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APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/418,925	01/02/2018	9857568	COREPH-0080 US CIP	5957

92342 7590 12/13/2017

Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

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):

Michael Dror, Nes Ziona, ISRAEL;
Corephotonics Ltd., Tel-Aviv, ISRAEL;
Ephraim Goldenberg, Ashdod, ISRAEL;
Gal Shabtay, Tel Aviv, ISRAEL;

IR103 (Rev. 10/09)

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/418,925	01/30/2017	Michael Dror	COREPH-0080 US CIP	5957

7590 12/01/2017

Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

EXAMINER	
LESTER, EVELYN A	

ART UNIT	PAPER NUMBER
2872	

NOTIFICATION DATE	DELIVERY MODE
12/01/2017	ELECTRONIC

NOTICE OF NON-COMPLIANT INFORMATION DISCLOSURE STATEMENT

An Information Disclosure Statement (IDS) filed 11.09.2017 in the above-identified application fails to meet the requirements of 37 CFR 1.97(d) for the reason(s) specified below. Accordingly, the IDS will be placed in the file, but the information referred to therein has not been considered.

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

- ☐ The IDS lacks a statement as specified in 37 CFR 1.97(e).
- ☐ The IDS lacks the fee set forth in 37 CFR 1.17(p).
- ☒ The IDS was filed after the issue fee was paid. Applicant may wish to consider filing a petition to withdraw the application from issue under 37 CFR 1.313(c) to have the IDS considered. See MPEP 1308.

for: D. Harden

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

FORM PTOM327-B (Rev. 02/08)

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15418925
	Filing Date	2017-01-30
	First Named Inventor	Michael Dror
	Art Unit	2872
	Examiner Name	Lester Evelyn A
	Attorney Docket Number	COREPH-0080 US CIP

U.S.PATENTS

Examiner Initial*	Cite No	Patent Number	Kind Code1	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	8395851		2013-03-12	Tang et al.	
	2	8508860		2013-08-13	Tang et al.	
	3	8072695		2011-12-06	Lee et al.	
	4	7826151		2010-11-02	Tsung-Han Tsai	
	5	5946142	A	1999-08-31	Hirata et al.	
	6	8233224	B2	2012-07-31	Chen	
	7	8310768	B2	2012-11-13	Lin et al.	
	8	5172235	A	1992-12-15	Wilm et al	

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)	Application Number	15418925
	Filing Date	2017-01-30
	First Named Inventor	Michael Dror
	Art Unit	2872
	Examiner Name	Lester Evelyn A
	Attorney Docket Number	COREPH-0080 US CIP

	9	8046026	B2	2011-10-25	Koa	
	10	8731390	B2	2014-05-20	Goldenberg et al.	

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

U.S.PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code1	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	20100254029		2010-10-07	Yoshikazu Shinohara	
	2	20120314296	A1	2012-12-13	Shabtay et al.	
	3	20070229987	A1	2007-10-04	Shinohara	
	4	20130038947	A1	2013-02-14	Tsai et al.	
	5	20070229987	A1	2007-10-04	Tang et al.	
	6	20120087020	A1	2010-04-12	Deng et al.	
	7	20110115965	A1	2011-05-19	Engelhardt et al.	

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)	Application Number: 15418925
	Filing Date: 2017-01-30
	First Named Inventor: Michael Dror
	Art Unit: 2872
	Examiner Name: Lester Evelyn A
	Attorney Docket Number: COREPH-0080 US CIP

	8	20080166115	A1	2008-07-10	Sachs et al.	
	9	20150085174	A1	2015-03-24	2015-03-24	
	10	20150029601	A1	2015-01-29	Dror et al.	
	11	20060187312	A1	2006-08-24	Labaziewicz et al.	
	12	20110080487	A1	2011-04-07	Vankataraman et al.	
	13	20090002839	A1	2009-01-01	Sato Kenichi	
	14	20080218613	A1	2008-09-11	Jenson Wilbert F et. al.	
	15	20080187310	A1	2008-08-24	Jenson Wilbert F et. al.	
	16	20100277269	A1	2010-11-04	Scarff Lawrence	

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

FOREIGN PATENT DOCUMENTS

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

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99)**		
	Application Number	15418925
	Filing Date	2017-01-30
	First Named Inventor	Michael Dror
	Art Unit	2872
	Examiner Name	Lester Evelyn A
	Attorney Docket Number	COREPH-0080 US CIP

	1	2013063097	WO	A1	2013-05-02	Cahall et al.		☐
	2	2014199338	WO	A2	2014-12-18	COREPHOTONICS LTD		☐
	3	5741395	JP		2015-07-01	KONICA MINOLTA ADVANCED LAYERS Inc.		☒
	4	2013105012	WO	A2	2013-07-18	Goldenberg et al.		☐
	5	2015015383	WO	A2	2015-02-05	Shabtay et al.		☐

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NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T5
	1		☐

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EXAMINER SIGNATURE

Examiner Signature		Date Considered	

*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.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	15418925
	Filing Date	2017-01-30
	First Named Inventor	Michael Dror
	Art Unit	2872
	Examiner Name	Lester Evelyn A
	Attorney Docket Number	COREPH-0080 US CIP

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	/Menachem Nathan/	Date (YYYY-MM-DD)	2017-11-09
Name/Print	MENACHEM NATHAN	Registration Number	65392

Privacy Act Statement

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

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

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

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

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

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

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

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

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

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

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

PTO/AIA/15 (03-13)
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

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	COREPH-0080 US CIP
First Named Inventor	Michael Dror
Title	MINIATURE TELEPHOTO LENS ASSEMBLY
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: **Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450**

1. ☐ **Fee Transmittal Form** (PTO/SB/17 or equivalent)
2. ☐ **Applicant asserts small entity status.** See 37 CFR 1.27
3. ☐ **Applicant certifies micro entity status.** See 37 CFR 1.29. Applicant must attach form PTO/SB/15A or B or equivalent.
4. ☐ **Specification** [*Total Pages* ____]
   Both the claims and abstract must start on a new page.
   (See MPEP § 608.01(a) for information on the preferred arrangement)
5. ☐ **Drawing(s)** (35 U.S.C. 113) [*Total Sheets* ____]
6. **Inventor's Oath or Declaration** [*Total Pages* ____]
   (including substitute statements under 37 CFR 1.64 and assignments serving as an oath or declaration under 37 CFR 1.63(e))
   a. ☐ Newly executed (original or copy)
   b. ☐ A copy from a prior application (37 CFR 1.63(d))
7. ☐ **Application Data Sheet** ** See note below.*
   See 37 CFR 1.76 (PTO/AIA/14 or equivalent)
8. **CD-ROM or CD-R**
   in duplicate, large table, or Computer Program (*Appendix*)
   ☐ Landscape Table on CD
9. **Nucleotide and/or Amino Acid Sequence Submission**
   (*if applicable, items a. – c. are required*)
   a. ☐ Computer Readable Form (CRF)
   b. ☐ Specification Sequence Listing on:
      i. ☐ CD-ROM or CD-R (2 copies); or
      ii. ☐ Paper
   c. ☐ Statements verifying identity of above copies

ACCOMPANYING APPLICATION PAPERS

10. ☐ **Assignment Papers**
    (cover sheet & document(s))
    Name of Assignee ____
11. ☐ **37 CFR 3.73(c) Statement** (*when there is an assignee*) ☐ **Power of Attorney**
12. ☐ **English Translation Document** (*if applicable*)
13. ☑ **Information Disclosure Statement**
    (PTO/SB/08 or PTO-1449)
    ☑ Copies of citations attached
14. ☐ **Preliminary Amendment**
15. ☐ **Return Receipt Postcard**
    (*MPEP § 503*) (*Should be specifically itemized*)
16. ☐ **Certified Copy of Priority Document(s)**
    (*if foreign priority is claimed*)
17. ☐ **Nonpublication Request**
    Under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or equivalent.
18. ☑ **Other:** Remarks - This is an IDS. Citation or identification of any reference in this IDS shall not be construed as an admission that such reference is available as prior art.

***Note**: (1) Benefit claims under 37 CFR 1.78 and foreign priority claims under 1.55 **must** be included in an Application Data Sheet (ADS).
(2) For applications filed under 35 U.S.C. 111, the application must contain an ADS specifying the applicant if the applicant is an assignee, person to whom the inventor is under an obligation to assign, or person who otherwise shows sufficient proprietary interest in the matter. See 37 CFR 1.46(b).

19. CORRESPONDENCE ADDRESS

☑ The address associated with Customer Number: 92342 **OR** ☐ Correspondence address below

Name					
Address					
City		State		Zip Code	
Country		Telephone		Email	

Signature	/Menachem Nathan/	Date	11-09-2017
Name (Print/Type)	MENACHEM NATHAN	Registration No. (Attorney/Agent)	65,392

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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.
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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)).
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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.

Electronic Patent Application Fee Transmittal

Application Number:	15418925
Filing Date:	30-Jan-2017
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Filer:	Menachem Nathan
Attorney Docket Number:	COREPH-0080 US CIP

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($)
Miscellaneous:				
SUBMISSION- INFORMATION DISCLOSURE STMT	2806	1	90	90
		Total in USD ($)		**90**

Electronic Acknowledgement Receipt

EFS ID:	30906963
Application Number:	15418925
International Application Number:	
Confirmation Number:	5957
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Customer Number:	92342
Filer:	Menachem Nathan
Filer Authorized By:	
Attorney Docket Number:	COREPH-0080 US CIP
Receipt Date:	09-NOV-2017
Filing Date:	30-JAN-2017
Time Stamp:	16:15:18
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$90
RAM confirmation Number	111317INTEFSW16171600
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	Foreign Reference	JP5741395B2.pdf	841182 b0ace14462e99d1db19037cc19f7bab216c41714	no	25

Warnings:

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
2	Foreign Reference	JP5741395B2_English.pdf	165732 773918f9280d2205c971a3240328ad18a69e68bf	no	3

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3	Foreign Reference	WO2013063097.pdf	3680212 78503dcdb868ebfd171d8e456b19c4d5562c9ba8	no	102

Warnings:

Information:

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4	Foreign Reference	WO2013105012.pdf	1136619 e80f6d29a749efab9a506d2147285a1dc2509445	no	29

Warnings:

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
5	Foreign Reference	WO2014199338A2.pdf	1378210 22047e122918c8f2e1c6de9cb2d459eb75ea3157	no	30

Warnings:

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
6	Foreign Reference	WO2015015383.pdf	1188350 ed8441e153e5d369874445fbcb1d7b79275f192a	no	29

Warnings:

Information:					
7	Information Disclosure Statement (IDS) Form (SB08)	IDS.pdf	1673957 ec9472933f7cbb9f582db96e6d2065beb2b50e77	no	6
Warnings:					
Information:					
This is not an USPTO supplied IDS fillable form					
8	Transmittal Letter	IDS_TF.pdf	282771 b713cb11f55fb298aee3040c0701c24d6f2f3785	no	2
Warnings:					
Information:					
9	Fee Worksheet (SB06)	fee-info.pdf	30169 c7b5a08a94234bbf37662540f2b5dfe6cbe44cfc	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	10377202		

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.

(19)日本国特許庁(JP)　(12)特　許　公　報(B2)　(11)特許番号 特許第5741395号 (P5741395)

(45)発行日　平成27年7月1日(2015.7.1)　(24)登録日　平成27年5月15日(2015.5.15)

(51) Int.Cl.		F I		
H04N 5/225	(2006.01)	H04N	5/225	D
H04N 5/228	(2006.01)	H04N	5/228	Z
G02B 13/00	(2006.01)	G02B	13/00	
G02B 15/00	(2006.01)	G02B	15/00	
G02B 13/18	(2006.01)	G02B	13/18	

請求項の数 10　(全 25 頁)

(21)出願番号　特願2011-250322 (P2011-250322)
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(54)【発明の名称】撮像装置

(57)【特許請求の範囲】

【請求項１】

同一方向を向いた単焦点の第１，第２撮像光学系を有し、前記第２撮像光学系の焦点距離が前記第１撮像光学系の焦点距離よりも長く、前記第１撮像光学系で得られた画像の切り出しによる電子ズームで広角端から中間焦点距離状態までのズーミングを行い、前記第２撮像光学系で得られた画像の切り出しによる電子ズームで中間焦点距離状態から望遠端までのズーミングを行うことにより、全体として広角端から望遠端までのズーミングを行う撮像装置であって、

前記第１，第２撮像光学系のいずれもが、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、を有する４枚以上のレンズから成るとともに、最も像側のレンズが負レンズであり、

前記第１レンズと第２レンズの合成焦点距離が正であり、かつ、以下の条件式（１）を満足することを特徴とする撮像装置；

１．０＜ｆＦｗ／ｆＦｍ＜１．５　…（１）

ただし、

ｆＦｗ：第１撮像光学系における第１レンズと第２レンズの合成焦点距離、

ｆＦｍ：第２撮像光学系における第１レンズと第２レンズの合成焦点距離、

である。

【請求項２】

以下の条件式（２Ａ）及び（２Ｂ）を満足することを特徴とする請求項１記載の撮像装

置；
ｆＦｗ／ｆｗ＞１　…（２Ａ）
ｆＦｍ／ｆｍ＜１　…（２Ｂ）
　ただし、
ｆｗ：第１撮像光学系全体の焦点距離、
ｆｍ：第２撮像光学系全体の焦点距離、
である。
【請求項３】
　以下の条件式（３）を満足することを特徴とする請求項１又は２記載の撮像装置；
－０．６＜ｆＸｗ／ｆＸｍ＜０．５　…（３）
　ただし、
ｆＸｗ：第１撮像光学系において像側から２番目のレンズの焦点距離、
ｆＸｍ：第２撮像光学系において像側から２番目のレンズの焦点距離、
である。
【請求項４】
　以下の条件式（４）を満足することを特徴とする請求項１～３のいずれか１項に記載の撮像装置；
９４＞２ωｗ＞７２　…（４）
　ただし、
２ωｗ：第１撮像光学系の全画角［ｄｅｇ］、
である。
【請求項５】
　前記第１撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、負パワーの第４レンズと、の４枚構成から成り、前記第２撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、負パワーの第３レンズと、負パワーの第４レンズと、の４枚構成から成ることを特徴とする請求項１～４のいずれか１項に記載の撮像装置。
【請求項６】
　前記第１撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、正パワーの第４レンズと、負パワーの第５レンズと、の５枚構成から成り、前記第２撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、負パワーの第４レンズと、負パワーの第５レンズと、の５枚構成から成ることを特徴とする請求項１～４のいずれか１項に記載の撮像装置。
【請求項７】
　以下の条件式（５）を満足することを特徴とする請求項１～６のいずれか１項に記載の撮像装置；
０．６＜ＦＮＯｗ／ＦＮＯｍ＜１．３　…（５）
　ただし、
ＦＮＯｗ：第１撮像光学系のＦナンバー、
ＦＮＯｍ：第２撮像光学系のＦナンバー、
である。
【請求項８】
　以下の条件式（６）を満足することを特徴とする請求項１～７のいずれか１項に記載の撮像装置；
０．７＜ＴＬｍ／ｆｍ＜１．０　…（６）
　ただし、
ＴＬｍ：第２撮像光学系のレンズ全長（最も物体側の面から像面までの距離）、
ｆｍ：第２撮像光学系全体の焦点距離、
である。

