number	69351

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	OUST-M01-PRV
	Application Number	
Title of Invention	OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD	

This collection of information is required by 37 CFR 1.76. 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 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet 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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The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

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

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

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

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

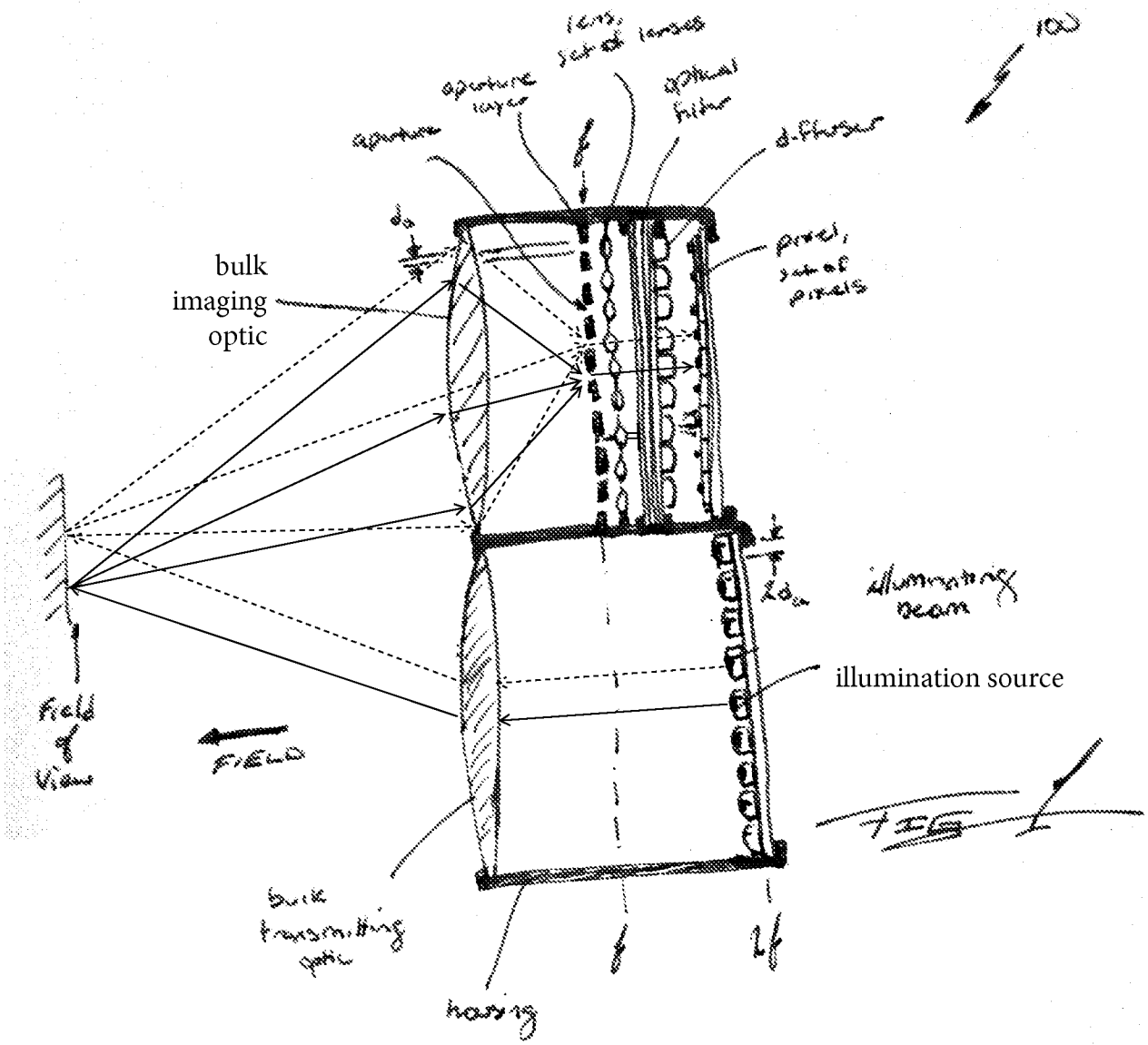
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.

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

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

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

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


bulk
imaging
optic
illumination source
Field
of
View
FIELD
bulk
transmitting
optic
housing

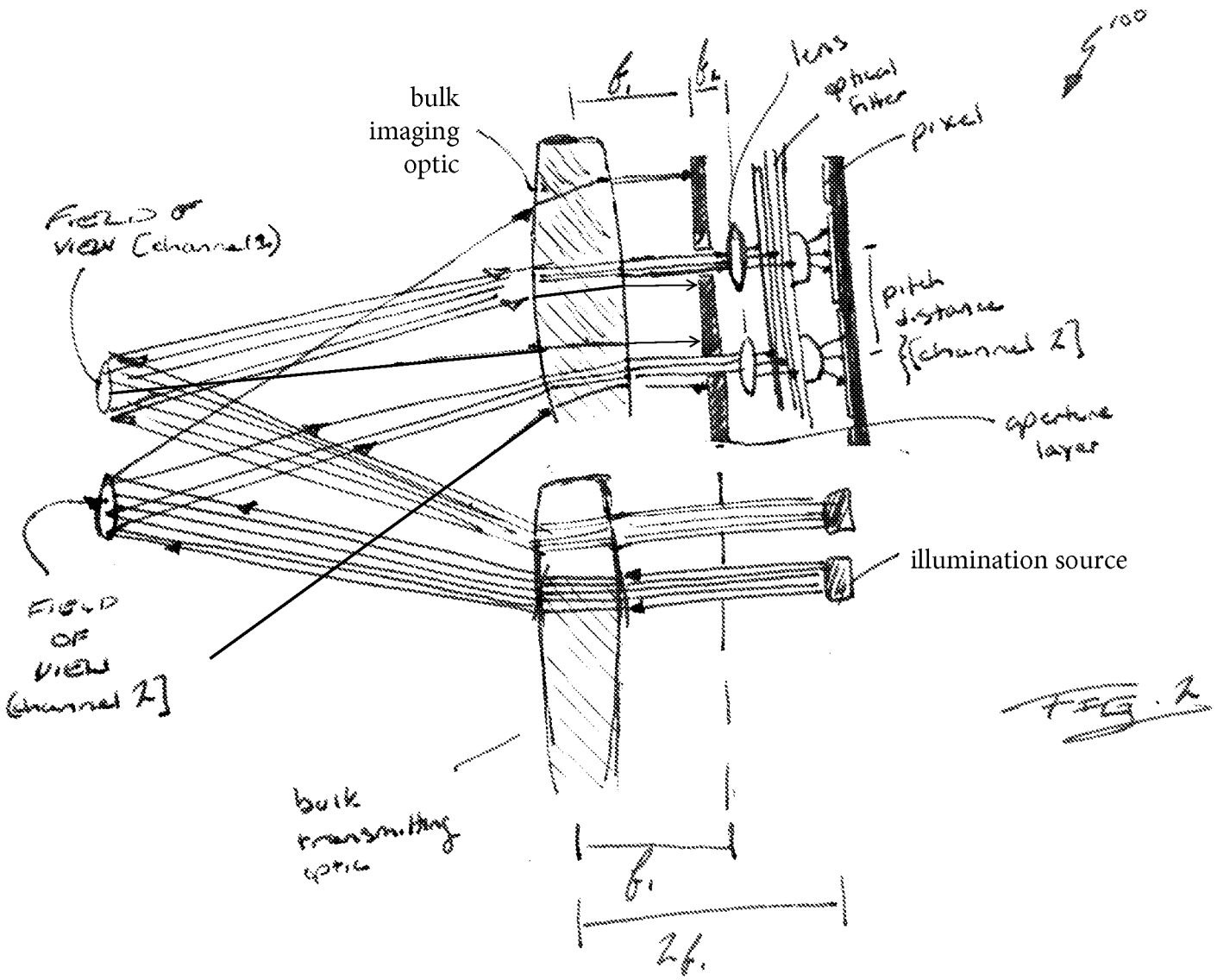

bulk
imaging
optic
lens
optical
filter
pixel
pitch
distance
(channel 2)
aperture
layer
illumination source
bulk
transmitting
optic
f_1
$2f_1$