【請求項９】
以下の条件式（７）を満足することを特徴とする請求項１～８のいずれか１項に記載の撮像装置；
１．０＜ＴＬｗ／ｆｗ＜１．４ …（７）
ただし、
ＴＬｗ：第１撮像光学系のレンズ全長（最も物体側の面から像面までの距離）、
ｆｗ：第１撮像光学系全体の焦点距離、
である。
【請求項１０】
前記第１，第２撮像光学系で形成された光学像を電気的な信号に変換する撮像素子を備え、その撮像素子で得られた信号を用いて前記電子ズームが行われ、以下の条件式（８）を満足することを特徴とする請求項１～９のいずれか１項に記載の撮像装置；
３＜ＰＸ／ＺＲ＜６ …（８）
ただし、
ＰＸ：撮像素子の画素数（メガピクセル）、
ＺＲ：広角端から望遠端までの全体の電子ズーム比（倍）、
である。
【発明の詳細な説明】
【技術分野】
【０００１】
本発明は、撮像装置に関するものである。更に詳しくは、被写体の映像を撮像素子（例えば、ＣＣＤ(Charge Coupled Device)型イメージセンサ，ＣＭＯＳ(Complementary Metal-Oxide Semiconductor)型イメージセンサ等の固体撮像素子）で取り込んで、映像の拡大縮小を行うことの可能な電子ズーム機能を有する小型の撮像装置に関するものである。
【背景技術】
【０００２】
近年、ＣＣＤ型イメージセンサやＣＭＯＳ型イメージセンサ等の固体撮像素子を用いた撮像装置の高性能化・小型化に伴い、撮像装置を備えた携帯電話や携帯情報端末が普及しつつある。また、これらの撮像装置に搭載される撮像光学系には、更なる小型化・高性能化への要求が高まっている。さらに、従来の撮像装置は単焦点であったが、ズーム機能への要求も高まっている。しかしながら、光学ズーム機能を有する撮像光学系を用いると、光学系自体が非常に大きくなってしまうことに加えて、ズーム駆動のアクチュエーターが必要になるため、結果として撮像装置は非常に大きくなってしまう。したがって、携帯電話や携帯情報端末に搭載することは困難であった。
【０００３】
そこで、全長の小さな単焦点の撮像光学系を用いて、電子ズーム機能（つまり、画像の切り出しによる擬似ズーム機能）を搭載することが考えられる。ところが、ズーム比の大きな電子ズームの場合、切り出す映像の画素数が望遠端で非常に小さくなってしまうという課題があった。この課題を克服するために、２つ又はそれ以上の異なる焦点距離を有する単焦点の撮像光学系を搭載し、電子ズーム機能を焦点距離ごとに切り替えることによって、画素数低下を防ぐということが特許文献１～３等で提案されている。例えば特許文献１では、単焦点レンズとズームレンズを有し、焦点距離のギャップは電子ズームで行うデジタルカメラが提案されている。特許文献２や特許文献３では、２個又は３個の単焦点レンズを用いて電子ズームを行う撮像装置が提案されている。
【先行技術文献】
【特許文献】
【０００４】
【特許文献１】特表２００８－５３０９５４号公報
【特許文献２】特開２００５－９９２６５号公報
【特許文献３】特開２００７－３０６２８２号公報

【発明の概要】
【発明が解決しようとする課題】
【０００５】
上記特許文献１～３に記載されているように、複数の撮像光学系を用いて電子ズームを行えば、画素数の大きな高変倍の撮像装置を実現することは可能である。しかしながら、上記特許文献１～３のいずれにも薄型化・高画質化を達成するための具体的な撮像光学系の構成に関する記載は無い。そのコンセプトを示しているにすぎず、薄型の実現性の実証は不十分であった。
【０００６】
本発明はこのような問題点に鑑みてなされたものであって、その目的は、広変倍域すべてにわたって高解像度で高画質の画像を得ることのできる高性能で薄型・小型の撮像装置を提供することにある。
【課題を解決するための手段】
【０００７】
上記目的を達成するために、第１の発明の撮像装置は、同一方向を向いた単焦点の第１，第２撮像光学系を有し、前記第２撮像光学系の焦点距離が前記第１撮像光学系の焦点距離よりも長く、前記第１撮像光学系で得られた画像の切り出しによる電子ズームで広角端から中間焦点距離状態までのズーミングを行い、前記第２撮像光学系で得られた画像の切り出しによる電子ズームで中間焦点距離状態から望遠端までのズーミングを行うことにより、全体として広角端から望遠端までのズーミングを行う撮像装置であって、前記第１，第２撮像光学系のいずれもが、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、を有する４枚以上のレンズから成るとともに、最も像側のレンズが負レンズであり、前記第１レンズと第２レンズの合成焦点距離が正であり、かつ、以下の条件式（１）を満足することを特徴とする。
１．０＜ｆＦｗ／ｆＦｍ＜１．５　…（１）
ただし、
ｆＦｗ：第１撮像光学系における第１レンズと第２レンズの合成焦点距離、
ｆＦｍ：第２撮像光学系における第１レンズと第２レンズの合成焦点距離、
である。
【０００８】
第２の発明の撮像装置は、上記第１の発明において、以下の条件式（２Ａ）及び（２Ｂ）を満足することを特徴とする。
ｆＦｗ／ｆｗ＞１　…（２Ａ）
ｆＦｍ／ｆｍ＜１　…（２Ｂ）
ただし、
ｆｗ：第１撮像光学系全体の焦点距離、
ｆｍ：第２撮像光学系全体の焦点距離、
である。
【０００９】
第３の発明の撮像装置は、上記第１又は第２の発明において、以下の条件式（３）を満足することを特徴とする。
－０．６＜ｆＸｗ／ｆＸｍ＜０．５　…（３）
ただし、
ｆＸｗ：第１撮像光学系において像側から２番目のレンズの焦点距離、
ｆＸｍ：第２撮像光学系において像側から２番目のレンズの焦点距離、
である。
【００１０】
第４の発明の撮像装置は、上記第１～第３のいずれか１つの発明において、以下の条件式（４）を満足することを特徴とする。
９４＞２ωｗ＞７２　…（４）

ただし、
２ωｗ：第１撮像光学系の全画角［ｄｅｇ］、
である。
【００１１】
第５の発明の撮像装置は、上記第１～第４のいずれか１つの発明において、前記第１撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、負パワーの第４レンズと、の４枚構成から成り、前記第２撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、負パワーの第３レンズと、負パワーの第４レンズと、の４枚構成から成ることを特徴とする。
【００１２】
第６の発明の撮像装置は、上記第１～第４のいずれか１つの発明において、前記第１撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、正パワーの第４レンズと、負パワーの第５レンズと、の５枚構成から成り、前記第２撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、負パワーの第４レンズと、負パワーの第５レンズと、の５枚構成から成ることを特徴とする。
【００１３】
第７の発明の撮像装置は、上記第１～第６のいずれか１つの発明において、以下の条件式（５）を満足することを特徴とする。
０．６＜ＦＮＯｗ／ＦＮＯｍ＜１．３　…（５）
ただし、
ＦＮＯｗ：第１撮像光学系のＦナンバー、
ＦＮＯｍ：第２撮像光学系のＦナンバー、
である。
【００１４】
第８の発明の撮像装置は、上記第１～第７のいずれか１つの発明において、以下の条件式（６）を満足することを特徴とする。
０．７＜ＴＬｍ／ｆｍ＜１．０　…（６）
ただし、
ＴＬｍ：第２撮像光学系のレンズ全長（最も物体側の面から像面までの距離）、
ｆｍ：第２撮像光学系全体の焦点距離、
である。
【００１５】
第９の発明の撮像装置は、上記第１～第８のいずれか１つの発明において、以下の条件式（７）を満足することを特徴とする。
１．０＜ＴＬｗ／ｆｗ＜１．４　…（７）
ただし、
ＴＬｗ：第１撮像光学系のレンズ全長（最も物体側の面から像面までの距離）、
ｆｗ：第１撮像光学系全体の焦点距離、
である。
【００１６】
第１０の発明の撮像装置は、上記第１～第９のいずれか１つの発明において、前記第１，第２撮像光学系で形成された光学像を電気的な信号に変換する撮像素子を備え、その撮像素子で得られた信号を用いて前記電子ズームが行われ、以下の条件式（８）を満足することを特徴とする。
３＜ＰＸ／ＺＲ＜６　…（８）
ただし、
ＰＸ：撮像素子の画素数（メガピクセル）、
ＺＲ：広角端から望遠端までの全体の電子ズーム比（倍）、
である。

【発明の効果】

【００１７】

本発明の構成を採用することにより、広変倍域すべてにわたって高解像度で高画質の画像を得ることのできる高性能で薄型・小型の撮像装置を実現することができる。

【図面の簡単な説明】

【００１８】

【図１】第１の実施の形態（実施例１）の第１撮像光学系の光学構成を示す断面図。

【図２】実施例１の第１撮像光学系の物体距離無限遠での縦収差図。

【図３】実施例１の第１撮像光学系の物体距離１０ｃｍでの縦収差図。

【図４】実施例１の第１撮像光学系の物体距離無限遠での横収差図。

【図５】実施例１の第１撮像光学系の物体距離１０ｃｍでの横収差図。

【図６】第１の実施の形態（実施例１）の第２撮像光学系の光学構成を示す断面図。

【図７】実施例１の第２撮像光学系の物体距離無限遠での縦収差図。

【図８】実施例１の第２撮像光学系の物体距離１０ｃｍでの縦収差図。

【図９】実施例１の第２撮像光学系の物体距離無限遠での横収差図。

【図１０】実施例１の第２撮像光学系の物体距離１０ｃｍでの横収差図。

【図１１】第２の実施の形態（実施例２）の第１撮像光学系の光学構成を示す断面図。

【図１２】実施例２の第１撮像光学系の物体距離無限遠での縦収差図。

【図１３】実施例２の第１撮像光学系の物体距離１０ｃｍでの縦収差図。

【図１４】実施例２の第１撮像光学系の物体距離無限遠での横収差図。

【図１５】実施例２の第１撮像光学系の物体距離１０ｃｍでの横収差図。

【図１６】第２の実施の形態（実施例２）の第２撮像光学系の光学構成を示す断面図。

【図１７】実施例２の第２撮像光学系の物体距離無限遠での縦収差図。

【図１８】実施例２の第２撮像光学系の物体距離１０ｃｍでの縦収差図。

【図１９】実施例２の第２撮像光学系の物体距離無限遠での横収差図。

【図２０】実施例２の第２撮像光学系の物体距離１０ｃｍでの横収差図。

【図２１】第１，第２撮像光学ユニットを搭載したデジタル機器の概略構成例を示す模式図。

【図２２】第１，第２撮像光学系を搭載した第１，第２撮像光学ユニットの概略構成例を示す外観図。

【図２３】第１，第２撮像光学ユニットを搭載したデジタル機器の概略構成例を示す外観図。

【発明を実施するための形態】

【００１９】

以下、本発明に係る撮像装置等を説明する。本発明に係る撮像装置は、同一方向を向いた単焦点の第１，第２撮像光学系を有し、前記第２撮像光学系の焦点距離ｆｍが前記第１撮像光学系の焦点距離ｆｗよりも長く、前記第１撮像光学系で得られた画像の切り出しによる電子ズームで広角端から中間焦点距離状態までのズーミング（ｆｗ～ｆｍ）を行い、前記第２撮像光学系で得られた画像の切り出しによる電子ズームで中間焦点距離状態から望遠端までのズーミング（ｆｍ～ｆｔ）を行うことにより、全体として広角端から望遠端までのズーミング（ｆｗ～ｆｔ）を行う撮像装置である。そして、前記第１，第２撮像光学系のいずれもが、物体側から順に、正パワー（パワー：焦点距離の逆数で定義される量）の第１レンズと、負パワーの第２レンズと、を有する４枚以上のレンズから成るとともに、最も像側のレンズが負レンズであり、前記第１レンズと第２レンズの合成焦点距離が正であり、かつ、以下の条件式（１）を満足することを特徴としている。なお、第１，第２撮像光学系間での切り替え点となる中間焦点距離状態では、第２撮像光学系で得られた画像を用いることが好ましいが、必要に応じて第１撮像光学系で得られた画像を用いてもよい。

１．０＜ｆＦｗ／ｆＦｍ＜１．５　…（１）

ただし、

ｆＦｗ：第１撮像光学系における第１レンズと第２レンズの合成焦点距離、
ｆＦｍ：第２撮像光学系における第１レンズと第２レンズの合成焦点距離、
である。

【００２０】

光学ズーム機能を有する撮像光学系は、メカ機構等が大きくなるため、携帯機器に適していない。一方、電子ズームという考え方もあるが、１つの撮像光学系で電子ズームを行う場合、大きな変倍比を得る際に望遠端の画素数が小さすぎて良好な画像を得ることができない、という問題がある。したがって、大きな変倍比を得ることができ、かつ、良好な画像を得るために、また、ズーム駆動機構等の大きな部品が無く小型の携帯機器に組み込みやすい大きさを満足するために、２眼の電子ズーム機能を採用することが好ましい。

【００２１】

良好な画像を得るためには、電子ズームを行っても十分な画素数が必要である。したがって、電子ズーム前の画素数は十分大きくなければならない。例えば、望ましい画素数は３百万画素（３メガピクセル）以上であり、電子ズームを行ってもその画素数を得るためには、１０メガピクセル等の大きな画素数をもつ撮像素子（つまり大型のセンサー）を有する必要がある。したがって、大きな画素数でも良好な性能を有することが必要であり、その条件として少なくとも４枚のレンズが必要である。

【００２２】

撮像装置を薄型のモジュールで構成するには、第１撮像光学系も第２撮像光学系も小型である必要がある。したがって、別々の光学系というより、両方の関係が重要となる。小型で高性能を達成するためには、どちらの光学系も、最も物体側のレンズが正レンズ、その像側に負レンズを配置し、第１レンズと第２レンズの合成焦点距離ｆＦｗ，ｆＦｍは正、さらに最も像側に負レンズを配置することが好ましい。

【００２３】

全体的には、小型に適したテレフォトタイプ（物体側が正パワーで像側が負パワー）である必要がある。その際には、前群を構成する第１レンズと第２レンズが正レンズと負レンズであることが、色収差やペッツバール和の補正という観点からも好ましい。また、最も像側が負レンズであることが、テレフォトタイプを構成するための条件となる。その際に、第１，第２レンズから成る前群の焦点距離の比を、前記条件式（１）を満たすようにすることが好ましい。

【００２４】

条件式（１）の下限を上回ることは、第２撮像光学系の前群の焦点距離が第１撮像光学系の前群の焦点距離よりも短い（つまりパワーが強い）ことを意味する。つまり、第２撮像光学系は全系の焦点距離が相対的に長いので、全体としては正のパワーが弱くなるが、それに反して、全系の焦点距離の短い第１撮像光学系の前群よりもパワーを強くする条件を下限で規定している。この条件式（１）を満足することにより、第２撮像光学系のテレフォト傾向を強くすることができるため、装置としての全長を小さくする効果が得られる。逆に、条件式（１）の上限を上回ると、第２撮像光学系の前群を強くしすぎることで性能や誤差感度が悪化し、結果として良好な画質が得られなくなる。

【００２５】

上記特徴的構成によると、広変倍域すべてにわたって高解像度で高画質の画像を得ることのできる高性能で薄型・小型の撮像装置（例えば、デジタルカメラ，携帯電話，携帯情報端末等のデジタル機器）を実現することが可能である。こういった効果をバランス良く得るとともに、更に高い光学性能，薄型・小型化等を達成するための条件等を以下に説明する。

【００２６】

以下の条件式（２Ａ）及び（２Ｂ）を満足することが望ましい。

ｆＦｗ／ｆｗ＞１　…（２Ａ）

ｆＦｍ／ｆｍ＜１　…（２Ｂ）

ただし、

ｆｗ：第１撮像光学系全体の焦点距離、
ｆｍ：第２撮像光学系全体の焦点距離、
である。

【００２７】

前群の焦点距離と全系の焦点距離との比は、テレフォト性を示す重要なパラメータである。条件式（２Ａ）及び（２Ｂ）を満たすということは、第１撮像光学系の前群のパワーは全体のパワーよりも小さいが、第２撮像光学系の前群のパワーは全体のパワーよりも大きいということである。条件式（２Ａ）及び（２Ｂ）を満たすことで、広角端の性能を確保しつつ、中間焦点距離状態の全長を小さくするという条件を満足することができる。