FIG. 2

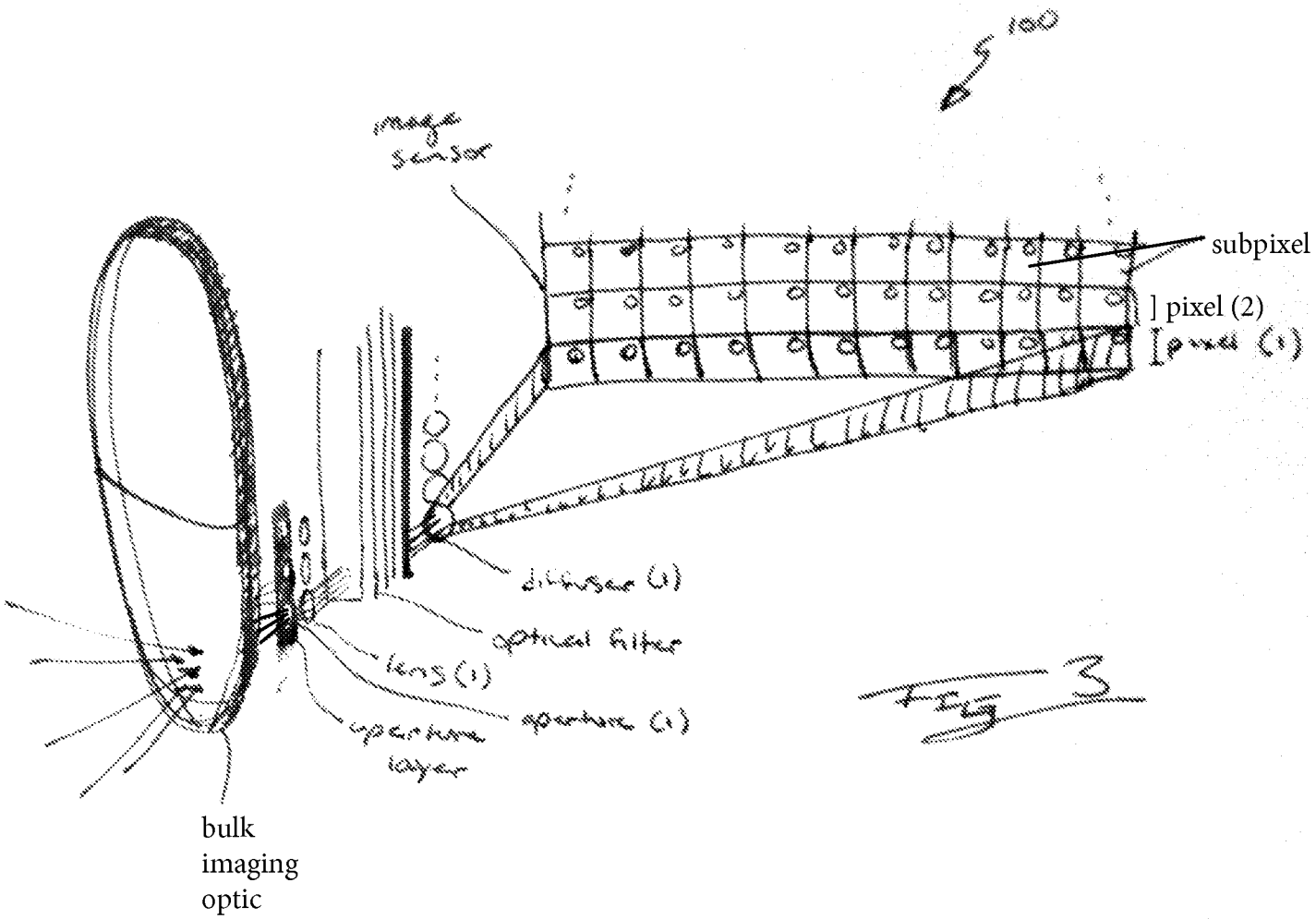

100
image sensor
subpixel
] pixel (2)
[pixel (1)
diffuser (1)
optical filter
lens (1)
aperture (1)
aperture layer
bulk imaging optic

Fig 3

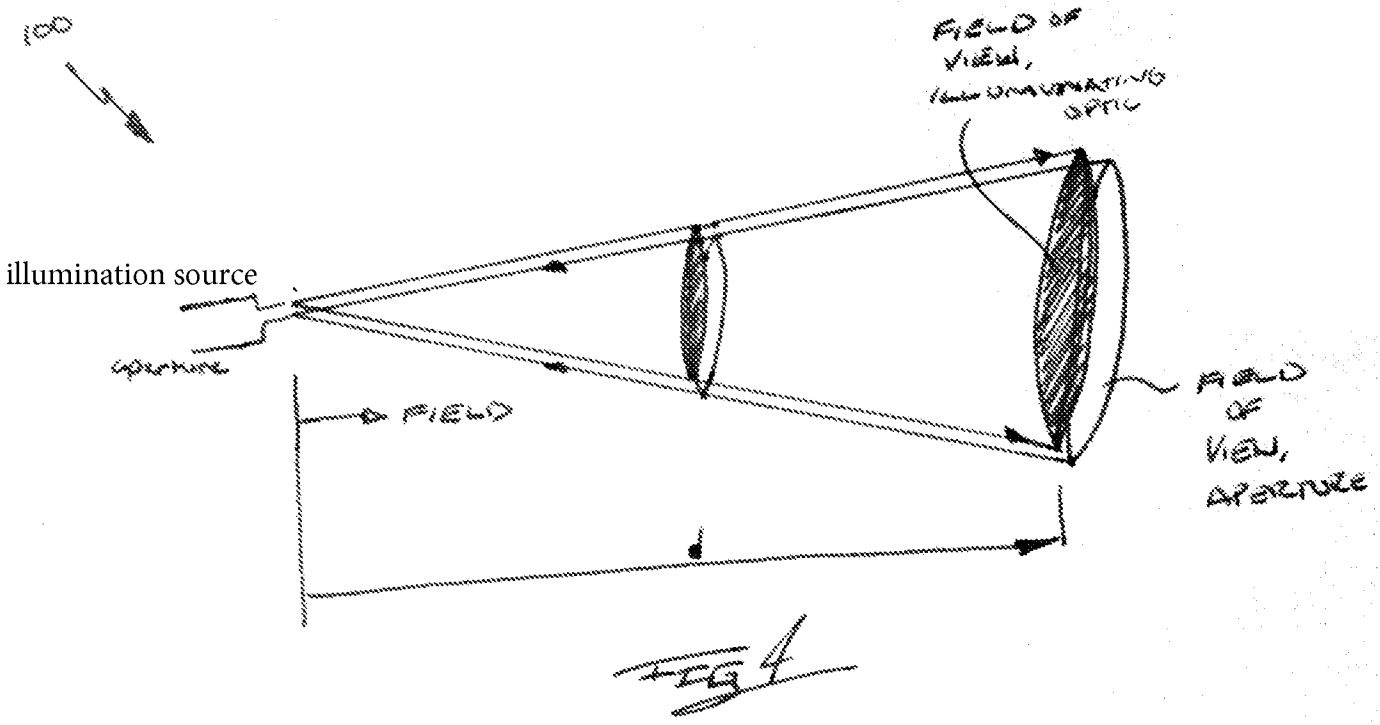


Fig 1

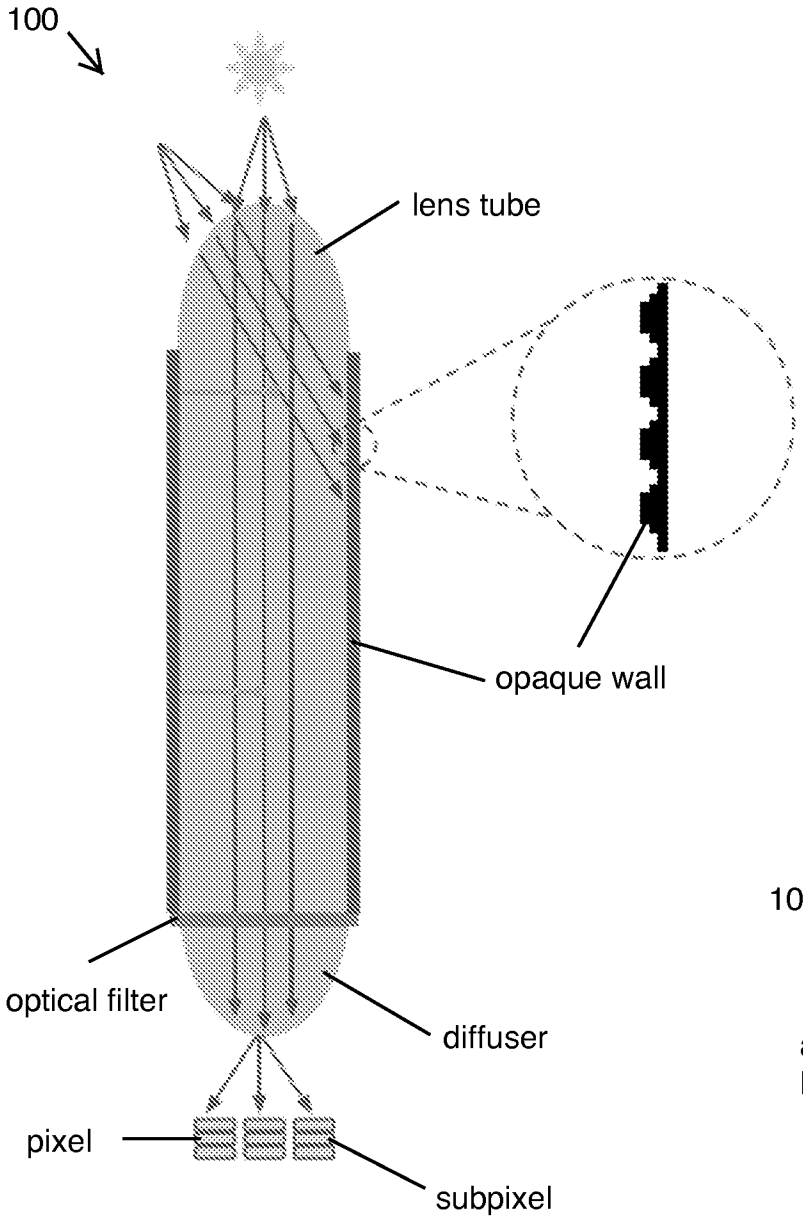


FIGURE 5

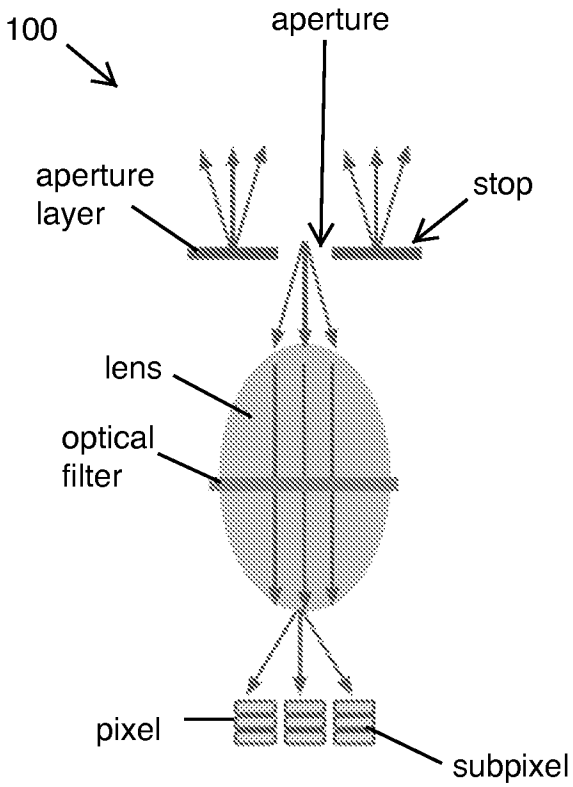


FIGURE 6

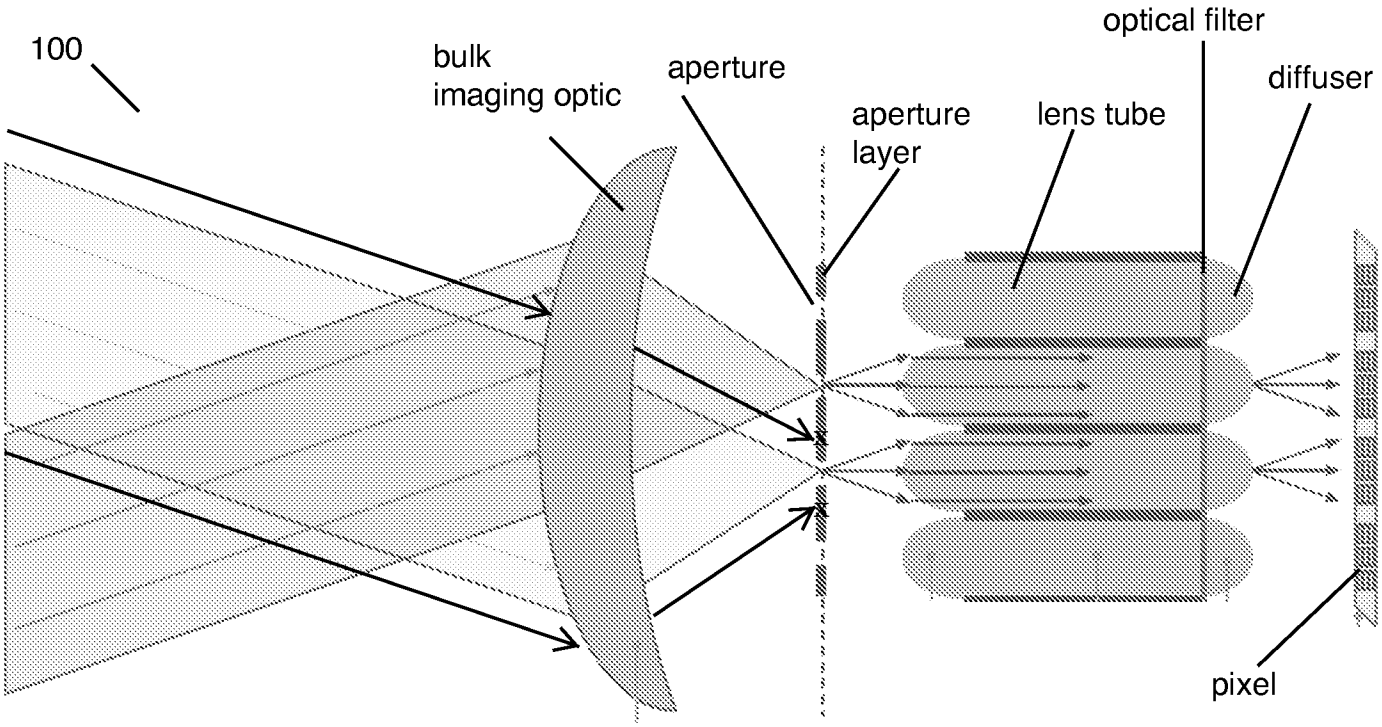


FIGURE 7

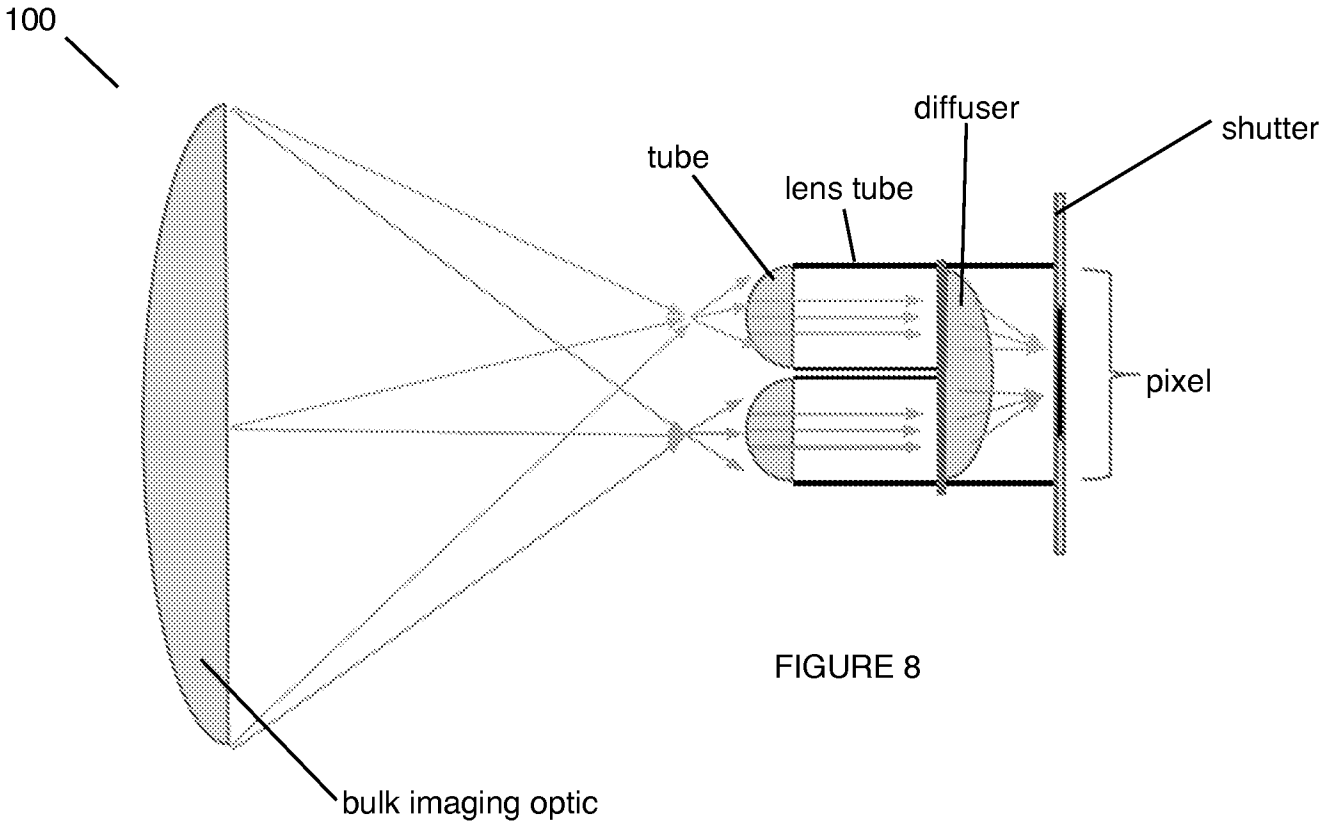


FIGURE 8

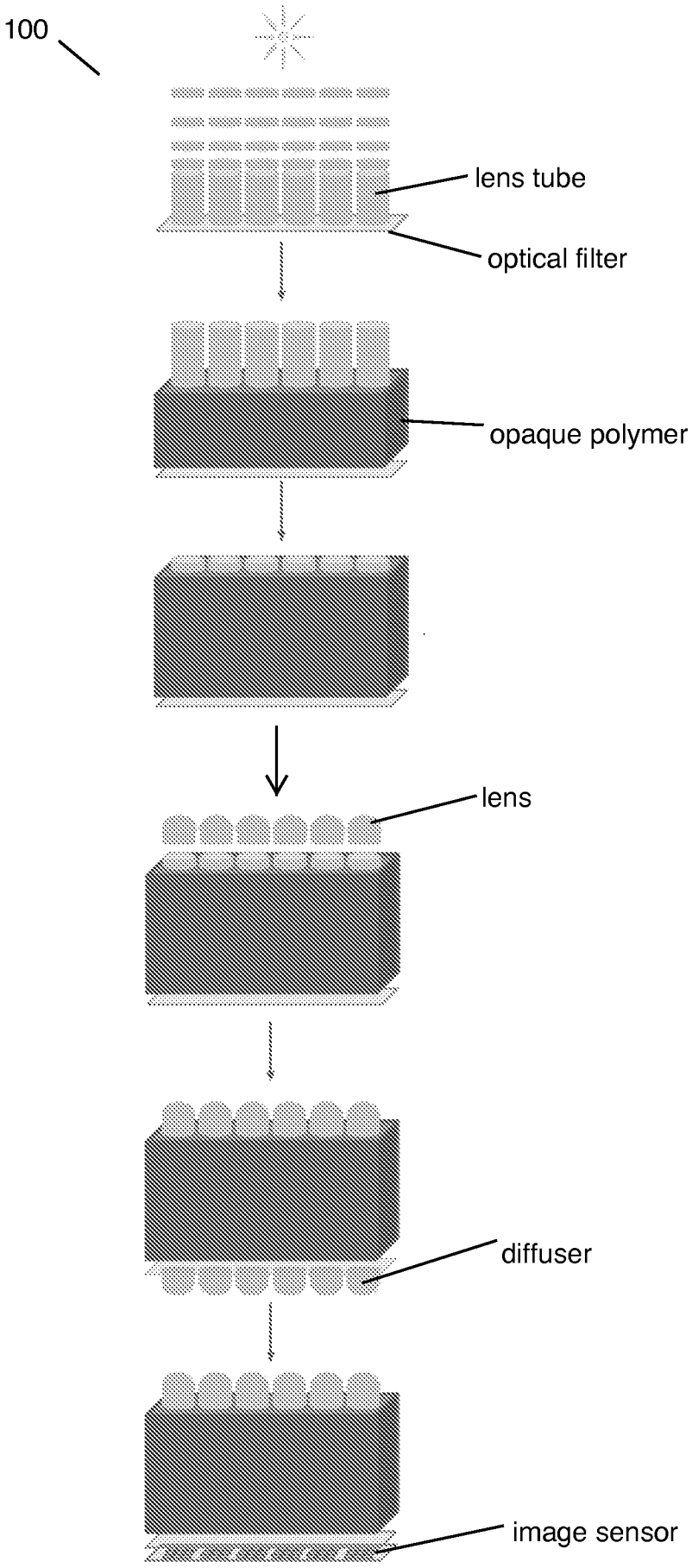

100
lens tube
optical filter
opaque polymer
lens
diffuser
image sensor

FIGURE 9

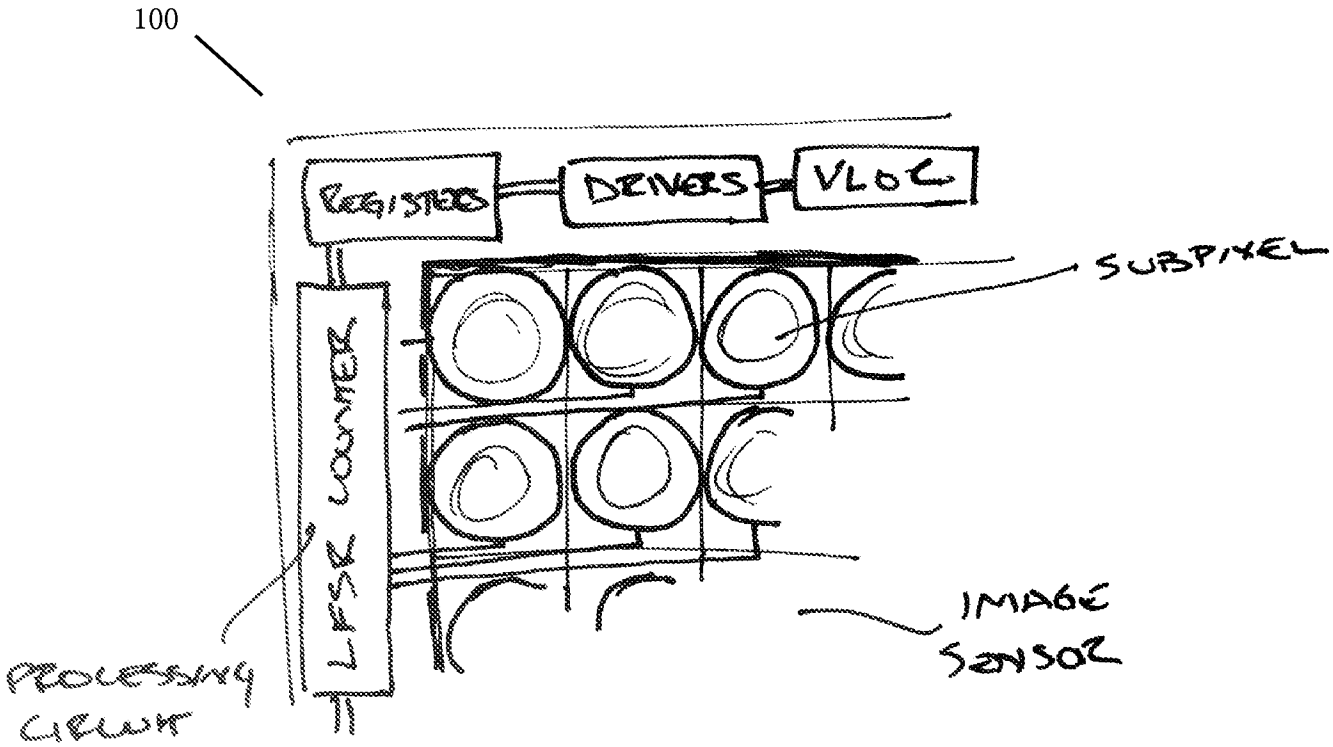

100
REGISTERS
DRIVERS
VLOC
SUBPIXEL
TDSK COUNTER
PROCESSING CIRCUIT
IMAGE SENSOR

FIGURE 10

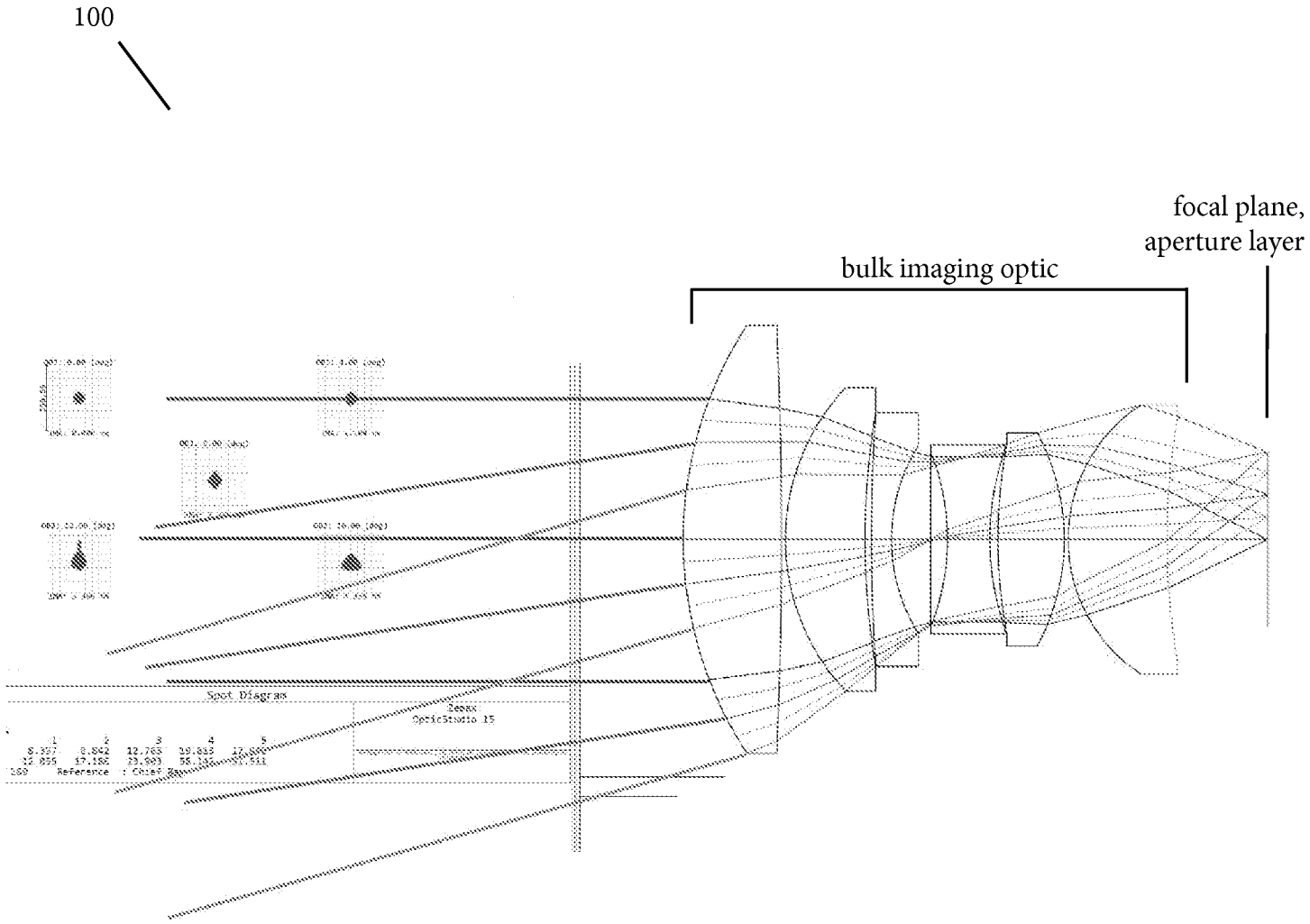

100
focal plane,
aperture layer
bulk imaging optic
Spot Diagram
Zemax
OpticStudio 15

FIGURE 11

OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD

TECHNICAL FIELD

[0001] This invention relates generally to the field of optical sensors and more specifically to a new and useful optical system for collecting distance information in the field of optical sensors.

BRIEF DESCRIPTION OF THE FIGURES

[0002] FIGURE 1 is a schematic representation of a system;

[0003] FIGURE 2 is a schematic representation in accordance with one variation of the system;

[0004] FIGURE 3 is a schematic representation in accordance with one variation of the system;

[0005] FIGURE 4 is a schematic representation in accordance with one variation of the system;

[0006] FIGURE 5 is a schematic representation in accordance with one variation of the system;

[0007] FIGURE 6 is a schematic representation in accordance with one variation of the system;

[0008] FIGURE 7 is a schematic representation in accordance with one variation of the system;

[0009] FIGURE 8 is a schematic representation in accordance with one variation of the system;

[0010] FIGURE 9 is a flowchart representation in accordance with one variation of the system;

[0011] FIGURE 10 is a schematic representation in accordance with one variation of the system; and

[0012] FIGURE 11 is a schematic representation in accordance with one variation of the system.

DESCRIPTION OF THE EMBODIMENTS

[0013] The following description of embodiments of the invention is not intended to limit the invention to these embodiments but rather to enable a person skilled in the art to make and use this invention. Variations, configurations, implementations, example implementations, and examples described herein are optional and are not exclusive to the variations, configurations, implementations, example implementations, and examples they describe. The invention described herein can include any and all permutations of these variations, configurations, implementations, example implementations, and examples.