【００２８】

以下の条件式（３）を満足することが望ましい。

－０．６＜ｆＸｗ／ｆＸｍ＜０．５　…（３）

ただし、

ｆＸｗ：第１撮像光学系において像側から２番目のレンズの焦点距離、
ｆＸｍ：第２撮像光学系において像側から２番目のレンズの焦点距離、
である。なお、像側から２番目のレンズは、最も像側のレンズの物体側にあるレンズであり、４枚構成では３枚目のレンズ、５枚構成では３枚目のレンズである。

【００２９】

第２撮像光学系では、全系の焦点距離が長いにも関わらず、全長を小さくする必要がある。テレフォト性の観点では前述の条件式（１），（２Ａ）及び（２Ｂ）を満たすことが有効であるが、後群のパワーを特定することも重要である。最も像側のレンズは像付近に位置するので、その焦点距離によるバック変動や全長への影響があまり大きくない。しかし、その物体側に位置するレンズの焦点距離は、全長と性能に対して重要な役割を果たすことになる。

【００３０】

条件式（３）の上限は、第２撮像光学系の該レンズパワーが第１撮像光学系の該レンズパワーよりも小さい（又は負である）ということを示しており、その程度を表している。この条件式（３）を満足することで、第１撮像光学系の性能を満足しつつ、第２撮像光学系の全長を小型にすることができる。条件式（３）の下限を越えた場合、第２撮像光学系の性能の要求から後群に大きな負のパワーを有すると、全体のレンズ構成が大きく変化してしまい、高性能で薄型という条件から外れてしまうおそれがある。

【００３１】

以下の条件式（３ａ）を満たすことが望ましい。

－０．６＜ｆＸｗ／ｆＸｍ＜０　…（３ａ）

この条件式（３ａ）は、前記条件式（３）が規定している条件範囲のなかでも、前記観点等に基づいた更に好ましい条件範囲を規定しており、符号反転していることに特徴がある。つまり、第１撮像光学系が正レンズであり、第２撮像光学系が負レンズである。テレフォト性が顕著に出ているが、この数値範囲であれば、更なる小型化と高性能化を達成することができる。したがって、好ましくは条件式（３ａ）を満たすことにより、上記効果をより一層大きくすることができる。

【００３２】

以下の条件式（４）を満足することが望ましい。

９４＞２ωｗ＞７２　…（４）

ただし、

２ωｗ：第１撮像光学系の全画角［ｄｅｇ］、
である。

【００３３】

条件式（４）の上限を越えると、ズームレンズとしての広角度合いが強くなりすぎてしまい、条件式（４）の下限を越えると、全体的な焦点距離が望遠側になって大型化を招くおそれがある。また、広角端での画角が狭くなると、中間ポジションでの焦点距離及びレ

ンズ全長の増大を招くおそれがある。

【００３４】

以下の条件式（４ａ）を満足することが更に望ましい。

９０＞２ωｗ＞７５ …（４ａ）

この条件式（４ａ）は、前記条件式（４）が規定している条件範囲のなかでも、前記観点等に基づいた更に好ましい条件範囲を規定している。したがって、好ましくは条件式（４ａ）を満たすことにより、上記効果をより一層大きくすることができる。

【００３５】

前記第１撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、負パワーの第４レンズと、の４枚構成から成り、前記第２撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、負パワーの第３レンズと、負パワーの第４レンズと、の４枚構成から成ることが望ましい。また、前記第１撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、正パワーの第４レンズと、負パワーの第５レンズと、の５枚構成から成り、前記第２撮像光学系が、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、正パワーの第３レンズと、負パワーの第４レンズと、負パワーの第５レンズと、の５枚構成から成ることが望ましい。

【００３６】

上記のように、第１撮像光学系を正負正負の４枚構成とし、第２撮像光学系を正負負負の４枚構成としたり、第１撮像光学系を正負正正負の５枚構成とし、第２撮像光学系を正負正負負の５枚構成としたりすれば、第１撮像光学系では像面湾曲，色収差等を補正するのに有利な構成となり、第２撮像光学系ではテレフォト性を強くして全長の短縮に有利な構成となる。

【００３７】

以下の条件式（５）を満足することが望ましい。

０．６＜ＦＮＯｗ／ＦＮＯｍ＜１．３ …（５）

ただし、

ＦＮＯｗ：第１撮像光学系のＦナンバー、

ＦＮＯｍ：第２撮像光学系のＦナンバー、

である。

【００３８】

切り替えの時にＦナンバーが大きく異なると、ボケの印象が大きく変わることになり、使用者にとっては不自然になるので、Ｆナンバーは条件式（５）を満たすように第１，第２撮像光学系で近い方が好ましい。第１撮像光学系よりも第２撮像光学系の方を暗くする方が全体の小型化を達成する上で有利になる。

【００３９】

以下の条件式（５ａ）を満足することが更に望ましい。

０．７＜ＦＮＯｗ／ＦＮＯｍ＜１．１ …（５ａ）

この条件式（５ａ）は、前記条件式（５）が規定している条件範囲のなかでも、前記観点等に基づいた更に好ましい条件範囲を規定している。したがって、好ましくは条件式（５ａ）を満たすことにより、上記効果をより一層大きくすることができる。

【００４０】

以下の条件式（６）を満足することが望ましい。

０．７＜ＴＬｍ／ｆｍ＜１．０ …（６）

ただし、

ＴＬｍ：第２撮像光学系のレンズ全長（最も物体側の面（第１面）から像面までの距離）、

ｆｍ：第２撮像光学系全体の焦点距離、

である。

【００４１】

第２撮像光学系を薄型にするために望遠比を小さくする必要があるが、性能との良好なバランスをとる上で、条件式（６）を満たすことが好ましい。条件式（６）の下限を越えると、パワーが強くなって収差劣化を招くおそれがある。また、第１，第２撮像光学系の性能差が大きくなって、切り替え時の映像劣化が生じるおそれがある。

【００４２】

以下の条件式（７）を満足することが望ましい。

１．０＜ＴＬｗ／ｆｗ＜１．４　…（７）

ただし、

ＴＬｗ：第１撮像光学系のレンズ全長（最も物体側の面から像面までの距離）、

ｆｗ：第１撮像光学系全体の焦点距離、

である。

【００４３】

第１撮像光学系は薄型にできるが、あまり薄すぎると性能が悪くなる。性能をとりつつ第２撮像光学系の厚みとのバランスを考えた場合、条件式（７）を満たすことが好ましい。

【００４４】

前記第１，第２撮像光学系で形成された光学像を電気的な信号に変換する撮像素子を備え、その撮像素子で得られた信号を用いて前記電子ズームが行われ、以下の条件式（８）を満足することが望ましい。

３＜ＰＸ／ＺＲ＜６　…（８）

ただし、

ＰＸ：撮像素子の画素数（メガピクセル）、

ＺＲ：広角端から望遠端までの全体の電子ズーム比（倍）、

である。

【００４５】

条件式（８）は、全体のズーム比と画素数との好適なバランスを規定している。一般的に、３００万画素～４００万画素程度の画質が求められている。電子ズームで良好な画質を得るには、条件式（８）を満足することが望ましい。条件式（８）の上限を越えると、センサー画素数に対して十分な変倍比を確保することが困難になり、広い変倍範囲が得られなくなる。条件式（８）の下限を越えると、最低画素が小さくなりすぎるため十分な高画質を得ることができなくなる。なおここでは、第１撮像光学系の電子ズームと第２撮像光学系の電子ズームとでズーム比は同じであり、共通の１つの撮像素子又は同じ画素数の２つの撮像素子を用いることを前提としている。

【００４６】

本発明に係る第１，第２撮像光学系は、画像入力機能付きデジタル機器（例えば、カメラ付き携帯電話，デジタルカメラ等の撮像装置）に適しており、これを撮像素子等と組み合わせることにより、被写体の映像を光学的に取り込んで電気的な信号として出力する撮像光学ユニットを構成することができる。撮像光学ユニットは、被写体の静止画撮影や動画撮影に用いられるカメラの主たる構成要素を成す光学装置であり、例えば、物体（すなわち被写体）側から順に、物体の光学像を形成する第１，第２撮像光学系と、その第１，第２撮像光学系により形成された光学像を電気的な信号に変換する撮像素子と、を備えることにより構成される。そして、撮像素子の受光面（すなわち撮像面）上に被写体の光学像が形成されるように、前述した特徴的構成を有する第１，第２撮像光学系が配置されることにより、薄型・小型・低コストで高変倍・高性能の撮像光学ユニットやそれを備えたデジタル機器を実現することができる。

【００４７】

画像入力機能付きデジタル機器の例としては、デジタルカメラ，ビデオカメラ，監視カメラ，車載カメラ，テレビ電話用カメラ等のカメラが挙げられ、また、パーソナルコンピュータ，携帯端末（例えば、携帯電話，モバイルコンピュータ等の小型で携帯可能な情報機器端末），これらの周辺機器（スキャナー，プリンター等），その他のデジタル機器等

に内蔵又は外付けされるカメラが挙げられる。これらの例から分かるように、撮像光学ユニットを用いることによりカメラを構成することができるだけでなく、各種機器に撮像光学ユニットを搭載することによりカメラ機能を付加することが可能である。例えば、カメラ付き携帯電話等の画像入力機能付きデジタル機器を構成することが可能である。

【００４８】

図２１に、画像入力機能付きデジタル機器の一例として、デジタル機器ＤＵの概略構成例を模式的断面で示し、図２２に、第１，第２撮像光学系ＬＮ１，ＬＮ２を搭載した第１，第２撮像光学ユニットＬＵ１，ＬＵ２の概略構成例の外観を示す。デジタル機器ＤＵに搭載されている撮像光学ユニットＬＵ１，ＬＵ２は、図２１に示すように、物体（すなわち被写体）側から順に、物体の光学像（像面）ＩＭ１，ＩＭ２を形成する単焦点の第１，第２撮像光学系ＬＮ１，ＬＮ２（ＡＸ１，ＡＸ２：光軸）と、平行平板ＰＴ１，ＰＴ２（撮像素子ＳＲ１，ＳＲ２のカバーガラス；必要に応じて配置される光学的ローパスフィルタ，赤外カットフィルタ等の光学フィルタ等に相当する。）と、第１，第２撮像光学系ＬＮ１，ＬＮ２により長方形状の受光面（撮像面）ＳＳ１，ＳＳ２上に形成された光学像ＩＭ１，ＩＭ２を電気的な信号に変換する第１，第２撮像素子ＳＲ１，ＳＲ２と、を備えている。この撮像光学ユニットＬＵ１，ＬＵ２で画像入力機能付きデジタル機器ＤＵを構成する場合、通常そのボディ内部に撮像光学ユニットＬＵ１，ＬＵ２を配置することになるが、カメラ機能を実現する際には必要に応じた形態を採用することが可能である。例えば、撮像光学ユニットＬＵ１，ＬＵ２をデジタル機器ＤＵの本体に対して着脱自在又は回動自在に構成することが可能である。

【００４９】

第１，第２撮像光学系ＬＮ１，ＬＮ２は、前述したように同一方向を向いた単焦点レンズであり、撮像素子ＳＲ１，ＳＲ２の撮像面ＳＳ１，ＳＳ２上に光学像ＩＭ１，ＩＭ２を形成する構成になっている。そして、第２撮像光学系ＬＮ２の焦点距離ｆｍが第１撮像光学系ＬＮ１の焦点距離ｆｗよりも長く、第１撮像光学系ＬＮ１で得られた画像（光学像ＩＭ１）の切り出しによる電子ズームで広角端から中間焦点距離状態までのズーミング（ｆｗ以上ｆｍ未満）を行い、第２撮像光学系ＬＮ２で得られた画像（光学像ＩＭ２）の切り出しによる電子ズームで中間焦点距離状態から望遠端までのズーミング（ｆｍ以上ｆｔ以下）を行うことにより、全体として広角端から望遠端までのズーミング（ｆｗ～ｆｔ）を行う構成になっている。なお、必要に応じて少なくとも一方の撮像光学系に光学ズーム機能を持たせてもよい。

【００５０】

図２２に示すように、第１撮像光学系ＬＮ１と第２撮像光学系ＬＮ２とは、隣接するように配置されている。このように配置することにより、パララックスをできるだけ小さくすることができる。第１，第２撮像光学系ＬＮ１，ＬＮ２を隣接配置した場合、フォーカス駆動素子は共通であることが好ましい。その際、フォーカスの移動量が全体繰り出しの場合では異なるので、第１撮像光学系ＬＮ１と第２撮像光学系ＬＮ２とでフォーカス移動量が揃うように、例えば、第２撮像光学系ＬＮ２では一部のレンズ又はレンズ群の駆動によるフォーカスを行う構成にすることが更に好ましい。

【００５１】

第１，第２撮像光学系ＬＮ１，ＬＮ２は同一方向を向いているため、光軸ＡＸ１，ＡＸ２は互いに平行になっているが、第１，第２撮像光学系ＬＮ１，ＬＮ２のいずれか一方を若干傾けることにより撮影距離に応じて発生する、第１，第２撮像光学系ＬＮ１，ＬＮ２間でのパララックスを補正してもよい。したがって、第１，第２撮像光学系ＬＮ１，ＬＮ２が同一方向を向いていることは、パララックス補正を考慮した上での方向性を意味しているので、厳密な意味で光軸ＡＸ１，ＡＸ２が互いに平行である必要は無い。また、光学的手ぶれ補正機能で第１，第２撮像光学系ＬＮ１，ＬＮ２のいずれか一方の、レンズモジュールの全体の傾き又は、少なくとも一部のレンズ移動によりパララックス補正を行うようにしてもよい。手ぶれ補正とパララックス補正とでアクチュエーターを共通化することができるので、撮像装置の薄型化・小型化を効果的に達成することが可能となる。

【００５２】
図２３に、第１，第２撮像光学ユニットＬＵ１，ＬＵ２を搭載したデジタル機器ＤＵの概略構成例の外観を示す。このデジタル機器ＤＵは、画面横方向に視差を発生させて立体視を行う方式の画像入出力機能付き携帯機器（例えば、デジタルカメラ，携帯電話，携帯型情報機器端末等）である。デジタル機器ＤＵの背面側（Ａ）には裸眼立体視可能な表示部５が設けられており、正面側（Ｂ）には第１撮像光学系ＬＮ１と第２撮像光学系ＬＮ２とが画面横方向に所定の間隔をあけて離れて位置するように第１，第２撮像光学ユニットＬＵ１，ＬＵ２が配置されている（なお、デジタル機器ＤＵの上面側には操作部４が設けられている。）。このように第１，第２撮像光学系ＬＮ１，ＬＮ２を離すことにより視差を発生させることができるため、第２撮像光学系ＬＮ２の焦点距離ｆｍにおいて、第１撮像光学系ＬＮ１で得られる画像と第２撮像光学系ＬＮ２で得られる画像を用いて立体映像の表示を行うことができる。

【００５３】
撮像素子ＳＲ１，ＳＲ２としては、例えば複数の画素を有するＣＣＤ型イメージセンサ，ＣＭＯＳ型イメージセンサ等の固体撮像素子が用いられる。第１，第２撮像光学系ＬＮ１，ＬＮ２は、撮像素子ＳＲ１，ＳＲ２の光電変換部である撮像面ＳＳ１，ＳＳ２上に被写体の光学像ＩＭ１，ＩＭ２が形成されるように設けられているので、第１，第２撮像光学系ＬＮ１，ＬＮ２によって形成された光学像ＩＭ１，ＩＭ２は、撮像素子ＳＲ１，ＳＲ２によって電気的な信号に変換される。なお、ここでは２つの撮像素子ＳＲ１，ＳＲ２を用いているが、第１，第２撮像光学系ＬＮ１，ＬＮ２に対して１つの撮像素子を共通に用いてもよい。

【００５４】
デジタル機器ＤＵ（図２１）は、第１，第２撮像光学ユニットＬＵ１，ＬＵ２の他に、信号処理部１，制御部２，メモリ３，操作部４，表示部５等を備えている。撮像素子ＳＲ１，ＳＲ２で生成した信号は、信号処理部１で所定のデジタル画像処理や画像圧縮処理等が必要に応じて施され、デジタル映像信号としてメモリ３（半導体メモリ，光ディスク等）に記録されたり、場合によってはケーブルを介したり赤外線信号等に変換されたりして他の機器に伝送される（例えば携帯電話の通信機能）。制御部２はマイクロコンピュータから成っており、電子ズーム機能，撮影機能（静止画撮影機能，動画撮影機能等），画像再生機能等の機能の制御；フォーカシング，手ぶれ補正等のためのレンズ移動機構の制御等を集中的に行う。例えば、被写体の静止画撮影，動画撮影のうちの少なくとも一方を行うように、制御部２により第１，第２撮像光学ユニットＬＵ１，ＬＵ２に対する制御が行われる。表示部５は液晶モニター等のディスプレイを含む部分であり、撮像素子ＳＲ１，ＳＲ２によって変換された画像信号あるいはメモリ３に記録されている画像情報を用いて画像表示を行う。操作部４は、操作ボタン（例えばレリーズボタン），操作ダイヤル（例えば撮影モードダイヤル）等の操作部材を含む部分であり、操作者が操作入力した情報を制御部２に伝達する。

【００５５】
次に、第１，第２の実施の形態を挙げて、第１，第２撮像光学系ＬＮ１，ＬＮ２の具体的な光学構成を説明する。図１は、第１の実施の形態を構成する第１撮像光学系ＬＮ１（ＥＸ１－ｗ）のレンズ構成，光路等を示す光学断面図であり、図６は、第１の実施の形態を構成する第２撮像光学系ＬＮ２（ＥＸ１－ｍ）のレンズ構成，光路等を示す光学断面図である。図１１は、第２の実施の形態を構成する第１撮像光学系ＬＮ１（ＥＸ２－ｗ）のレンズ構成，光路等を示す光学断面図であり、図１６は、第２の実施の形態を構成する第２撮像光学系ＬＮ２（ＥＸ２－ｍ）のレンズ構成，光路等を示す光学断面図である。

【００５６】
第１の実施の形態では、第１撮像光学系ＬＮ１（図１）は正負正負の４枚構成になっており、第２撮像光学系ＬＮ２（図６）は正負負負の４枚構成になっている。また第２の実施の形態では、第１撮像光学系ＬＮ１（図１１）は正負正正負の５枚構成になっており、第２撮像光学系ＬＮ２（図１６）は正負正負負の５枚構成になっている。なお、撮像面Ｓ

Ｓ１，ＳＳ２と隣り合うように第１，第２撮像光学系ＬＮ１，ＬＮ２の像側に配置されている平行平板ＰＴは、光学的ローパスフィルタ，ＩＲカットフィルタ，固体撮像素子のシールガラス等を想定したものである。

【実施例】

【００５７】

以下、本発明を実施した撮像装置の光学構成等を、実施例のコンストラクションデータ等を挙げて更に具体的に説明する。ここで挙げる実施例１，２（ＥＸ１，２）は、前述した第１，第２の実施の形態にそれぞれ対応する数値実施例であり、第１，第２の実施の形態を表す光学構成図（図１，図６；図１１，図１６）は、対応する実施例１，２の第１，第２撮像光学系ＬＮ１，ＬＮ２のレンズ構成をそれぞれ示している。

【００５８】

各実施例のコンストラクションデータでは、面データとして、左側の欄から順に、面番号，曲率半径ｒ（ｍｍ），軸上面間隔ｄ（ｍｍ），ｄ線（波長５８７．５６ｎｍ）に関する屈折率ｎｄ，ｄ線に関するアッベ数ｖｄを示す。面番号に＊が付された面は非球面であり、その面形状は面頂点を原点とするローカルな直交座標系（ｘ，ｙ，ｚ）を用いた以下の式（ＡＳ）で定義される。非球面データとして、非球面係数等を示す。なお、各実施例の非球面データにおいて表記の無い項の係数は０であり、すべてのデータに関してＥ－ｎ＝$\times 10^{-n}$である。

$z=(c\cdot h^2)/[1+\sqrt{\{1-(1+K)\cdot c^2\cdot h^2\}}]+\Sigma(Aj\cdot h^j)$ …（ＡＳ）

ただし、

ｈ：ｚ軸（光軸ＡＸ１，ＡＸ２）に対して垂直な方向の高さ（$h^2=x^2+y^2$）、

ｚ：高さｈの位置での光軸ＡＸ１，ＡＸ２方向のサグ量（面頂点基準）、

ｃ：面頂点での曲率（曲率半径ｒの逆数）、

Ｋ：円錐定数、

Ａｊ：ｊ次の非球面係数、

である。

【００５９】

表１に、各種データとして、全系の焦点距離（ｆｗ又はｆｍ，単位：ｍｍ），Ｆナンバー（ＦＮＯｗ又はＦＮＯｍ），物体距離無限遠時のレンズ全長（ＴＬｗ又はＴＬｍ，単位：ｍｍ），撮像素子ＳＲ１，ＳＲ２の受光面ＳＳ１，ＳＳ２の対角長２Ｙ’（Ｙ’：像面ＩＭ１，ＩＭ２における最大像高），全画角（２ωｗ又は２ωｍ，°），第ｉレンズＬｉ（ｉ＝１，２，３，…）の焦点距離（ｆｉｗ又はｆｉｍ，単位：ｍｍ），第１，第２レンズＬ１，Ｌ２の合成焦点距離（ｆＦｗ又はｆＦｍ，単位：ｍｍ），像側から２番目のレンズＬＸの焦点距離（ｆＸｗ又はｆＸｍ，単位：ｍｍ），撮像素子ＳＲ１，ＳＲ２の画素数（ＰＸ，メガピクセル），電子ズーム時の切り出しの最小画素数（メガピクセル），電子ズーム時の切り出しの最大焦点距離（ｍｍ），電子ズーム比（ＺＲ），及び１３５換算での焦点距離（ｍｍ）を示す。なお、レンズ全長ＴＬｗ又はＴＬｍは最前面（面番号：１）から像面ＩＭ１，ＩＭ２までの距離である。また、表２に条件式対応値を各実施例について示す。

【００６０】

図２，図３は、実施例１（ＥＸ１）の第１撮像光学系ＬＮ１の無限遠物体距離時（物体距離：∞）と有限物体距離時（物体距離：１０ｃｍ）の縦収差図であり、図７，図８は、実施例１（ＥＸ１）の第２撮像光学系ＬＮ２の無限遠物体距離時（物体距離：∞）と有限物体距離時（物体距離：１０ｃｍ）の縦収差図である。図１２，図１３は、実施例２（ＥＸ２）の第１撮像光学系ＬＮ１の無限遠物体距離時（物体距離：∞）と有限物体距離時（物体距離：１０ｃｍ）の縦収差図であり、図１７，図１８は、実施例２（ＥＸ２）の第２撮像光学系ＬＮ２の無限遠物体距離時（物体距離：∞）と有限物体距離時（物体距離：１０ｃｍ）の縦収差図である。なお、有限物体距離時（物体距離：１０ｃｍ）の性能評価では、フォーカス方式として全体繰り出しを想定している。

【００６１】
図２，図３；図７，図８；図１２，図１３；図１７，図１８のそれぞれにおいて、（Ａ）は球面収差図、（Ｂ）は非点収差図、（Ｃ）は歪曲収差図である。球面収差図は、実線で示すｄ線（波長５８７．５６ｎｍ）に対する球面収差量、一点鎖線で示すＣ線（波長６５６．２８ｎｍ）に対する球面収差量、破線で示すｇ線（波長４３５．８４ｎｍ）に対する球面収差量を、それぞれ近軸像面からの光軸ＡＸ１，ＡＸ２方向のズレ量（単位：ｍｍ）で表しており、縦軸は瞳への入射高さをその最大高さで規格化した値（すなわち相対瞳高さ）を表している。非点収差図において、破線Ｔはｄ線に対するタンジェンシャル像面、実線Ｓはｄ線に対するサジタル像面を、近軸像面からの光軸ＡＸ１，ＡＸ２方向のズレ量（単位：ｍｍ）で表しており、縦軸は像高（ＩＭＧ　ＨＴ，単位：ｍｍ）を表している。歪曲収差図において、横軸はｄ線に対する歪曲（単位：％）を表しており、縦軸は像高（ＩＭＧ　ＨＴ，単位：ｍｍ）を表している。なお、像高ＩＭＧ　ＨＴの最大値は、像面ＩＭ１，ＩＭ２における最大像高Ｙ’（撮像素子ＳＲ１，ＳＲ２の受光面ＳＳ１，ＳＳ２の対角長の半分）に相当する。
【００６２】
図４，図５は、実施例１（ＥＸ１）の第１撮像光学系ＬＮ１の無限遠物体距離時（物体距離：∞）と有限物体距離時（物体距離：１０ｃｍ）の横収差図であり、図９，図１０は、実施例１（ＥＸ１）の第２撮像光学系ＬＮ２の無限遠物体距離時（物体距離：∞）と有限物体距離時（物体距離：１０ｃｍ）の横収差図である。図１４，図１５は、実施例２（ＥＸ２）の第１撮像光学系ＬＮ１の無限遠物体距離時（物体距離：∞）と有限物体距離時（物体距離：１０ｃｍ）の横収差図であり、図１９，図２０は、実施例２（ＥＸ２）の第２撮像光学系ＬＮ２の無限遠物体距離時（物体距離：∞）と有限物体距離時（物体距離：１０ｃｍ）の横収差図である。
【００６３】
図４，図５；図９，図１０；図１４，図１５；図１９，図２０のそれぞれにおいて、（Ａ）～（Ｅ）はタンジェンシャル光束での横収差図であり、（Ｆ）～（Ｊ）はサジタル光束での横収差図である。各横収差図は、ＲＥＬＡＴＩＶＥ　ＦＩＥＬＤ　ＨＥＩＧＨＴで表されている像高比（半画角ω°）での横収差（ｍｍ）を、実線で示すｄ線（波長５８７．５６ｎｍ）、一点鎖線で示すＣ線（波長６５６．２８ｎｍ）、破線で示すｇ線（波長４３５．８４ｎｍ）のそれぞれについて示している。なお像高比は、像高を最大像高Ｙ’で規格化した相対的な像高である。
【００６４】
実施例１の第１撮像光学系ＬＮ１（図１，ＥＸ１－ｗ）は、物体側から順に、開口絞りＳＴと、正の第１レンズＬ１と、負の第２レンズＬ２と、正の第３レンズＬ３と、負の第４レンズＬ４と、から構成されており、レンズ面は全て非球面である。近軸の面形状で各レンズを見た場合、第１レンズＬ１は物体側に凸の正メニスカスレンズであり、第２レンズＬ２は両凹の負レンズであり、第３レンズＬ３は像側に凸の正メニスカスレンズであり、第４レンズＬ４は両凹の負レンズである。レンズはすべてプラスチックレンズであるが、ガラスレンズを用いてもよい。また、フォーカスは全体繰り出しを想定している。
【００６５】
実施例１の第２撮像光学系ＬＮ２（図６，ＥＸ１－ｍ）は、物体側から順に、開口絞りＳＴと、正の第１レンズＬ１と、負の第２レンズＬ２と、負の第３レンズＬ３と、負の第４レンズＬ４と、から構成されており、レンズ面は全て非球面である。近軸の面形状で各レンズを見た場合、第１レンズＬ１は物体側に凸の正メニスカスレンズであり、第２レンズＬ２は両凹の負レンズであり、第３レンズＬ３は物体側に凹の負メニスカスレンズであり、第４レンズＬ４は両凹の負レンズである。レンズはすべてプラスチックレンズであるが、ガラスレンズを用いてもよい。また、フォーカスは全体繰り出しを想定している。
【００６６】
実施例２の第１撮像光学系ＬＮ１（図１１，ＥＸ２－ｗ）は、物体側から順に、開口絞りＳＴと、正の第１レンズＬ１と、負の第２レンズＬ２と、正の第３レンズＬ３と、正の

第４レンズＬ４と、負の第５レンズＬ５と、から構成されており、レンズ面は全て非球面である。近軸の面形状で各レンズを見た場合、第１レンズＬ１は両凸の正レンズであり、第２レンズＬ２は像側に凹の負メニスカスレンズであり、第３レンズＬ３は物体側に凸の正メニスカスレンズであり、第４レンズＬ４は像側に凸の正メニスカスレンズであり、第５レンズＬ５は両凹の負レンズである。レンズはすべてプラスチックレンズであるが、ガラスレンズを用いてもよい。また、フォーカスは全体繰り出しを想定している。

【００６７】

実施例２の第１撮像光学系ＬＮ２（図１６，ＥＸ２－ｍ）は、物体側から順に、開口絞りＳＴと、正の第１レンズＬ１と、負の第２レンズＬ２と、正の第３レンズＬ３と、負の第４レンズＬ４と、負の第５レンズＬ５と、から構成されており、レンズ面は全て非球面である。近軸の面形状で各レンズを見た場合、第１レンズＬ１は物体側に凸の正メニスカスレンズであり、第２レンズＬ２は像側に凹の負メニスカスレンズであり、第３レンズＬ３は物体側に凸の正メニスカスレンズであり、第４レンズＬ４は物体側に凹の負メニスカスレンズであり、第５レンズＬ５は両凹の負レンズである。レンズはすべてプラスチックレンズであるが、ガラスレンズを用いてもよい。また、フォーカスは全体繰り出しを想定している。

【００６８】

実施例１の第１撮像光学系ＬＮ１

単位：mm

面データ

面番号	r	d	nd	vd
物面	∞	∞		
1(絞り)	∞	0.000		
2*	1.135	0.455	1.54470	56.15
3*	4.929	0.106		
4*	-13.457	0.300	1.63469	23.87
5*	8.084	0.242		
6*	-21893.628	0.397	1.54470	56.15
7*	-1.708	0.725		
8*	-2.118	0.400	1.54470	56.15
9*	1.712	0.106		
10	∞	0.110	1.51633	64.14
11	∞	0.200		
像面	∞			

【００６９】

非球面データ

面番号	K	A4	A6	A8	A10	A12	A14
2	1.132	-1.01E-01	-4.36E-01	1.01E+00	-3.63E+00	0.00E+00	0.00E+00
3	-50	-3.04E-01	-3.41E-01	-5.62E-01	-1.59E+00	0.00E+00	0.00E+00
4	46.321	-4.39E-01	-3.45E-01	1.49E+00	-2.08E+00	-2.01E-01	0.00E+00
5	-50	-1.06E-01	1.38E-01	3.63E-01	1.34E+00	-1.19E+00	0.00E+00
6	50	7.51E-02	-1.73E-01	4.42E-02	1.16E-01	-1.70E-01	0.00E+00
7	-12.577	-1.36E-01	3.68E-01	-3.45E-01	2.00E-01	-6.20E-02	0.00E+00
8	0	-3.14E-01	1.22E-01	1.41E-02	2.68E-03	-9.50E-04	-1.27E-03
9	-27.755	-9.32E-02	3.04E-02	-2.11E-02	4.91E-03	4.96E-04	-2.50E-04