1. One-Dimensional Optical System: Aperture Array

[0014] As shown in FIGURE 1, a one-dimensional optical system for collecting distance information within a field includes: a set of illumination sources arranged along a first axis, each illumination source in the set of illumination sources configured

to output an illuminating beam of an operating wavelength toward a discrete spot in the field ahead of the illumination source; a bulk imaging optic characterized by a focal plane opposite the field; an aperture layer coincident the focal plane, defining a set of apertures in a line array parallel to the first axis, and defining a stop region around the set of apertures, each aperture in the set of apertures defining a field of view in the field coincident a discrete spot output by a corresponding illumination source in the set of illumination sources, the stop region absorbing light rays reflected from surfaces in the field outside of fields of view defined by the set of apertures and passing through the bulk imaging optic; a set of lenses, each lens in the set of lenses characterized by a second focal length, offset from the focal plane opposite the bulk imaging optic by the second focal length, aligned with an aperture in the set of apertures, and configured to collimate light rays passed by the aperture; an optical filter adjacent the set of lenses opposite the aperture layer and configured to pass light rays at the operating wavelength; a set of pixels adjacent the optical filter opposite the set of lenses, each pixel in the set of pixels corresponding to a lens in the set of lenses and including a set of subpixels arranged along a second axis non-parallel to the first axis; and a diffuser interposed between the optical filter and the set of pixels and configured to spread collimated light output from each lens in the set of lenses across a set of subpixels of a corresponding pixel in the set of pixels.

1.1 Applications

[0015] Generally, the one-dimensional optical system (the "system") functions as an image sensor that, when rotated about an axis parallel to a column of apertures, collects three-dimensional distance data of a volume occupied by the system.