【００７０】

実施例１の第２撮像光学系ＬＮ２

単位：mm

面データ

面番号	r	d	nd	vd

物面	∞	∞		
1(絞り)	∞	0.000		
2*	1.001	0.548	1.54470	56.15
3*	6.361	0.050		
4*	-10.735	0.300	1.63469	23.87
5*	5.243	0.457		
6*	-1.751	0.300	1.54470	56.15
7*	-2.426	1.021		
8*	-3.987	0.400	1.54470	56.15
9*	3.008	0.262		
10	∞	0.110	1.51633	64.14
11	∞	0.200		
像面	∞			

【００７１】

非球面データ

面番号	K	A4	A6	A8	A10	A12	A14
2	0.222	-7.13E-03	-2.33E-01	5.01E-01	-9.32E-01	0.00E+00	0.00E+00
3	-1.95E+01	-1.81E-01	-2.57E-01	2.18E-01	-6.66E-02	0.00E+00	0.00E+00
4	-8.218	-5.94E-02	-2.10E-01	1.26E+00	-1.65E+00	7.66E-01	0.00E+00
5	18.999	1.58E-01	6.91E-01	-1.08E+00	3.38E+00	8.27E-01	0.00E+00
6	-50	-7.63E-01	1.63E+00	-2.67E+00	2.02E+00	-3.48E-01	0.00E+00
7	-50	-2.13E-01	4.09E-01	-2.19E-01	7.14E-02	-4.63E-02	0.00E+00
8	0	-2.33E-01	1.27E-01	-1.65E-02	-2.95E-03	1.02E-03	-8.08E-05
9	-50	-1.56E-01	2.81E-02	5.81E-03	-2.63E-03	-2.09E-04	1.08E-04

【００７２】

実施例２の第１撮像光学系ＬＮ１

単位：mm

面データ

面番号	r	d	nd	vd
物面	∞	∞		
1(絞り)	∞	0.100		
2*	1.583	0.535	1.54470	56.15
3*	-7.954	0.050		
4*	86.727	0.300	1.63469	23.87
5*	2.182	0.334		
6*	7.448	0.300	1.63469	23.87
7*	57.053	0.539		
8*	-5.230	0.556	1.54470	56.15
9*	-1.093	0.280		
10*	-6.245	0.400	1.53048	55.72
11*	1.182	0.516		
12	∞	0.300	1.51633	64.14
13	∞	0.250		
像面	∞			

【００７３】

非球面データ

面番号	K	A4	A6	A8	A10	A12	A14
2	-0.044	-3.30E-04	-6.93E-03	-1.27E-02	-1.13E-02	0.00E+00	0.00E+00
3	41.478	2.10E-02	4.82E-02	-1.22E-01	3.74E-02	0.00E+00	0.00E+00
4	-50	-6.95E-02	1.87E-01	-2.49E-01	1.63E-01	-3.57E-02	0.00E+00

5	-9.645	9.23E-03	1.01E-01	-9.27E-02	5.26E-02	0.00E+00	0.00E+00
6	-10	-1.14E-01	9.59E-03	5.60E-02	1.32E-02	-3.15E-02	2.39E-03
7	-10	-9.96E-02	3.49E-02	1.17E-02	3.44E-02	-1.00E-02	-1.64E-03
8	6.135	-1.59E-02	2.85E-02	-3.90E-03	-2.50E-04	4.73E-05	0.00E+00
9	-4.282	-3.60E-02	5.02E-02	-1.18E-02	4.81E-04	9.17E-05	0.00E+00
10	6.752	-6.15E-02	7.9236E-03	1.6618E-03	-1.87E-04	9.66E-07	3.77E-06
11	-8.272	-6.71E-02	1.5803E-02	-3.38E-03	4.65E-04	-2.76E-05	-1.31E-06

【００７４】

実施例２の第２撮像光学系ＬＮ２

単位：mm

面データ

面番号	r	d	nd	vd
物面	∞	∞		
1(絞り)	∞	0.050		
2*	1.364	0.530	1.54470	56.15
3*	88.751	0.071		
4*	21.096	0.300	1.63469	23.87
5*	2.261	0.181		
6*	4.669	0.500	1.63469	23.87
7*	6.586	1.592		
8*	-2.380	0.800	1.54470	56.15
9*	-9.846	0.050		
10*	-5.628	0.300	1.53048	55.72
11*	15.370	0.111		
12	∞	0.300	1.51633	64.14
13	∞	0.121		
像面	∞			

【００７５】

非球面データ

面番号	K	A4	A6	A8	A10	A12	A14
2	0.153	1.38E-02	-7.55E-03	2.15E-02	-1.49E-02	0.00E+00	0.00E+00
3	-50	3.82E-02	5.46E-02	-1.31E-01	4.19E-02	0.00E+00	0.00E+00
4	40.974	-8.78E-02	1.97E-01	-2.34E-01	1.50E-01	-5.70E-02	0.00E+00
5	-20.224	5.40E-02	1.33E-01	1.46E-02	1.40E-01	0.00E+00	0.00E+00
6	-10	2.21E-02	1.16E-01	3.89E-02	-1.37E-02	-3.27E-02	8.28E-03
7	-10	1.05E-01	9.54E-02	-4.58E-02	4.26E-02	5.53E-03	-1.91E-02
8	-0.226	-4.11E-02	-5.66E-02	5.73E-02	-2.77E-02	1.12E-03	0.00E+00
9	30.588	-1.09E-01	8.44E-03	-6.32E-03	3.35E-03	-8.67E-04	0.00E+00
10	6.752	-1.54E-01	3.00E-02	-8.96E-04	-4.30E-04	1.43E-04	-3.32E-06
11	-8.272	-1.29E-01	3.68E-02	-4.67E-03	2.52E-04	-3.73E-05	3.70E-06

【００７６】

【表１】

		実施例1		実施例2	
		LN1	LN2	LN1	LN2
全系の焦点距離[mm]	fw又はfm	2. 73	4. 32	3. 70	5. 51
Fno	FNOw又はFNOm	4. 00	4. 00	3. 00	4. 00
レンズ全長(無限時)[mm]	TLw又はTLm	3. 04	3. 65	4. 45	4. 91
最大像高[mm]	2Y'	5. 12	5. 12	5. 80	5. 80
全画角[deg]	2ωw又は2ωm	86. 32	61. 28	76. 18	55. 52
L1焦点距離[mm]	f1w又はf1m	2. 60	2. 10	2. 47	2. 54
L2焦点距離[mm]	f2w又はf2m	−7. 91	−5. 51	−3. 53	−4. 02
L3焦点距離[mm]	f3w又はf3m	3. 14	−13. 70	13. 47	22. 96
L4焦点距離[mm]	f4w又はf4m	−1. 68	−3. 09	2. 42	−5. 99
L5焦点距離[mm]	f5w又はf5m	−−	−−	−1. 84	−7. 73
L1−L2合成焦点距離[mm]	fFw又はfFm	3. 48	2. 91	5. 48	4. 84
レンズLXの焦点距離[mm]	fXw又はfXm	3. 14	−13. 70	2. 42	−5. 99
センサー画素数[MegaPixels]	PX	10. 00	10. 00	13. 00	13. 00
切出し最小画素数[MegaPixels]		4. 00	4. 00	5. 86	5. 86
切出し最大焦点距離[mm]		4. 32	6. 83	5. 51	8. 21
電子ズーム比[倍]	ZR		2. 50		2. 22
焦点距離(135換算)[mm]		23. 07	36. 52	27. 60	41. 10

【００７７】

【表２】

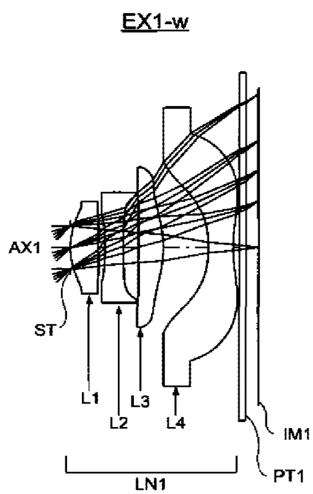
条件式		実施例1	実施例2
(1)	fFw／fFm	1. 20	1. 13
(2A)	fFw／fw	1. 27	1. 48
(2B)	fFm／fm	0. 67	0. 88
(3)	fXw／fXm	−0. 23	−0. 40
(4)	2ωw	86. 32	76. 18
(5)	FNOw／FNOm	1. 0	0. 8
(6)	TLm／fm	0. 84	0. 89
(7)	TLw／fw	1. 11	1. 20
(8)	PX／ZR	3. 99	5. 86

【符号の説明】

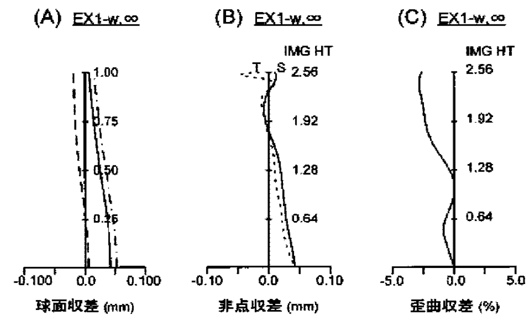
【００７８】

ＤＵ　デジタル機器（撮像装置）
ＬＵ１，ＬＵ２　第１，第２撮像光学ユニット
ＬＮ１，ＬＮ２　第１，第２撮像光学系
Ｌ１～Ｌ５　第１～第５レンズ
ＳＴ　開口絞り（絞り）
ＳＲ１，ＳＲ２　撮像素子
ＳＳ１，ＳＳ２　受光面（撮像面）
ＩＭ１，ＩＭ２　像面（光学像）
ＡＸ１，ＡＸ２　光軸
１　信号処理部
２　制御部
３　メモリ
４　操作部
５　表示部

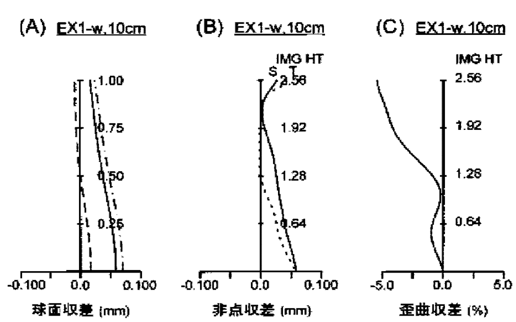
【図１】


EX1-w
AX1
ST
L1
L2
L3
L4
IM1
PT1
LN1

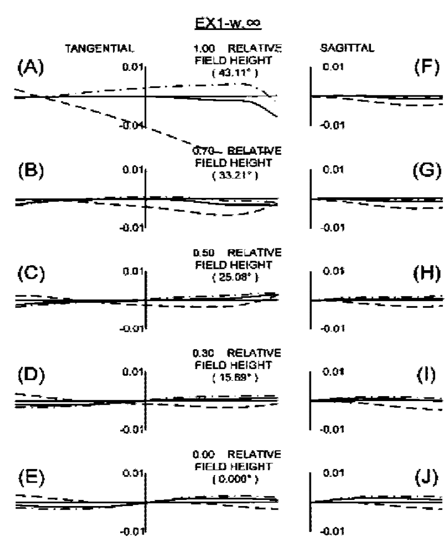
【図２】


(A) EX1-w,∞
(B) EX1-w,∞
(C) EX1-w,∞
IMG HT
球面収差 (mm)
非点収差 (mm)
歪曲収差 (%)

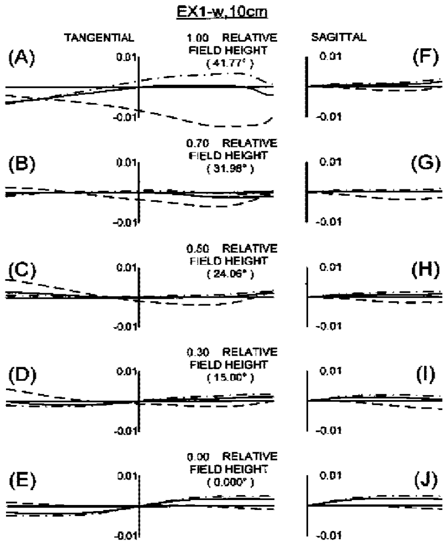
【図３】


(A) EX1-w,10cm
(B) EX1-w,10cm
(C) EX1-w,10cm
IMG HT
球面収差 (mm)
非点収差 (mm)
歪曲収差 (%)

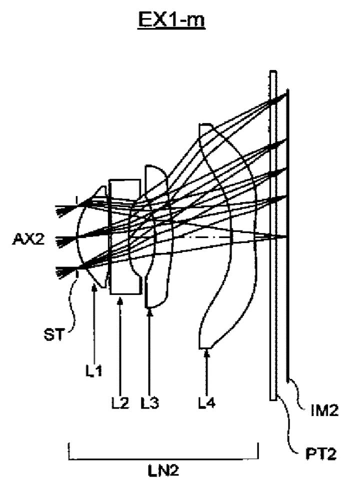
【図４】


EX1-w,∞
TANGENTIAL
SAGITTAL
1.00 RELATIVE FIELD HEIGHT
0.70 RELATIVE FIELD HEIGHT
0.50 RELATIVE FIELD HEIGHT
0.30 RELATIVE FIELD HEIGHT
0.00 RELATIVE FIELD HEIGHT

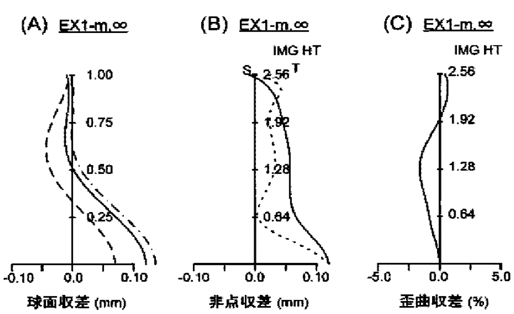
【図５】


EX1-w,10cm
TANGENTIAL
SAGITTAL
1.00 RELATIVE FIELD HEIGHT (41.77°)
0.70 RELATIVE FIELD HEIGHT (31.98°)
0.50 RELATIVE FIELD HEIGHT (24.06°)
0.30 RELATIVE FIELD HEIGHT (15.00°)
0.00 RELATIVE FIELD HEIGHT (0.000°)
(A)
(B)
(C)
(D)
(E)
(F)
(G)
(H)
(I)
(J)
0.01
-0.01

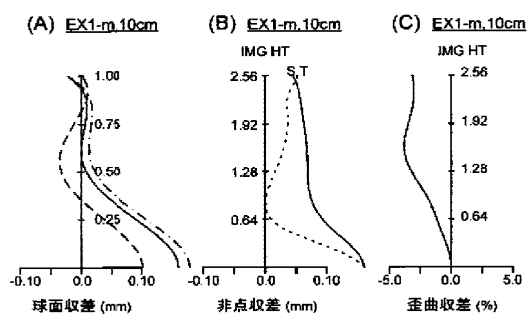
【図６】


EX1-m
AX2
ST
L1
L2
L3
L4
IM2
PT2
LN2

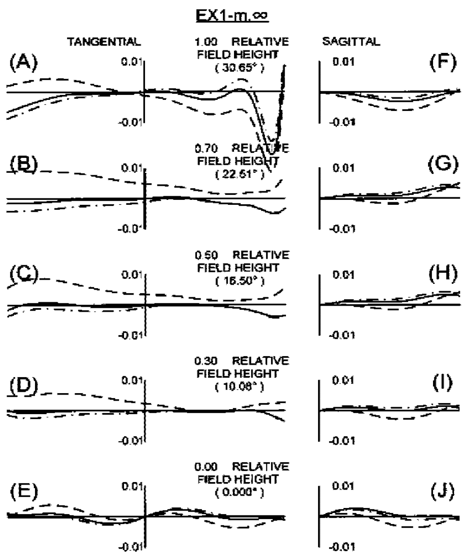
【図７】


(A) EX1-m,∞
(B) EX1-m,∞
(C) EX1-m,∞
IMG HT
球面収差 (mm)
非点収差 (mm)
歪曲収差 (%)

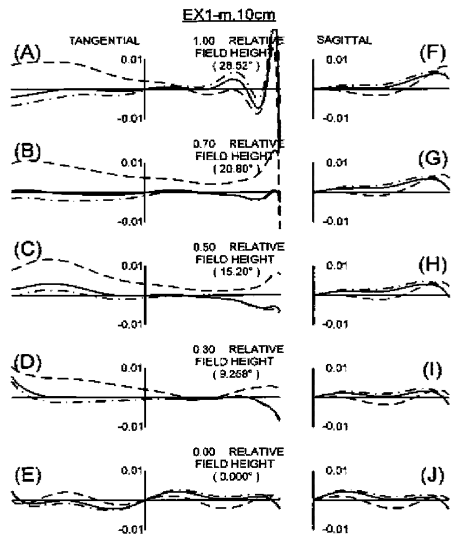
【図８】


(A) EX1-m,10cm
(B) EX1-m,10cm
(C) EX1-m,10cm
IMG HT
球面収差 (mm)
非点収差 (mm)
歪曲収差 (%)

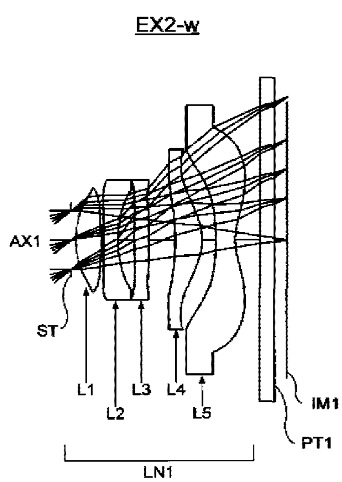
【図９】



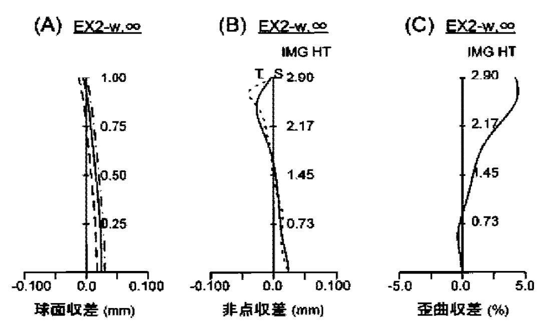
【図１０】



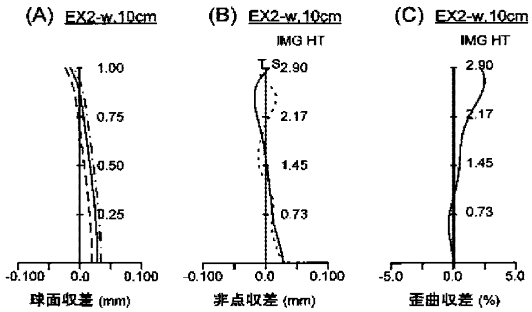
【図１１】



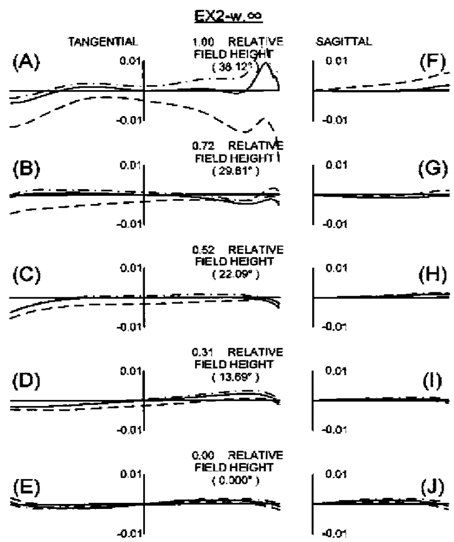
【図１２】



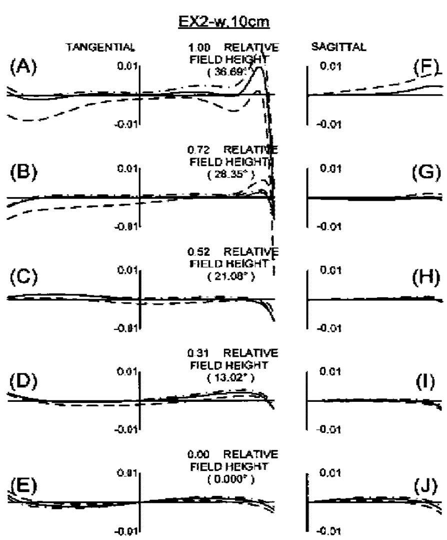
【図１３】



【図１４】



【図１５】



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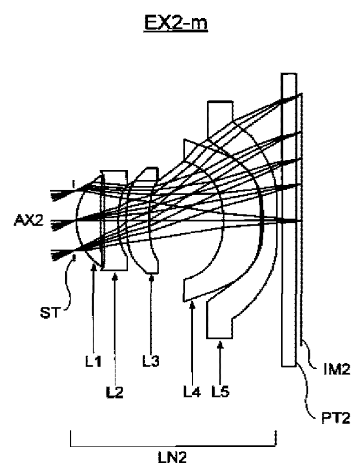

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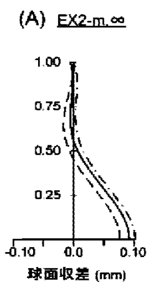

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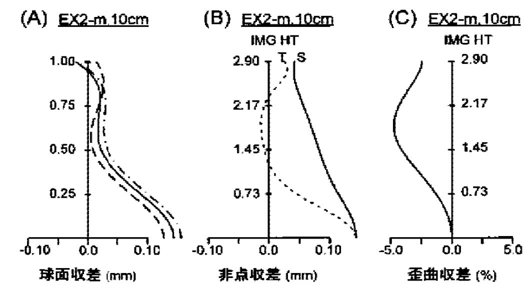

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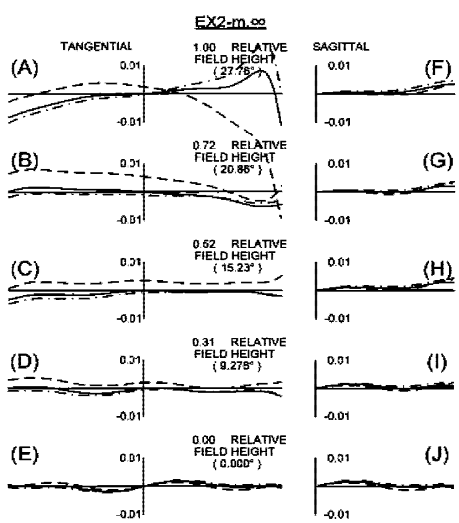

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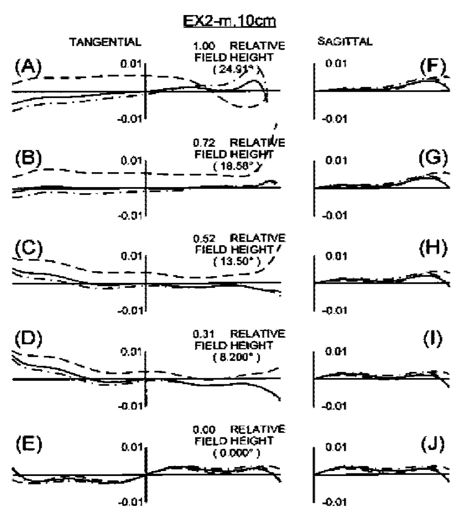

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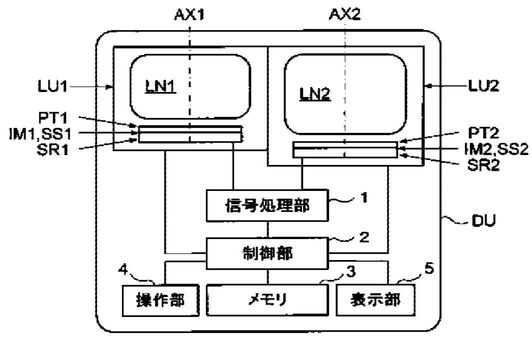
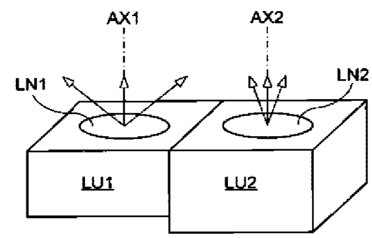

AX1
AX2
LU1
LN1
LN2
LU2
PT1
IM1,SS1
SR1
PT2
IM2,SS2
SR2
信号処理部
1
DU
制御部
2
4
3
5
操作部
メモリ
表示部

【図２２】


AX1
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LN2
LU1
LU2

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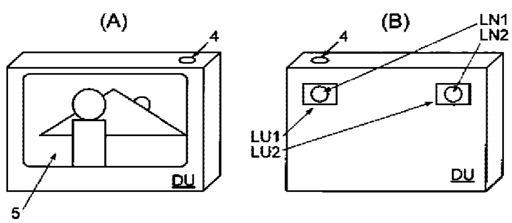
(A)
4
DU
5
(B)
4
LN1
LN2
LU1
LU2
DU

フロントページの続き

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(56)参考文献　特開２００５－１０１８７４（ＪＰ，Ａ）
特開２０１０－２６３６１９（ＪＰ，Ａ）
特開２００５－９９２６５（ＪＰ，Ａ）
特開２００９－２８２２２３（ＪＰ，Ａ）
特開２０１１－６４９８９（ＪＰ，Ａ）
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Ｈ０４Ｎ　　５／２２５
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IMAGING APPARATUS

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Applicant(s):	KONICA MINOLTA ADVANCED LAYERS ± (KONICA MINOLTA ADVANCED LAYERS INC)
Classification:	**- international:** ***G02B13/00; G02B13/18; G02B15/00; G03B19/07; H04N5/225; H04N5/228; H04N5/232*** **- cooperative:**
Application number:	JP20110250322 20111116 Global Dossier
Priority number (s):	JP20110250322 20111116
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Abstract of JP2013106289 (A)

PROBLEM TO BE SOLVED: To provide high image quality with high resolution for an entire wide variable power region. ;SOLUTION: An imaging apparatus includes first and second imaging optical systems LN1 and LN2 with single focus, which look the same direction. A focal length of the second imaging optical system LN2 is longer than that of the first imaging optical system LN1. Zooming is performed from a wide angle end to an intermediate focal length state with an electronic zoom by segmentation of an image obtained in the first imaging optical system LN1, and zooming is performed from the intermediate focal length state to a telescopic end with an electronic zoom by segmentation of an image obtained in the second imaging optical system. Thus, zooming from the wide angle end to the telescopic end is performed as a whole.; Both the first and second imaging optical systems LN1 and LN2 consist of four or more lenses of first lenses of positive power and second lenses of negative power in order from an object side, the lenses nearest to the image side are negative lenses, composite focal lengths of the first lenses and the second lenses are positive and they satisfy a conditional expression :1.0<fFw/fFm<1.5. ;COPYRIGHT: (C) 2013,JPO&INPIT;PROBLEM TO BE SOLVED: To provide high image quality with high resolution for an entire wide variable power region.SOLUTION: An imaging apparatus includes first and second imaging optical systems LN1 and LN2 with single focus, which look the same direction. A focal length of the second imaging optical system LN2 is longer than that of the first imaging optical system LN1. Zooming is performed from a wide angle end to an intermediate focal length state with an electronic zoom by segmentation of an image obtained in the first imaging optical system LN1, and zooming is performed from the intermediate focal length state to a telescopic end with

an electronic zoom by segmentation of an image obtained in the second imaging optical system. Thus, zooming from the wide angle end to the telescopic end is performed as a whole.; Both the first and second imaging optical systems LN1 and LN2 consist of four or more lenses of first lenses of positive power and second lenses of negative power in order from an object side, the lenses nearest to the image side are negative lenses, composite focal lengths of the first lenses and the second lenses are positive and they satisfy a conditional expression :$1.0<fFw/fFm<1.5$.

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H04N	***5/225***	***(2006.01)***	H04N	5/225	Z	2H087
G02B	***13/00***	***(2006.01)***	G02B	13/00		5C122
G02B	***15/00***	***(2006.01)***	G02B	15/00		
G02B	***13/18***	***(2006.01)***	G02B	13/18		

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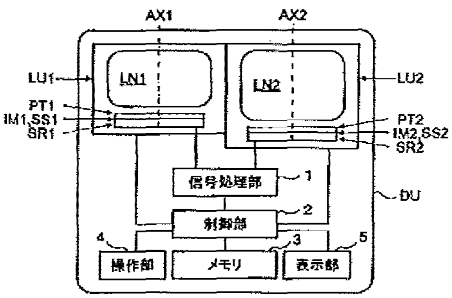
最終頁に続く

(54)【発明の名称】撮像装置

(57)【要約】　（修正有）
【課題】広変倍域すべてにわたって高解像度で高画質の画像を得る。
【解決手段】同一方向を向いた単焦点の第１，第２撮像光学系ＬＮ１，ＬＮ２を有し、第２撮像光学系ＬＮ２の焦点距離が第１撮像光学系ＬＮ１の焦点距離よりも長く、第１撮像光学系ＬＮ１で得られた画像の切り出しによる電子ズームで広角端から中間焦点距離状態までのズーミングを行い、前記第２撮像光学系で得られた画像の切り出しによる電子ズームで中間焦点距離状態から望遠端までのズーミングを行うことにより、全体として広角端から望遠端までのズーミングを行う。第１，第２撮像光学系ＬＮ１，ＬＮ２のいずれもが、物体側から順に、正パワーの第１レンズと、負パワーの第２レンズと、を有する４枚以上のレンズから成るとともに、最も像側のレンズが負レンズであり、第１レンズと第２レンズの合成焦点距離が正であり、条件式：１．０＜ｆＦｗ／ｆＦｍ＜１．５を満足する。
【選択図】図２１



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— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) Title: OPTICAL OBJECTIVE HAVING FIVE LENSES WITH FRONT FOCUSING

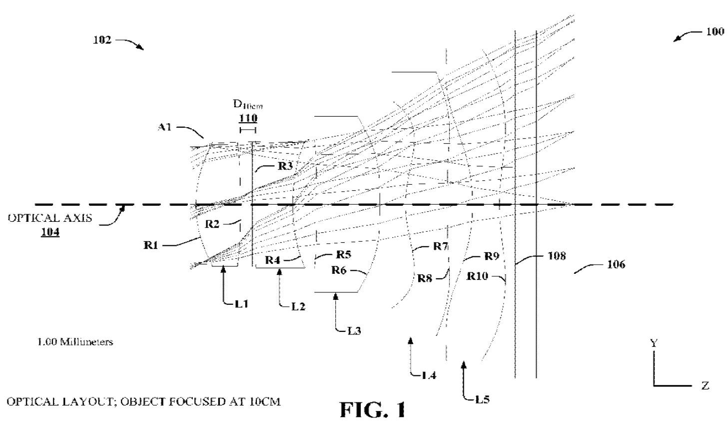

FIG. 1

(57) Abstract: Optical system comprising five lenses, a front pupil and achieving focus for objects from close to infinity by adjusting, via a MEMS actuator, the position of a subset of lenses located on the object-side of the optical system. The most object-side, biconvex, lens provides a substantial amount of the system's optical power for achieving focus from an object as close as 10 cm away from the aperture stop.