Specifically, the one-dimensional optical system can scan a volume to collect three-dimensional distance data that can then be reconstructed into a virtual three-dimensional representation of the volume, such as based on recorded times between transmission of illuminating beams from the illumination sources and detection of photons – likely originating from the illumination sources – incident on the set of pixels, based on phase-based measurements techniques, or based on any other suitable distance measurement technique. The system includes: a column of offset apertures arranged behind a bulk imaging optic and defining discrete fields of view in a field ahead of the bulk imaging optic (that is non-overlapping fields of view beyond a threshold distance from the system); a set of illumination sources that project discrete illuminating beams at an operating wavelength into (and substantially only into) the fields of view defined by the apertures; a column of lenses that collimate light rays passed by corresponding apertures; and an optical filter that selectively passes a narrow band of wavelengths of light (i.e., electromagnetic radiation) including the operating wavelength; and a set of pixels that detect incident photons (e.g., count incident photons, tracks times between consecutive incident photons). The system can therefore selectively project illuminating beams into a field ahead of the system according to an illumination pattern that substantially matches – in size and geometry across a range of distances from the system – the fields of view of the apertures. In particular, the illumination sources are configured to illuminate substantially only surfaces in the field ahead of the system that can be detected by pixels in the system such that minimal power output by the system (via the illumination sources) is wasted by illuminating surfaces in the field for which the pixels are blind. The system can therefore achieve a relatively high ratio of output signal (i.e., illuminating beam power) to input signal (i.e.,

photons passed to an incident on the pixel array). Furthermore, the set of lenses can collimate light rays passed by adjacent apertures such that light rays incident on the optical filter meet the optical filter at an angle of incidence of approximately 0°, thereby maintaining a relatively narrow band of wavelengths of light passed by the optical filter and achieving a relatively high signal-to-noise ratio ("SNR") for light rays reaching the set of pixels.

[0016] The system includes pixels arranged in a column and aligned with the apertures, and each pixel can be non-square in geometry (e.g., short and wide) to extend the sensing area of the system for a fixed aperture pitch and pixel column height. The system also includes a diffuser that spreads light rays passed from an aperture through the optical filter across the area of a corresponding pixel such that the pixel can detect incident photons across its full width and height thereby increasing the dynamic range of the system.

[0017] The system is described herein as projecting electromagnetic radiation into a field and detecting electromagnetic radiation reflected from a surface in the field back to bulk reliever optic. Terms "illumination beam," "light," "light rays," and "photons" recited herein refer to such electromagnetic radiation. The term "channel" recited herein refers to one aperture in the aperture layer, a corresponding lens in the set of lenses, and a corresponding pixel in the set of pixels.

1.2 Bulk Imaging Optic

[0018] The system includes a bulk imaging optic characterized by a focal plane opposite the field. Generally, the bulk imaging optic functions to project incident light rays from outside the system toward the focal plane where light rays incident on a stop

region of the aperture layer are rejected (e.g., mirrored or absorbed) and where light rays incident on apertures in the aperture layer are passed into a lens characterized by a focal length and offset from the focal plane by the focal length.

[0019] In one implementation, the bulk imaging optic includes a converging lens, such as a bi-convex lens (shown in FIGURE 2) or a plano-convex lens, characterized by a particular focal length at the operating wavelength of the system. The bulk imaging optic can also include multiple discrete lens that cooperate to project light rays toward the aperture layer and that are characterized by a composite focal place opposite the field, as shown in FIGURE 11. However, the bulk imaging optic can be any other suitable type of lens or combination of lenses of any other type or geometry.

1.3 Aperture Layer

[0020] As shown in FIGURE 1 and 2, the system includes an aperture layer coincident the focal plane, defining a set of apertures in a line array parallel to the axes of the illumination sources, and defining a stop region around the set of apertures, wherein each aperture in the set of apertures defines a field of view in the field coincident a discrete spot output by a corresponding illumination source in the set of illumination sources, and wherein the stop region absorbs and/or reflects light rays reflected from surfaces in the field outside of fields of view defined by the set of apertures and passing through the bulk imaging optic. Generally, the aperture layer defines an array of open regions (i.e., apertures, including one aperture per lens) and closed regions ("stop regions") between adjacent opens. Each aperture in the aperture layer defines a "pinhole" that defines a field of view for its corresponding sense channel and passes light rights reflected from an external surface within its field of the view into

its corresponding lens, and each stop region can block light rays incident on select regions of the focal plane from passing into the lens array, as shown in FIGURE 6.

[0021] The aperture layer includes a relatively thin opaque structure coinciding with (e.g., arranged along) the focal plane of the bulk imaging optic, as shown in FIGURES 1 and 2. For example, the aperture layer can include a 10 micrometer-thick copper, silver, or nickel film deposited (e.g., plated) over a photocurable transparent polymer and then selectively etched to form the array of apertures. In a similar example, a reflective metalized layer or a light-absorbing photopolymer (e.g., a photopolymer mixed with a light absorbing dye) can be deposited onto a glass wafer and selectively cured with a photomask to form the aperture layer and the set of apertures. Alternatively, the aperture layer can include a discrete metallic film that is mechanically or chemically perforated to form the array of apertures, bonded to the lens array, and then installed over the bulk imaging optic along the focal plane. However, the aperture layer can include any other reflective (e.g., mirrored) or light-absorbing material formed in any other way to define the array of apertures along the focal plane of the bulk imaging optic.

[0022] In the one-dimensional optical system, the aperture layer can define a single column of multiple discrete circular apertures of substantially uniform diameter, wherein each aperture defines an axis substantially parallel to and aligned with one lens in the lens array, as shown in FIGURE 3. Adjacent apertures are offset by an aperture pitch distance greater than the aperture diameter and substantially similar to the lens pitch distance, and the aperture layer defines a stop region (i.e., an opaque or reflecting region) between adjacent apertures such that the apertures define discrete, non-overlapping fields of view for their corresponding sense channels. At increasingly

smaller diameters up to a diffraction-limited diameter – which is a function of wavelength of incident light and numeric aperture of the bulk imaging lens – an aperture defines a narrower field of view (i.e., a field of view of smaller diameter) and passes a sharper but lower-intensity (attenuated) signal from the bulk imaging optic into its corresponding lens. The aperture layer can therefore define apertures of diameter: greater than the diffraction-limited diameter for the wavelength of light output by the illumination sources (e.g., 900 nm); substantially greater than the thickness of the aperture layer; and less than the aperture pitch distance, which is substantially equivalent to the lens pitch distance and the pixel pitch distance. In one example, aperture layer can define apertures of diameters approaching the diffraction-limited diameter to maximize geometrical selectivity of the field of view of each sense channel. Alternatively, the apertures can be of diameter less that the diffraction-limited diameter for the wavelength of light output by the illumination sources. In one example, the aperture layer can define apertures of diameters matched to a power output of illumination sources in the system and to a number and photon detection capacity of subpixel photodetectors in each pixel in the set of pixels to achieve a target number of photons incident on each pixel within each sampling period. In this example, each aperture can define a particular diameter that achieves target attenuation range for pixels originating from a corresponding illumination source and incident on the bulk imaging optic during a sampling period. In particular, because an aperture in the aperture layer attenuates a signal passed to its corresponding lens and on to its corresponding pixel, the diameter of the aperture can be matched to the dynamic range of its corresponding pixel.

[0023] In one implementation, a first aperture in the aperture layer passes light rays – reflected from a discrete region of a surface in the field (the field of view of the sense channel) ahead of the bulk imaging optic – into its corresponding lens; a stop region interposed between the first aperture and adjacent apertures in the aperture layer blocks light rays – reflected from a region of the surface outside of the field of view of the first aperture – from passing into the lens corresponding to the first aperture. In the one-dimensional optical system, the aperture layer therefore defines a column of apertures that define multiple discrete, non-overlapping fields of view of substantially infinite depth of field, as shown in FIGURE 2.

[0024] In this implementation, a first aperture in the aperture layer defines a field of view that is distinct and that does not intersect a field of view defined by another aperture in the aperture layer, as shown in FIGURE 2. The set of illumination sources includes a first illumination source paired with the first aperture and configured to project an illuminating beam substantially aligned with (i.e., overlapping) the field of view of the first aperture in the field ahead of the bulk imaging optic. Furthermore, the first illumination source and a bulk transmitting optic can cooperate to project an illuminating beam of a cross-section substantially similar to (and slightly larger than) the cross section of the field of view of the first aperture as various distances from the bulk imaging optic. Therefore light output by the first illumination source – paired with the first aperture – and projected into the field of view of the first aperture can remain substantially outside the fields of view of other apertures in the aperture layer.

[0025] Generally, photons projected into the field by the first illumination source illuminate a particular region of a surface (or multiple surfaces) in the field within the field of view of the first sense channel and are reflected (e.g., scattered) by the

surface(s); at least some of these photons reflected by the particular region of a surface may reach the bulk imaging optic, which directs these photons toward the focal plane. Because these photons were reflected by a region of a surface within the field of view of the first aperture, the bulk imaging optic may project these photons into the first aperture, and the first aperture may pass these photons into the first lens (or a subset of these photons incident at an angle relative to the axis of the first aperture below a threshold angle). However, because a second aperture in the aperture layer is offset from the first aperture and because the particular region of the surface in the field illuminated via the first illumination source does not (substantially) coincide with the field of view of the second aperture, photons reflected by the particular region of the surface and reaching the bulk imaging optic are projected into the second aperture and passed to a second lens behind the second aperture, and vice versa, as shown in FIGURE 2. Furthermore, a stop region between the first and second apertures can block photons directed toward the focal plane between the first and second apertures reflected by the bulk imaging optic, thereby reducing crosstalk between the first and second sense channels.

[0026] For a first aperture in the aperture layer paired with a first illumination source in the set of illumination sources, the first aperture in the aperture layer defines a first field of view and passes – into the first lens – incident light rays originating at or reflected from a surface in the field coinciding with the first field of view. Because the first illumination source projects an illuminating beam that is substantially coincident (and substantially the same size as or minimally larger than) the field of view defined by the first aperture (as shown in FIGURE 4), a signal passed into the first lens by the first aperture in the aperture layer can exhibit a relatively high ratio of light rays originating

from the first illumination source to light rays originating from other illumination sources in the system. Generally, because various illumination sources in the system may output illuminating beams at different frequencies, duty cycles, and/or power levels, etc. at a particular time during operation, light rays passed from the bulk imaging optic into a first pixel in the set of pixels but originating from an illumination source other than the first illumination source paired with the first pixel constitute noise at the first pixel. Though the relatively small diameters of apertures in the aperture layer may attenuate a total light signal passed from the bulk imaging optic into the set of lenses, each aperture in the aperture layer may pass a relatively high proportion of photons originating from its corresponding illumination source than from other illumination sources in the system; that is, due to the geometry of a particular aperture and its corresponding illumination source, a particular aperture may pass a signal exhibiting a relatively high SNR to its corresponding lens and thus into its corresponding pixel. Furthermore, at smaller aperture diameters in the aperture layer – and therefore smaller fields of view of corresponding channels – the system can pass less noise from solar radiation or other ambient light sources to the set of pixels.