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OPTICAL OBJECTIVE HAVING FIVE LENSES WITH FRONT FOCUSING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U. S. Provisional Patent Application Serial No. 61/550,789 entitled "OPTICAL SYSTEM WITH MICROELECTROMECHANICAL SYSTEM IMAGE FOCUS ACTUATOR" filed October 24, 2011. The entirety of the above-noted application is incorporated by reference herein.

TECHNICAL FIELD

[0002] The following relates generally to imaging optics, and more particularly to a compact optical lens system with micro electromechanical system (MEMS) actuator for focusing the optical lens system.

BACKGROUND

[0003] Applications for optics and optical devices have become numerous in conjunction with advances in optical fabrication technology. One interesting advancement in optical technology is fabrication of micro lenses, and other optical components on a millimeter or micrometer scale, or less. Compared with traditional optical elements typically on the scale of centimeters or larger, micro optics have made optical systems compatible with smaller devices than traditional telescopes, microscopes, cameras, and so on.

[0004] One mechanism facilitating the fabrication of micro optics is wafer-level optics. Wafer-level optics is a fabrication technology that enables design and manufacture of optical components using techniques similar to semiconductor manufacturing. The technology is generally scalable with different size scales (e.g., millimeter, micrometer, etc.). Moreover, wafer-level optics can produce single-element as well as multi-element optical structures, yielding precision aligned stacks of lens elements. The end result of wafer-level optics provide cost effective, miniaturized optical components that enable reduced form factor for optical systems. These optical systems can be employed in a wide range of small or miniature devices, including camera modules for mobile phones, surveillance equipment, miniature video cameras, and the like.

[0005] Although wafer-level optics is one relatively recent technology for fabricating small optical components, some traditional fabrication techniques have been adapted to small-scale optical fabrication as well. For instance, plastic fabrication techniques including injection molding, and others can be employed for manufacturing small-scale optical components. Further, glass fabrication techniques have been adapted for miniaturized optical components, providing high quality optical surfaces for small-scale devices.

[0006] In addition to optical elements, the miniaturization of digital imaging sensors has also facilitated the continuing miniaturization of image capture and recording devices. Improvements in image sensors have provided high resolution image detectors utilizing micro-scale pixilation, and at high signal to noise ratio and increasingly lower cost. In conjunction with micro optics, such as wafer-level optical components, small, relatively inexpensive digital capture and recording devices can match or exceed the capabilities of relatively expensive, yet very high quality camera systems utilizing traditional optics of just a decade ago. Although quality is very high for modern micro optical devices, one persistent limitation has been zoom capability for miniature optical systems. One solution has been the introduction of digital zoom, which sacrifices optical resolution to enlarge an image. For high resolution sensors, this often provides a suitable alternative to traditional optical zoom capability. However, optical zoom provides advantages that digital zoom cannot achieve.

[0007] For example, the inventors of the disclosed subject matter suggest it would be desirable to have a miniature optical system with optical auto-focus capability. Such an optical system that achieves close focus would be additionally desirable.

SUMMARY

[0008] The following presents a simplified summary of one or more aspects in order to provide a basic understanding of such aspects. This summary is not an extensive overview of all contemplated aspects, and is intended to neither identify key or critical elements of all aspects nor delineate the scope of any or all aspects. Its sole purpose is to present some concepts of one or more aspects in a simplified form as a prelude to the more detailed description that is presented later.

[0009] Particular aspects of the subject disclosure provide a miniaturized optical system. In some aspects, the miniaturized optical system can comprise an injection

molded optical system. In further aspects, the miniaturized optical system can be an auto-focus optical system comprising five optical components. In still other aspects, the miniaturized optical system can be an auto-focus optical system employing a micro electromechanical system (MEMS) actuator to achieve focusing of the optical system.

[0010] In one or more other aspects of the subject disclosure, provided is an optical system that employs a MEMS actuator to achieve close focus. In one such aspect, the close focus can comprise a substantially 10cm object distance. Further, according to other aspects, the optical system can be configured to achieve close focus and infinity focus by adjusting position of a subset of optical components of the optical system. In particular aspects, the subset of optical components can comprise a single optical component of the optical system. In at least one such aspect, the single optical component can be a lens closest along an optical axis of the optical system to an object being imaged by the optical system (referred to as an object-side lens). In such aspect(s), the MEMS actuator can be configured to displace the object-side lens of the optical system a first distance configured to focus an object at infinity onto an image sensor associated with the optical system, and to displace the object-side lens a second distance configured to focus a close object (*e.g.*, an object substantially 10cm from the object-side lens) onto the image sensor.

[0011] According to one or more additional aspects, an auto-focus optical system disclosed herein can be configured to include an aperture stop. In a particular aspect, the auto-focus optical system can comprise injection molded plastic lenses, whereas in other aspects, the auto-focus optical system can comprise wafer-level optical lenses, glass lenses, or a suitable combination thereof. In another aspect, the aperture stop can be positioned on an object side of the object–side lens of the optical system. In one alternative aspect, a MEMS actuator can be configured to move a subset of optical components of the optical system to focus an object, while maintaining the aperture stop in a fixed position along an optical axis of the optical system. In another alternative aspect, the MEMS actuator can instead be configured to move both the subset of optical components and the aperture stop relative to the optical axis, to focus the object.

[0012] According to still other aspects, disclosed is an auto-focus optical system comprising a plurality of optical components. The plurality of optical components can, in some such aspects, comprise an object-side lens providing a substantial amount of optical power to the optical system. In at least one such aspect, the object-side lens can comprise substantially half or greater than half of the combined focal length of the optical system. In another aspect, the object-side lens can comprise substantially three-quarters or more of the combined focal length of the optical system. In a particular aspect, a MEMS actuator is connected to the object-side lens, and is configured to displace the object-side lens a first distance configured to focus an object at infinity, and a second distance configured to focus an object close to the optical system. According to one specific embodiment, a ratio of the focal length of the object-side lens and of a combined focal length of the optical system can be a function of a difference in magnitude of the first distance and the second distance along an optical axis of the optical system.

[0013] According to additional aspects, the subject disclosure provides a micro-optical system comprising five optical lenses. In one such aspect, an objective lens of the five optical lenses can be configured to supply all positive refractive power of the five optical lenses. In this aspect, the remaining four lenses have a combined net negative refractive power. In at least one particular aspect, the remaining four lenses can have respective negative refractive powers, with a combined net negative refractive power. According to an alternative or additional aspect, a third lens of the five optical lenses can a convex object side surface and a concave image side surface. As yet another alternative or additional aspect, a spacing between a fourth of the five optical lenses and a fifth of the five optical lenses can be a largest spacing between lenses of the optical system. In another aspect, the micro-optical system can be an auto-focus system in which a subset of the five optical lenses are movable along an optical axis to refine a focus of the optical system. In one specific aspect, the subset of the five optical lenses can comprise the objective lens, and the subset being movable by a MEMS actuator.

[0014] In further aspects of the subject disclosure, provided is a micro-optical system comprising five optical lenses. The five optical lenses can be arranged into a plurality of lens groups, each lens group comprising respective subsets of the five optical lenses. Each group comprises inter-lens distances equal to or less than a distance(s) between the plurality of optical groups. In a further aspect, each lens within at least one of the plurality of lens groups comprises at least one optical surface having both a concave portion and a convex portion. In a particular aspect, an effective focal length of the micro-optical system varies in response to a change in position along an optical axis of a first lens of the five optical lenses, and in an alternative or additional aspect, a back focal length of the micro-optical system remains substantially the same in response to the change in position along the optical axis of the first lens.

[0015] To the accomplishment of the foregoing and related ends, the one or more aspects comprise the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative aspects of the one or more aspects. These aspects are indicative, however, of but a few of the various ways in which the principles of various aspects can be employed and the described aspects are intended to include all such aspects and their equivalents.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Figure 1 illustrates a diagram of an example optical imaging system configured to focus a relatively close object, according to various aspects of the subject disclosure.

[0017] Figure 2 illustrates a diagram of a sample optical imaging system configured to focus an object substantially at infinity, according to other disclosed aspects.

[0018] Figure 3 depicts a diagram of an example optical imaging system comprising a plurality of injection molded optical components.

[0019] Figure 4 illustrates a diagram of example field curvature and distortion graphs for a sample optical imaging system focusing a relatively close object.

[0020] Figure 5 illustrates a diagram of example field curvature and distortion graphs for the sample optical imaging system of Figure 4, focusing an object substantially at infinity.

[0021] Figure 6 depicts a diagram of a sample lateral color graph for an example optical imaging system focusing a relatively close object, according to further aspects.

[0022] Figure 7 illustrates a diagram of a sample lateral color graph for the example optical imaging system of Figure 6 focusing an object substantially at infinity, according other aspects.

[0023] Figure 8 depicts a diagram of transverse ray fan plots for a disclosed optical imaging system with an object focused at 10cm.

[0024] Figure 9 illustrates a diagram of transverse ray fan plots for the disclosed optical imaging system of Figure 8, with an object focused substantially at infinity.

[0001] Figure 10 illustrates a cross-section of a sample optical system for focusing an image of an object at 10cm according to aspects of the subject disclosure.

[0002] Figure 11 illustrates a cross-section of a sample optical system for focusing an image of an object at infinity according to aspects of the subject disclosure.

[0003] Figure 12 illustrates an example graph of field curvature and distortion for an object at 10cm according to aspects of the subject disclosure.

[0004] Figure 13 illustrates an example graph of field curvature and distortion for an object at infinity in other aspects of the subject disclosure.

[0005] Figure 14 illustrates an example graph of primary lateral color for an object at 10cm according to an aspect(s).

[0006] Figure 15 illustrates an example graph of primary lateral color for an object at infinity according to one or more other aspects.

[0007] Figure 16 illustrates an example transverse ray fan plot for various image heights for an object at 10cm according to still other aspects.

[0025] Figure 17 illustrates an example transverse ray fan plot for various image heights for an object at infinity according to at least one other aspect.

[0026] Figure 18 depicts a transverse ray fan plot for a range of field angles for an example micro-optical system according to additional disclosed aspects.

[0027] Figure 19 illustrates a sample diagram of the micro-optical system of Figure 18 including lenses and optical surfaces.

[0028] Figure 20 depicts an example graph of field curvature and distortion for an object focused by the micro-optical system of Figure 18.

[0029] Figure 21 illustrates a sample graph of longitudinal aberration for a pupil radius of 0.90 millimeters in an aspect.

[0030] Figure 22 depicts an example graph of lateral color for a disclosed micro-optical system according to further aspects.

[0031] Figure 23 illustrates a transverse ray fan plot for a range of field angles for a micro-optical system focused in the near-field according to disclosed aspects.

[0032] Figure 24 depicts a sample diagram of the micro-optical system of Figure 23 including lenses and optical surfaces.

[0033] Figure 25 illustrates an example diagram of field curvature and distortion for a near-field object focused by the micro-optical system of Figure 23.

[0034] Figure 26 depicts a sample diagram of longitudinal aberration for pupil radius of 0.90 millimeters for a disclosed micro-optical system, in an aspect.

[0035] Figure 27 illustrates an example diagram of lateral color for a disclosed micro-optical system according to still other disclosed aspects.

[0036] Figures 28A, 28B, 28C and 28D illustrate diagrams of an example micro-optical system focused at infinity according to further aspects, and related optical performance graphs.

[0037] Figures 29A, 29B, 29C and 29D depict the micro-optical system of Figure 28 focused in the near-field and related optical performance graphs.

DETAILED DESCRIPTION

[0038] Various aspects are now described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more aspects. It will be evident, however, that such aspect(s) can be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to facilitate describing one or more aspects.

[0039] In addition, it should be apparent that the teaching herein can be embodied in a wide variety of forms and that the specific structures or functions disclosed herein are merely representative. Based on the teachings herein one skilled in the art should appreciate that the disclosed aspects can be implemented independently of other aspects, and that two or more of these aspects can be combined in various ways. For example, an apparatus can be implemented and/or a method practiced using any number of the aspects set forth herein. In addition, an apparatus can be implemented and/or a method practiced using other structure and/or functionality in addition to or other than one or more of the aspects set forth herein. As an example, many of the apparatuses and lens systems disclosed herein are described in the context of providing high resolution optical imaging *via* compact fixed position optical lens arrangements. One skilled in the art should appreciate that similar techniques could apply to other optical lens architectures. For example, the lens arrangements used herein may be used in mechanical focus or auto-focus systems whereby the optical arrangement is automatically or manually displaced relative to the image plane.

[0040] In at least one aspect of the subject disclosure, an optical imaging system is provided. The optical imaging system can comprise a first group of lenses and a second group of lenses. The optical imaging system can be focused by repositioning the first group of lenses relative to the second group of lenses along an optical axis of the optical imaging system. In at least one aspect of the subject disclosure, the second group of lenses includes an image sensor for the optical imaging system. In particular aspects of the subject disclosure, the first group of lenses can comprise a single lens. For instance, the single lens can include an object-side lens, which is an optical element closes to an object side of the optical imaging system.

[0041] Referring now to the drawings, Figure 1 depicts a block diagram of an example optical system 100 according to aspects of the subject disclosure. System 100 comprises an arrangement of optical elements 102 positioned transverse to an optical axis 104. As utilized herein, an optical element refers to a single piece of refractive or reflective material at least partially transparent to electromagnetic radiation at least partially within the visible spectrum (*e.g.*, including wavelengths approximately 400 to 700 nanometers [nm]). Examples of suitable material include ground and polished glass, molded glass or glass formed from a replication molding process, wafer-level optics (WLO), injection-molded plastic, etched micro optics formed on an optical substrate, or the like. Additionally, an optical element will have at least one refractive or reflective surface. One example of an optical element utilized herein is an optical lens. An optical lens is an optical element comprising two opposing refractive surfaces, and an edge between the opposing surfaces that defines an outer diameter (for a circular lens) or perimeter of the lens, and an edge thickness of the lens. A typical arrangement of optical lenses includes a series of lenses 102 at least generally transverse to an axis (optical axis 104). It should be appreciated, however, that other possible arrangements can exist consistent with the subject disclosure. A "lens component" is defined herein as (A) a single lens element spaced so far from any adjacent lens element that the spacing cannot be neglected in computing the image forming properties of the respective lens elements, or (B) two or more lens elements that have adjacent lens surfaces either in full overall contact or so close together that any spacing between the adjacent lens surfaces are so small that the spacing(s) can be neglected in computing image forming properties of the two or more lens elements. Thus, some lens elements can also be lens components, and the terms "lens element" and "lens component" are not mutually exclusive terms. In addition, it should be appreciated that the term "optical component" is utilized herein to refer to a superset of items having significant properties related to imaging optical systems, and includes optical elements such as lens elements and lens components, as well as various optical stops including but not limited to aperture stops, but can also include various other items such as a thin film, a bandpass filter, a lowpass or highpass filter, a polarizing filter, a mirror, *etc.*

[0042] Light entering the left side, or object side, of optical elements 102 can interact sequentially with respective elements (102) and exit the right side, or image side, of the elements 102, toward an optical sensor 106. It should be appreciated that not all light interacting with the left side of the optical elements 102 will be transmitted to the sensor 106; some light can be reflected off of respective elements (102), some light can be scattered away from the optical axis 104 and absorbed (*e.g.*, by an optical stop – not depicted), and so forth. However, in general, the optical elements 102 will receive light from an object on one side of the elements (*e.g.*, the left side) and form a real image of the object on an opposite side of the elements (*e.g.*, on the right side). The real image will be formed along the optical axis 104 a certain distance from the optical elements 102, called an image distance (ID). Notably, the ID depends primarily on a corresponding object distance (OD – distance between the object and the optical elements 102 along the optical axis 104) and a refractive power, or optical power, of the combined optical elements 102.