[0027] In one variation, the system includes a second aperture layer interposed between the lens array and the optical filter, wherein the second aperture layer defines a second set of apertures, each aligned with a corresponding lens in the set of lenses, as described above. In this variation, an aperture in the second aperture layer can absorb or reflect errant light rays passed by a corresponding lens, as described above, to further reduce crosstalk between channels, thereby improving SNR within the system. Similarly, the system can additionally or alternatively include a third aperture layer interposed between the optical filter and the diffuser(s), wherein the third aperture layer

defines a third set of apertures, each aligned with a corresponding lens in the set of lenses, as described above. In this variation, an aperture in the third aperture layer can absorb or reflect errant light rays passed by the light filter, as described above, to again reduce crosstalk between channels, thereby improving SNR within the system.

1.4 Lens Array

[0028] The system includes a set of lenses, wherein each lens in the set of lenses is characterized by a second focal length, is offset from the focal plane opposite the bulk imaging optic by the second focal length, is aligned with a corresponding aperture in the set of apertures, and is configured to collimate light rays passed by the corresponding aperture. Generally, a lens in the set of lenses functions to collimate lights rays passed by its corresponding aperture and to pass these collimated light rays into the optical filter.

[0029] In the one-dimensional optical system, the lenses are arranged in a single column, and adjacent lenses are offset by a uniform lens pitch distance (i.e., a center-to-center-distance between adjacent pixels), as shown in FIGURE 3. The set of lenses is interposed between the aperture layer and the optical filter. In particular, each lens can include a converging lens characterized by a second focal length and can be offset from the focal plane of the bulk imaging optic – opposite the bulk imaging optic – by the second focal length to preserve the aperture of the bulk imaging optic and to collimate light incident on the bulk imaging optic and passed by a corresponding aperture. Each lens in the set of lens can be characterized by a relatively short focal length (i.e., less than a focal length of the bulk imaging optic) and a relatively large marginal ray angle (e.g., a relatively high numeric aperture lens) such that the lens can capture highly-

angled light rays projected toward the lens by the extent of the bulk imaging optic. That is, each lens in the set of lens can be characterized by a ray cone substantially matched to a ray cone of the bulk imaging optic.

[0030] Lenses in the set of lenses can be substantially similar. A lens in the set of lenses is configured to collimate light rays focused into its corresponding aperture by the bulk imaging optic. For example, a lens in the set of lenses can include a bi-convex or plano-convex lens characterized by a focal length selected based on the size (e.g., diameter) of its corresponding aperture and the operating wavelength of the system. In this example, the focal length (f) of a lens in the set of lenses can be calculated according to the formula:

$$f = \frac{d^2}{2\lambda}$$

where d is the diameter of the corresponding aperture in the aperture layer and λ is the operating wavelength of light output by the illumination source (e.g., 900 nm). The geometry of a lens in the set of lenses can therefore be matched to the geometry of a corresponding aperture in the aperture layer such that the lens passes a substantially sharp image of light rays – at or near the operating wavelength – into the optical filter and thus on to the pixel array.

[0031] However, the set of lenses can include lenses of any other geometry and arranged in any other way adjacent the aperture layer.

1.5 Optical Filter

[0032] As shown in FIGURE 3, the system includes an optical filter adjacent the set of lenses opposite the aperture layer and configured to pass light rays at the

operating wavelength. Generally, the optical filter receives electromagnetic radiation across a spectrum from the set of lenses, passes a relatively narrow band of electromagnetic radiation – including radiation at the operating wavelength – to the pixel array, and blocks electromagnetic radiation outside of the band. In particular, electromagnetic radiation other than electromagnetic radiation output by the illumination source – such as ambient light – incident on a pixel in the set of pixels constitutes noise in the system. The optical filter therefore functions to reject electromagnetic radiation outside of the operating wavelength or, more pragmatically, outside of a narrow wavelength band, thereby reducing noise in the system and increasing SNR.

[0033] In one implementation, the optical filter includes an optical bandpass filter that passes a narrow band of electromagnetic radiation substantially centered at the operating wavelength of the system. In one example, the illumination sources output light (predominantly) at an operating wavelength of 900 nm, and the optical filter is configured to pass light between 899.95 nm and 900.05 nm and to block light outside of this band.

[0034] The optical filter may selectively pass and reject wavelengths of light as a function of angle of incidence on the optical filter. Generally, optical bandpass filters may pass wavelengths of light inversely proportional to their angle of incidence on the light optical bandpass filter. For example, for an optical filter including a 0.5 nm-wide optical bandpass filter, the optical filter may pass over 95% of electromagnetic radiation over a sharp band from 899.75 nm to 900.25 nm and reject approximately 100% of electromagnetic radiation below 899.70 nm and above 900.30 nm for light rays incident on the optical filter at an angle of incidence of approximately 0°. However, in this

example, the optical filter may pass over 95% of electromagnetic radiation over a narrow band from 899.5 nm to 900.00 nm and reject approximately 100% of electromagnetic radiation over a much wider band below 899.50 nm and above 900.30 nm for light rays incident on the optical filter at an angle of incidence of approximately 15°. Therefore, the incidence plane of the optical filter can be substantially normal to the axes of the lenses, and the set of lenses can collimate light rays received through a corresponding aperture and output these light rays substantially normal to the incidence plane of the optical filter (i.e., at an angle of incidence of approximately 0° on the optical filter). Specifically, the set of lenses can output light rays toward the optical filter at angles of incidence approximating 0° such that substantially all electromagnetic radiation passed by the optical filter is at or very near the operating wavelength of the system.

[0035] In the one-dimensional optical system, the system can include a single optical filter that spans the column of lens in the set of lenses. Alternatively, the system can include multiple optical filters, each adjacent a single lens or a subset of lenses in the set of lenses. However, the optical filter can define any other geometry and can function in any other way to pass only a limited band of wavelengths of light.

1.6 Pixel Array and Diffuser

[0036] The system includes a set of pixels adjacent the optical filter opposite the set of lenses, each pixel in the set of pixels corresponding to a lens in the set of lenses and including a set of subpixels arranged along a second axis non-parallel to the first axis. Generally, the set of pixels are offset from the optical filter opposite the set of lenses, and each pixel in the set of pixels functions to output a single signal or stream of signals corresponding to the count of photons incident on the pixel within one or more

sampling periods, wherein each sampling period may be picoseconds, nanoseconds, microseconds, or milliseconds in duration.

[0037] The system also includes a diffuser interposed between the optical filter and the set of pixels and configured to spread collimated light output from each lens in the set of lenses across a set of subpixels of a single corresponding pixel in the set of pixels. Generally, for each lens in the set of lenses, the diffuser functions to spread light rays – previously collimated by the lens and passed by the optical filter – across the width and height of a sensing area within a corresponding pixel. The diffuser can define a single optic element spanning the set of lenses, or the diffuser can include multiple discrete optical elements, such as including one optical diffuser element aligned with each channel in the system.

[0038] In one implementation, a first pixel in the set of pixels includes an array of single-photon avalanche diode detectors (hereinafter "SPADs"), and the diffuser spreads lights rays – previously passed by a corresponding first aperture, collimated by a corresponding first lens, and passed by the optical filter – across the area of the first pixel, as shown in FIGURES 3, 5, and 6. Generally, adjacent apertures can be aligned and offset vertically by an aperture pitch distance, adjacent lenses can be aligned and offset vertically by a lens pitch distance substantially identical to the aperture pitch distance, and adjacent pixels can be aligned and offset vertically by a pixel pitch distance substantially identical to the lens and aperture pitch distances. However, the pixel pitch distance may accommodate only a relatively small number of (e.g., two) vertically-stacked SPADs. Each pixel in the set of pixels can therefore define an aspect ratio greater than 1:1, and the diffuser can spread light rays passed by the optical filter

according to the geometry of a corresponding pixel in order to accommodate a larger sensing area per pixel.

[0039] In one example, each pixel in the set of pixels is arranged on an image sensor, and a first pixel in the set of pixels includes a single row of 16 SPADs spaced along a lateral axis perpendicular to a vertical axis bisecting the column of apertures and lenses. In this example, the height of a single SPAD in the first pixel can be less than the height (e.g., diameter) of the first lens, but the total length of the 16 SPADs can be greater than the width (e.g., diameter) of the first lens; the diffuser can therefore converge light rays output from the first lens to a height corresponding to the height of a SPAD at the plane of the first pixel and can diverge light rays output from the first lens to a width corresponding to the width of the 16 SPADs at the plane of the first pixel. In this example, the remaining pixels in the set of pixels can include similar rows of SPADs, and the diffuser can similarly converge and diverge light rays passed by corresponding apertures onto corresponding pixels.

[0040] In the foregoing example, the aperture layer can include a column of 16 like apertures, the set of lenses can include a column of 16 like lenses arranged behind the aperture layer, and the set of pixels can include a set of 16 like pixels – each including a similar array of SPADs – arranged behind the set of lenses. For a 6.4 mm-wide, 6.4 mm-tall image sensor, each pixel can include a single row of 16 SPADs, wherein each SPAD is electrically coupled to a remote analog front-end processing electronics/digital processing electronics circuit. Each SPAD can be arranged in a 400 μm-wide, 400 μm-tall SPAD area and can define an active sensing area approaching 400 μm in diameter. Adjacent SPADs can be offset by a SPAD pitch distance of 400 μm. In this example, the aperture pitch distance along the vertical column of apertures, the

lens pitch distance along the vertical column of lenses, and the pixel pitch distance along the vertical column of pixels can each be approximately 400 μm accordingly. For the first sense channel in the system (i.e., the first aperture, the first lens, and the first pixel, etc.), a first diffuser can diverge a cylindrical column of light rays passed from the first lens through the optical filter – such as a column of light approximately 100 μm in diameter for an aperture layer aspect ratio of 1:4 – to a height of approximately 400 μm aligned vertically with the row of SPADs in the first pixel. The first diffuser can similarly diverge the cylindrical column of light rays passed from the first lens through the optical filter to a width of approximately 6.4 μm centered horizontally across the row of SPADs in the first pixel. Other diffusers in the system can similarly diverge (or converge) collimated light passed by corresponding lenses across corresponding pixels in the set of pixels. Therefore, in this example, by connecting each SPAD (or each pixel) to a remote analog front-end processing electronics/digital processing electronics circuit and by incorporating diffusers that spread light passed by the optical filter across the breadths and heights of corresponding pixels, the system can achieve a relatively high sensing area fill factor across the imaging sensor.

[0041] Therefore, in the one-dimensional optical system, pixels in the set of pixels can include an array of multiple SPADS arranged in aspect ratio exceeding 1:1, and the diffuser can spread light rays across corresponding non-square pixels that enables a relatively large numbers of SPADs to be tiled across a single pixel to achieve a greater dynamic range across the image sensor than an image sensor with a single SPAD per pixel, as shown in FIGURE 3. In particular, by incorporating multiple SPADs per pixel (i.e., per sense channel), a first sense channel in the system can detect multiple incident photons – originating from a surface in the field bound by a field of view defined by the

first aperture – within the span of the dead time characteristic of the SPADs. The first sense channel can therefore detect a "brighter" surface in its field of view. Additionally or alternatively, the first pixel in the first sense channel can be sampled faster than the dead time characteristic of SPADs in the first pixel because, though a first subset of SPADs in the first pixel may be down (or "dead") during a first sampling period due to collection of incident photons during the first sampling period, other SPADs in the first pixel remain on (or "alive") and can therefore collect incident photons during a subsequent sampling period. Furthermore, by incorporating pixels characterized by relatively high aspect ratios of photodetectors, the image sensor can include pixels offset by a relatively small pixel pitch, but the system 100 can still achieve a relatively high dynamic range pixel.

[0042] However, pixels in the set of pixels can include any other number of SPADs arranged in any other arrays, such as in a 64-by-1 grid array (as described above), in a 32-by-2 grid array, or in a 16-by-4 grid array, and the diffuser can converge and/or diverge collimated light rays onto corresponding pixels accordingly in any other suitable way. Furthermore, rather than (or in addition to) SPADs, each pixel in the set of pixels can include one or more linear avalanche photodiodes, Geiger mode avalanche photodiodes, photomultipliers, resonant cavity photodiodes, QUANTUM DOT detectors, or other types of photodetectors arranged as described above, and the diffuser(s) can similarly converge and diverge signals passed by the optical filter(s) across corresponding pixels, as described herein.

1.7 Illumination Sources

[0043] The system includes a set of illumination sources arranged along a first axis, each illumination source in the set of illumination sources configured to output an illuminating beam of an operating wavelength toward a discrete spot in a field ahead of the illumination source. Generally, each illumination source functions to output an illuminating beam coincident a field of view defined by a corresponding aperture in the set of apertures, as shown in FIGURES 1 and 2.

[0044] In one implementation, the set of illumination sources includes a bulk transmitter optic and one discrete emitter per sense channel. For example, the set of illumination sources can include a monolithic VCSEL arrays including a set of discrete emitters. In this implementation, the bulk transmitter optic can be substantially identical to the bulk imaging optic in material, geometry (e.g., focal length), thermal isolation, etc., and the bulk transmitter optic is adjacent and offset laterally and/or vertically from the bulk imaging optic. In a first example, set of illumination sources includes a laser array including discrete emitters arranged in a column with adjacent emitters offset by an emitter pitch distance substantially identical to the aperture pitch distance. In this first example, each emitter outputs an illuminating beam of diameter substantially identical to or slightly greater than the diameter of a corresponding aperture in the apertures layer, and the column of emitters is arranged along the focal plane of the bulk transmitter optic such that each illuminating beam projected from the bulk transmitter optic into the field intersects and is of substantially the same size and geometry as the field of view of the corresponding sense channel, as shown in FIGURE 4. Therefore, substantially all power output by each emitter in the set of illumination sources can be projected into the field of view of its corresponding sense channel with

relatively minimal power wasted illuminating surfaces in the field outside of the fields of view of the sense channels.

[0045] In a second example, the discrete emitters are similarly arranged in a column with adjacent emitters offset by an emitter pitch distance twice the aperture pitch distance, as shown in FIGURE 2. In this second example, each emitter is characterized by an illuminating active area (or aperture) of diameter approximately (or slightly greater than) twice the diameter of a corresponding aperture in the apertures layer, and the column of emitters is offset behind the bulk transmitter optic by twice the focal length of the bulk transmitter optic such that each illuminating beam projected from the bulk transmitter optic into the field intersects and is of substantially the same size and geometry as the field of view of the corresponding sense channel, as described above. Furthermore, for the same illumination beam power density, an illuminating beam output by an emitter in this second example may contain four times the power of an illuminating beam output by an emitter in the first example described above. The system can therefore include a set of emitter arranged according to an emitter pitch distance, configured to output illuminating beams of diameter, and offset behind the bulk transmitter optic by an offset distance as a function of a scale factor (e.g., 2.0 or 3.0) and 1) the aperture pitch distance in the aperture layer, 2) the diameter of apertures in the aperture layer, and 3) the focal length of bulk transmitter optic, respectively. The system can therefore include an illuminating subsystem that is proportionally larger than a corresponding receiver subsystem to achieve greater total output illumination power within the same beam angles and fields of view of corresponding channels in the receiver subsystem.

[0046] The system can also include multiple discrete sets of illumination sources, each set of illumination sources paired with a discrete bulk transmitter optic adjacent the bulk imaging optic. For example, the system can include a first bulk transmitter optic, a second bulk transmitter optic, and a third bulk transmitter optic patterned radially about the bulk imaging optic at a uniform radial distance from the center of the bulk imaging optic and spaced apart by an angular distance of 120°. In this example, the system can include a laser array with one emitter – as described above – behind each of the first, second, and third bulk transmitter optics. Each discrete laser array and its corresponding bulk transmitter optic can thus project a set of illuminating beams into the fields of view of defined by corresponding in the apertures in the aperture layer. Therefore, in this example, the three discrete laser arrays and the three corresponding bulk transmitter optics can cooperate to project three times the power onto the fields of view of the sense channels in the system, as compared to a single laser array and one bulk transmitter optic. Additionally or alternatively, the system can include multiple discrete layer arrays and bulk transmitter optics to both: 1) achieve a target illumination power output into the field of view of each sensing channel in the receiver subsystem with multiple lower-power emitters per sensing channel; and 2) distribute optical energy over a larger area in the near-field to achieve an optical energy density less than a threshold allowable optical energy density for the human eye.

[0047] However, the system can include any other number and configuration of illumination source sets and bulk transmitter optics configured to illuminate fields of view defined by the sense channels. The set of illumination sources can also include any other suitable type of optical transmitter, such as a 1x16 optical splitter powered by a

single laser diode, a side-emitting laser diode array, an LED array, or a quantum dot LED array, etc.

1.8 Fabrication

[0048] In one implementation, the bulk receiver lens, the aperture layer, the set of lenses, the optical filter, and the diffuser are fabricated and then aligned with and mounted onto an image sensor. For example, the optical filter can be fabricated by coating a fused silica substrate. Photoactive optical polymer can be deposited over optical filter, and a lens mold can be placed over the photoactive optical polymer and a UV light source activated to cure the photoactive optical polymer in the form of lenses patterned across the optical filter. Standoffs can be similarly molded or formed across the optical filter via photolithography techniques, and an aperture layer defined by a selectively-cured, metallized glass wafer can then be bonded or otherwise mounted to the standoffs to form the aperture layer. The assembly can then be inverted, and a set of discrete diffusers and standoffs can be similarly fabricated across the opposite side of the optical filter. A discrete image sensor can then be aligned with and bonded to the standoffs, and a bulk imaging optical can be similarly mounted over the aperture layer.

[0049] Alternatively, photolithography and wafer level bonding techniques can be implemented to fabricate the bulk imaging loptics, the aperture layer, the set of lenses, the optical filter, and the diffuser directly on to the un-diced semiconductor wafer containing the detector chips in order to simplify manufacturing, reduce cost, and reduce optical stack height for decreased pixel crosstalk.

2. One-Dimensional Optical System: Lens Tube

[0050] One variation of the system includes: a set of illumination sources arranged along a first axis, each illumination source in the set of illumination sources configured to output an illuminating beam of an operating wavelength toward a discrete spot in a field ahead of the illumination source; a bulk imaging optic characterized by a focal plane opposite the field; a set of lens tubes arranged in a line array parallel to the first axis, each lens tube in the set of lens tubes including: a lens characterized by a focal length, offset from the focal plane by the focal length, and configured to collimate light rays reflected into the bulk imaging optic from a discrete spot in the field illuminated by a corresponding illumination source in the set of optics into the bulk imaging optic; and a cylindrical wall extending from the lens opposite the focal plane, defining a long axis substantially perpendicular to the first axis, and configured to absorb incident light rays reflected into the bulk imaging optic from a region in the field outside the discrete spot illuminated by the corresponding illumination source. In this variation, the system also includes: an optical filter adjacent the set of lens tubes opposite the focal plane and configured to pass light rays at the operating wavelength; a set of pixels adjacent the optical filter opposite the set of lenses, each pixel in the set of pixels corresponding to a lens in the set of lenses and including a set of subpixels aligned along a third axis perpendicular to the first axis; and a diffuser interposed between the optical filter and the set of pixels and configured to spread collimated light output from each lens in the set of lenses across a set of subpixels of a corresponding pixel in the set of pixels.

[0051] Generally, in this variation, the system includes a lens tube in replacement of (or in addition to) each aperture and lens pair described above. In this variation, each lens tube can be characterized by a second (short) focal length and can be offset from the focal plane of the bulk imaging optic by the second focal length to preserve the

aperture of the bulk imaging optic and to collimate incident light received from the bulk imaging optic, as described above and as shown in FIGURES 5 and 7.

[0052] Each lens tube also defines an opaque cylindrical wall defining an axis normal to the incidence plane of the adjacent optical filter and configured to absorb incident light rays, as shown in FIGURE 5. Generally, at greater axial lengths, the cylindrical wall of a lens tube may absorb light rays passing through the lens tube at shallower angles to the axis of the lens tube, thereby reducing the field of view of the lens tube (which may be similar to decreasing the diameter of an aperture in the aperture layer up to the diffraction-limited diameter, as described above) and yielding an output signal of collimated light rays nearer to perpendicular to the incidence plane of the optical filter. Each lens tube can therefore define an elongated cylindrical wall of length sufficient to achieve a target field of view and to pass collimated light rays at maximum angles to the axis of the lens tube less than a threshold angle. In this variation, a lens tube can thus function as an aperture-sense pair described above to define a narrow field of view and to output substantially collimated light to the adjacent optical filter.

[0053] The cylindrical wall of a lens tube can define a coarse or patterned opaque interface about a transparent (or translucent) lens material, as shown in FIGURE 5, to increase absorption and decrease reflection of light rays incident on the cylindrical wall. Each lens tube (and each lens described above) can also be coated with an anti-reflective coating.

[0054] As shown in FIGURE 9, in this variation, the set of lens tubes can be fabricated by implementing photolithography techniques to pattern a photoactive optical polymer (e.g., SU8) onto the optical filter (e.g., on a silicon wafer defining the

optical filter). A light-absorbing polymer can then be poured between the lens tubes and cured. A set of lenses can then be fabricated (e.g., molded) separately and then bonded over the lens tubes. Alternatively, lenses can be fabricated directly onto the lens tubes by photolithography techniques. Yet alternatively, a mold for lenses can be cast directly onto the lens tubes by injecting polymer into a mold arranged over the lens tubes. A singular diffuser or multiple discrete diffusers can be similarly fabricated and/or assembled on the optical filter opposite the lens tubes. Standoffs extending from the optical filter can be similarly fabricated or installed around the diffuser(s), and the image sensor can be aligned with and bonded to the standoffs opposite the optical filter. Other optical elements within the system (e.g., the bulk imaging lens, the bulk transmitting lens, etc.) can be fabricated according to similar techniques and with similar materials.

3. Two-Dimensional Optical System

[0055] Another variation of the system includes: a set of illumination sources arranged in a first rectilinear grid array, each illumination source in the set of illumination sources configured to output an illuminating beam of an operating wavelength toward a discrete spot in a field ahead of the illumination source; a bulk imaging optic characterized by a focal plane opposite the field; an aperture layer coincident the focal plane, defining a set of apertures in a second rectilinear grid array proportional to the first rectilinear grid array, and defining a stop region around the set of apertures, each aperture in the set of apertures defining a field of view in the field coincident a discrete spot output by a corresponding illumination source in the set of illumination sources, the stop region absorbing light rays reflected from surfaces in the

field outside of fields of view defined by the set of apertures and passing through the bulk imaging optic; a set of lenses, each lens in the set of lenses characterized by a second focal length, offset from the focal plane opposite the bulk imaging optic by the second focal length, aligned with an aperture in the set of apertures, and configured to collimate light rays passed by the aperture; an optical filter adjacent the set of lenses opposite the aperture layer and configured to pass light rays at the operating wavelength; a set of pixels adjacent the optical filter opposite the set of lenses, each pixel in the set of pixels aligned with a subset of lenses in the set of lenses; and a diffuser interposed between the optical filter and the set of pixels and configured to spread collimated light output from each lens in the set of lenses across a corresponding pixel in the set of pixels.

[0056] Generally, in this variation, the system includes a two-dimensional grid array of channels (i.e., aperture, lens, and pixel sets or lens tube and pixel sets) and is configured to image a volume occupied by the system in two dimensions. The system can collect one-dimensional distance data – such as counts of incident photons within a sampling period and/or times between consecutive photons incident on pixels of known position corresponding to known fields of view in the field – across a two-dimensional field. The one-dimensional distance data can then be merged with known positions of the fields of view for each channel in the system to reconstruct a virtual three-dimensional representation of the field ahead of the system.

[0057] In this variation, the aperture layer can define a grid array of apertures, the set of lenses can be arranged in a similar grid array with one lens aligned with one aperture in the aperture layer, and the set of pixels can include one pixel per aperture and lens pair, as described above. For example, the aperture layer can define a 24-by-24

grid array of 200-μm-diameter apertures offset vertically and laterally by an aperture pitch distance of 300 μm, and the set of lenses can similarly define a 24-by-24 grid array of lenses offset vertically and laterally by a lens pitch distance of 300 μm. In this example, the set of pixels can include a 24-by-24 grid array of 300-μm-square pixels, wherein each pixel includes a 3x3 square array of nine 100-μm-square SPADs.

[0058] Alternatively, in this variation, the set of pixels can include one pixel per group of multiple aperture and lens pairs. In the foregoing example, the set of pixels can alternatively include a 12-by-12 grid array of 600-μm-square pixels, wherein each pixel includes a 6x6 square array of 36 100-μm-square SPADs and wherein each pixel is aligned with a group of four adjacent lenses in a square grid. In this example, for each group of four adjacent lenses, the diffuser: can bias collimated light rays output from a lens in the (1,1) position in the square grid upward and to the right to spread light rays passing through the (1,1) lens across the full breadth and width of the corresponding pixel; can bias collimated light rays output from a lens in the (2,1) position in the square grid upward and to the left to spread light rays passing through the (2,1) lens across the full breadth and width of the corresponding pixel; can bias collimated light rays output from a lens in the (1,2) position in the square grid downward and to the right to spread light rays passing through the (1,2) lens across the full breadth and width of the corresponding pixel; and can bias collimated light rays output from a lens in the (2,2) position in the square grid downward and to the left to spread light rays passing through the (2,2) lens across the full breadth and width of the corresponding pixel, as shown in FIGURE 8.

[0059] In the foregoing example, for each group of four illumination sources in a square grid and corresponding to one group of four lenses in a square grid, the system

can actuate one illumination source in the group of four illumination sources at any given instance in time. In particular, for each group of four illumination sources in a square grid corresponding to one pixel in the set of pixels, the system can actuate a first illumination source in a (1,1) position during a first sampling period to illuminate a field of view defined by a first aperture corresponding to a lens in the (1,1) position in the corresponding group of four lenses, and the system can sample all 36 SPADs in the corresponding pixel during the first sampling period. The system can then shut down the first illumination source and actuate a second illumination source in a (1,2) position during a subsequent second sampling period to illuminate a field of view defined by a second aperture corresponding to a lens in the (1,2) position in the corresponding group of four lenses, and the system can sample all 36 SPADs in the corresponding pixel during the second sampling period. Subsequently, the system can then shut down the first and second illumination sources and actuate a third illumination source in a (2,1) position during a subsequent third sampling period to illuminate a field of view defined by a third aperture corresponding to a lens in the (2,1) position in the corresponding group of four lenses, and the system can sample all 36 SPADs in the corresponding pixel during the third sampling period. Finally, the system can shut down the first, second, and third illumination sources and actuate a fourth illumination source in a (2,2) position during a fourth sampling period to illuminate a field of view defined by a fourth aperture corresponding to a lens in the (2,2) position in the corresponding group of four lenses, and the system can sample all 36 SPADs in the corresponding pixel during the fourth sampling period. The system can repeat this process throughout its operation.

[0060] Therefore, in the foregoing example, the system can include a set of pixels arranged across an image sensor 7.2 mm in width and 7.2 mm in length and can

implement a scanning schema such that each channel in the system can access (can project light rays onto) a number of SPADs otherwise necessitating a substantially larger image sensor (e.g., a 14.4 mm by 14.4 mm image sensor). In particular, the system can implement a serial scanning schema per group of illumination sources to achieve an exponential increase in the dynamic range of each channel in the system. In particular, in this variation, the system can implement the foregoing imaging techniques to increase imaging resolution of the system.

[0061] In the foregoing implementation, the system can also include a shutter between each channel and the image sensor, and the system can selectively open and close each shutter when the illumination source for the corresponding channel is actuated and deactivated, respectively. For example, the system can include one independently-operable electrochromic shutter interposed between each lens, and the system can open the electrochromic shutter over the (1,1) lens in the square-gridded group of four lenses and close electrochromic shutters over the (1,2), (2,1), and (2,2) lens when the (1,1) illumination source is activated, thereby rejecting noise passing through the (1,2), (2,1), and (2,2) lens from reaching the corresponding pixel on the image sensor. The system can therefore selectively open and close shutters between each channel and the image sensor to increase SNR per channel during operation. Alternatively, the system can include one independently-operable electrochromic shutter arranged over select regions of each pixel, as shown in FIGURE 8, wherein each electrochromic shutter is aligned with a single channel (i.e., with a single lens in the set of lenses). The system can alternatively include MEMS mechanical shutters or any other suitable type of shutter interposed between the set of lenses and the image sensor.

[0062] In this variation, the system can define two-dimension grid arrays of apertures, lenses, diffusers, and/or pixels characterized by a first pitch distance along a first (e.g., X) axis and a second pitch distance – different from the first pitch distance – along a second (e.g., Y) axis. For example, the image sensor can include pixels offset by a 25μm horizontal pitch and a 300μm vertical pitch, wherein each pixel includes a single row of twelve subpixels.

[0063] However, in this variation, the two-dimensional optical system can include an array of any other number and pattern of channels (e.g., apertures, lenses (or lens tubes), and diffusers) and pixels and can execute any other suitable scanning schema to achieve higher spatial resolutions per channel than the raw pixel resolution of the image sensor. The system can additionally or alternatively include a converging optic, a diverging optic, and/or any other suitable type of optical element to spread light rights passed from a channel across the breadth of a corresponding pixel.

[0064] As a person skilled in the art will recognize from the previous detailed description and from the figures and claims, modifications and changes can be made to the embodiments of the invention without departing from the scope of this invention as defined in the following claims.

CLAIMS

I Claim:

1. The inventions as shown and/or described herein.

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	OPTICAL SYSTEM FOR COLLECTING DISTANCE INFORMATION WITHIN A FIELD
First Named Inventor/Applicant Name:	Angus Pacala
Filer:	Peter D'Elia Miller
Attorney Docket Number:	OUST-M01-PRV

Filed as Small Entity

Filing Fees for Provisional

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Provisional Application Filing Fee	2005	1	130	130
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Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**130**

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First Named Inventor/Applicant Name:	Angus Pacala
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1	Application Data Sheet	OUST-M01-PRV-ADS.pdf	1278899 5453411a327162a89662204af08febfb921b654e	no	7
Warnings:					
Information:					
2	Drawings-only black and white line drawings	OUST-M01-PRV-DRW.pdf	4757833 2cb477d834b385b74e7a74c040304e36b2840093	no	9
Warnings:					
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3	Specification	OUST-M01-PRV-TXT.pdf	254043 dd507efe4d13c45bb75cc4300b24d45cc96980c5	no	32
Warnings:					
Information:					
4	Fee Worksheet (SB06)	fee-info.pdf	29732 62b1e8aa358f5d2cdd34ae85bcd3709041ae8343	no	2
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