[0043] Sensor 106 can be a digital device comprising a multi-dimensional array (*e.g.*, a two dimensional array) of electro-optical sensors, or pixels. Examples of such a device can include a charge-coupled device (CCD) array, or a complementary metal-oxide semiconductor (CMOS) array, or some other suitable array of optical sensors. Each electro-optical sensor, or pixel, of such array is configured to output an electric signal when irradiated with light. Furthermore, an amount of electric current for the electric signal is directly related to energy density of light irradiating the pixel. Accordingly, by collecting output current levels from each pixel of the array, sensor 106 can digitally reproduce a two dimensional radiant energy pattern of light irradiating the sensor 106. Additionally, where the pixel surface or sensor plane of sensor 106 is placed at the above-mentioned ID, the two dimensional radiant energy pattern that is produced is that of a real optical image generated by optical elements 102. Accordingly, sensor 106 can be utilized to digitally reproduce that image. Resolution of a digital image generated by sensor 106 depends on a number of pixels within an active array of sensor 106. In addition, optical system 100 can comprise a cover plate 108 between the optical elements 102 and image sensor 106, as depicted by Figure 1.

[0044] As depicted by optical system 100, optical elements 102 can comprise five optical lenses, including lens L1, lens L2, lens L3, lens L4 and lens L5, from the object-side of optical elements 102 to an image-side of optical elements 102. As depicted, lens L1 is a biconvex lens having positive optical power, having convex object-side and convex image-side surfaces, R1 and R2, respectively. Additionally, lens L1 can have a relatively strong positive optical power, relative to lenses L2, L3, L4 and L5. In at least one aspect, lens L1 can have a relatively strong positive optical power relative to a combination of lenses L2, L3, L4 and L5. In a particular aspect, lens L1 can provide at least about half or more of the combined focal length of optical elements 102. In an alternative aspect, lens L1 can provide substantially about three-quarters or more of the combined focal length of optical elements 102. In related aspects, the optical power of the object-side lens ($L1_{power}$) can be about 1.25x the combined optical power of optical elements 102 (*e.g.*, $L1_{power} \leq 1.25*(L1_{power} + L2_{power} + L3_{power} + L4_{power} + L5_{power})$. In a particular aspect, an aperture stop A1 can be positioned at or in front of an object-side of lens L1. Aperture stop A1 is described in more detail below.

[0045] Lens L2 can have an overall negative optical power. Further, lens L2, in one aspect, can have a mildly concave object-side surface R3. In an alternative aspect, object-side surface R3 can be flat, with no optical power. As yet another alternative aspect, object-side surface R3 can be mildly convex. An image-side surface R4 of lens L2 can have concave curvature. Moreover, lens L2 can be configured to provide chromatic aberration correction for optical system 100. In at least one aspect, lens L2 can provide a majority of chromatic aberration correction for optical system 100.

[0046] Lens L3 comprises an object-side surface R5 and an image-side surface R6. Object-side surface R5 can be mildly concave, in particular aspects. Moreover, image-side surface R6 can be convex. In a particular aspect, lens L3 can have a positive optical power.

[0047] Lens L4 comprises an object-side surface R7 and an image-side surface R8. Object-side surface R7 can have convex curvature near optical axis 104. Moreover, in at least one aspect of the subject disclosure, object-side surface R7 can transition to concave further from optical axis 104. Moreover, image-side surface R8 can be substantially flat with little or no optical power near optical axis 104, and transition to convex curvature away from optical axis 104. In an alternative aspect, image-side surface R8 can be convex near optical axis 104 having significant optical power for low to mid field angles, as well as convex away from optical axis 104. In a particular aspect, lens L4 can have positive power for low field angles (*e.g.*, field angles between zero and about 12 to 15 degrees). In another aspect, lens L4 can have small positive, small negative, or substantially zero optical power for medium field angles (*e.g.*, field angles between about 12 to 15 degrees and about 22 to 25 degrees). In yet another aspect, lens L4 can have small positive, small negative, or substantially zero optical power for for high field angles (*e.g.*, field angles between about 22 to 25 degrees and about 33 or more degrees, up to a maximum accepted field angle of optical system 100).

[0048] Lens L5 comprises an object-side surface R9 and an image-side surface R10. Object-side surface R9 can have concave curvature for low and medium field angles. In at least one aspect, object-side surface R9 can transition to mildly concave or no curvature for high field angles. Image-side surface R10 can be concave near optical axis 104. Moreover, image-side surface R10 can transition from concave to convex for medium and high field angles, as depicted.

[0049] As depicted, optical elements 102 can have respective spaces (*e.g.*, air spacing) between respective lenses L1, L2, L3, L4 and L5. In at least one disclosed embodiment, a first on-axis distance between lens L1 and L2 can be substantially small compared with a third on-axis distance between lens L3 and lens L4. In another embodiment, the first on-axis distance can be substantially small compared to a second on-axis distance between lens L2 and L3, and a fourth on-axis distance between lens L4 and L5, in addition to the third on-axis distance. In at least one embodiment, the second, third and fourth on-axis distances can be substantially similar in magnitude, at least in comparison with the first on-axis distance. In other embodiments, these relations between the first, second, third and fourth on-axis distances need not exist. For instance, other relationships between the first, second, third and fourth on-axis distances may exist instead.

[0050] In at least one aspect of the subject disclosure, a MEMS actuator can be connected at least to lens L1. The MEMS actuator can be configured to reposition lens L1 along optical axis 104 to focus objects at different object distances. As one example, the MEMS actuator can change the first distance between lens L1 and lens L2 to focus objects at differing object distances. In at least one aspect, the MEMS actuator can position lens L1 a distance D_{10cm} 110 from lens L2 to focus onto sensor 106 an image of an object that is substantially 10 centimeters (cm) from a position of aperture stop A1 on optical axis 104.

[0051] According to further aspects, aperture stop A1 can be fixed relative to optical axis 104. In another aspect, aperture stop A1 can be fixed relative to a position of lens L1. In the latter aspect, aperture stop A1 can be moved by a MEMS actuator in conjunction with lens L1 when focusing an image of an object. According to still other aspects, the MEMS actuator can be configured to move lens L1, either alone or in conjunction with aperture stop A1, a total distance along optical axis 104. The total distance can, in a particular aspect, at one end thereof focus an image of an object at infinity, and at an opposite end thereof, focus an image of an object substantially at 10cm from aperture stop A1. As utilized herein, an object at infinity includes an object distance that satisfies the paraxial approximation known in the art of optical imaging science. The paraxial approximation, broadly stated, refers to an object at such a distance that an angle - subtending a first optical ray that is parallel with optical axis 104 and a second optical ray that originates at a point on the object farthest from the optical axis and passes through optical axis 104 at aperture stop A1 – is substantially zero degrees. In yet another aspect, lens L1 can have a focal length that is at least in part a function of a magnitude of the total distance. In still other aspects, a ratio of the focal length of lens L1 and a combined focal length of optical elements 102 can at least in part be a function of the magnitude of the total distance.

[0052] Because the pixel array of sensor 106 generates an electronic reproduction of a real image, data generated by sensor 106 (and other sensors disclosed herein) in the form of electric signals can be saved to memory, projected to a display for viewing (*e.g.*, digital display screen), edited in software, and so on. Thus, at least one application of optical system 100 is in conjunction with a digital camera or video camera comprising a digital display. Furthermore, optical system 100 and other optical systems included in the subject disclosure can be implemented in conjunction with a camera module of an electronic device. Such an electronic device can include a wide array of consumer, commercial or industrial devices. Examples include consumer electronics, including a cell phone, smart phone, laptop computer, net-book, PDA, computer monitor, television, flat-screen television, and so forth, surveillance or monitoring equipment, including commercial equipment (*e.g.*, ATM cameras, bank teller window cameras, convenience store cameras, warehouse cameras and so on), personal surveillance equipment (*e.g.*, pen camera, eyeglass camera, button camera, *etc.*), or industrial surveillance equipment (*e.g.*, airfield cameras, freight yard cameras, rail yard camera, and so on). For instance in consumer electronics, because optical system 100 can comprise optical components having physical dimensions on the order of a few millimeters or less, and because at least some of optical elements 102 can have a fixed position, system 100 and other disclosed systems are well suited for various types of mini or micro camera modules. It is to be appreciated, however, that the disclosed systems are not limited to this particular application; rather, other applications known to those of skill in the art or made known by way of the context provided herein, are included within the scope of the subject disclosure.

[0053] Figure 2 illustrates a diagram of an example optical imaging system 200 according to additional aspects of the subject disclosure. Optical imaging system 200 can comprise a set of optical elements 202 arranged transverse to an optical axis 204. Furthermore, optical elements 202 can be configured to focus an image onto an image plane 206 of an object located substantially at infinity from an aperture stop A1 of optical imaging system 200. In at least one aspect, optical elements 202 can be substantially similar to optical elements 102 of Figure 1, *supra*, except for the first distance between lens L1 and lens L2. Particularly, this first distance in optical imaging system 200 can be a distance $D_{INFINITY}$ 210 configured to focus the object located substantially at infinity, discussed above. Furthermore, as described at Figure 1, *supra*, aperture stop A1 can, in one aspect, be fixed in position relative to optical axis 204. In an alternative aspect, aperture stop A1 can be fixed in position relative to lens L1, and move along optical axis 204 with lens L2.

[0054] It should be appreciated that surfaces R1 through R10 of lenses L1 through L5 of optical elements 102 and 202 (as well as other optical surfaces described throughout the subject disclosure) can be of varying shapes. In one aspect, one or more of the surfaces can be spherical surfaces. In other aspects, one or more of the surfaces can be conic surfaces. In yet other aspects, one or more of the surfaces can be aspheric surfaces, according to a suitable aspheric equation, such as the even aspheric equation:

(1) $z = [\frac{CY^2}{\{1 + (1 - (1+K)C^2Y^2)^{1/2}\}}] + \sum_i (A_i * Y^i)$, where z is the sag height (in mm) of a line drawn from a point on the aspheric lens surface at a radial distance, Y from the optical axis to the tangential plane of the aspheric surface vertex, C is the curvature of the aspheric lens surface on the optical axis, Y is the radial distance (in mm) from the optical axis, K is the conic constant, and A_i is the i^{th} aspheric coefficient, with the summation over even number i. However, these aspects are not to be construed as limiting the scope of the subject disclosure. Rather, various surfaces can be odd aspheric, or of an aspheric equation comprising even and odd coefficients.

[0055] Further to the above, it should be appreciated that lenses of optical elements 102 and 202 (and optical lenses of various other optical systems provided throughout the subject disclosure) can be made of various suitable types of transparent material, and formed according to various suitable processes for generating an optical quality surface. In one aspect, lenses L1 through L5 can be ground and polished glass, where the glass is selected to have an index of refraction resulting in a desired effective focal length for the combined lenses L1 through L5. In another aspect, the lenses can be an optical-quality injected molded plastic (or plastic of optical quality formed by another suitable method), wherein the plastic has an index of refraction suitable to provide the desired effective focal length. In at least one other aspect, the lenses L1 through L5 can be etched from a transparent glass, crystalline or other suitable structure (*e.g.*, silicon dioxide – SiO_2 wafer) with a lithographic etching process similar to that used to etch semiconductor chips (*e.g.*, solid state memory chip, data processing chip). In a particular aspect, optical elements 102 and optical elements 202 can be described according to the optical prescription of Tables 1 – 9, below.

Parameter Description	Value
Effective Focal Length (in air at system temperature and pressure)	4.131396
Effective Focal Length (in image space)	4.131396
Back Focal Length	0.349633
Total Track Length (TTL)	5.49089
Image Space F/#	2.293412
Paraxial Working F/#	2.44
Working F/#	2.857105
Image Space NA	0.1752143
Object Space NA	0.008991
Stop Radius	0.90071
Paraxial Image Height	2.956
Paraxial Magnification	-0.04388
Entrance Pupil Diameter	1.801419
Entrance Pupil Position	0.18
Exit Pupil Diameter	1.236574
Exit Pupil Position	-3.03634
Maximum Radial Field	2.956

Lens Units	Millimeters (mm)
Angular Magnification	1.183246

Table 1: General Optical Properties

Field #	X-Value	Y-Value	Weight
1	0	0	1
2	0	0.571	1
3	0	1.142	1
4	0	1.714	1
5	0	2.285	1
6	0	2.57	1
7	0	2.856	0.2
8	0	2.956	0.2

Table 2: Field Type v. Real Image Height (in mm)

Field / #	VDX	VDY	VCX	VCY	VAN
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	-0.04364	0.000234	0.043642	0
6	0	-0.081	0.001432	0.081006	0
7	0	-0.1227	0.004184	0.122713	0
8	0	-0.13916	0.006035	0.139171	0

Table 3: Vignetting Factors for Fields of Table 2

Wavelength #	Value (in μm)	Weight
1	0.47	91
2	0.51	503
3	0.555	1000
4	0.61	503
5	0.65	107

Table 4: Wavelengths Used for Raytracing

Surface	Type	Radius	Thickness	Material	Diameter	Conic	Notes
Object	Standard	Infinity	100		132.3188	0	
1	Standard	Infinity	0.18		2.036472	0	
Stop	Standard	Infinity	-0.1		1.85939	0	
3	EvenAsph	1.974507	0.637634	APEL5514ML	1.907153	0	
4	EvenAsph	-13.5665	0.166808		1.939212	0	
5	Standard	Infinity	0.049504		1.939212	0	not vignetting
6	EvenAsph	68.79989	0.528506	OKP4HT	1.951274	0	
7	EvenAsph	2.992822	0.247886		1.977445	0	
8	Standard	Infinity	0.09498		2	0	Vignetting at 1.000
9	EvenAsph	143.3822	0.902332	APEL5514ML	2.122436	0	
10	EvenAsph	-24.6284	0.367969		2.741479	0	
11	EvenAsph	1.97917	0.596974	APEL5514ML	3.225637	0	
12	EvenAsph	91.68886	0.360983		4.127183	0	
13	EvenAsph	-3.10061	0.382215	APEL5514ML	4.395569	0	
14	EvenAsph	3.497914	0.2251		4.876466	0	
15	EvenAsph	Infinity	0.3	N-BK7	5.271775	0	
16	Standard	Infinity	0.55		5.427336	0	
Image	Standard				0	0	

Table 5: Surface Data Summary

Surface	Parameter Description	Value
R1	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.01328
	Coefficient on r 6	0.020358
	Coefficient on r 8	-0.03418
	Coefficient on r 10	0.012665
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R2	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.0043
	Coefficient on r 6	0.001395
	Coefficient on r 8	-0.02717
	Coefficient on r 10	0.022646
	Coefficient on r 12	0
	Coefficient on r 14	0

	Coefficient on r 16	0
R3	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.01683
	Coefficient on r 6	0.019474
	Coefficient on r 8	-0.03875
	Coefficient on r 10	0.034171
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R4	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.01678
	Coefficient on r 6	0.057631
	Coefficient on r 8	-0.06199
	Coefficient on r 10	0.029185
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R5	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.07378
	Coefficient on r 6	0.078871
	Coefficient on r 8	-0.04834
	Coefficient on r 10	0.007991
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R6	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.20739
	Coefficient on r 6	0.12271
	Coefficient on r 8	-0.04163
	Coefficient on r 10	0.006751
	Coefficient on r 12	0

	Coefficient on r 14	0
	Coefficient on r 16	0
R7	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.15706
	Coefficient on r 6	0.019487
	Coefficient on r 8	-0.00924
	Coefficient on r 10	0.001005
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R8	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	0.054595
	Coefficient on r 6	-0.04501
	Coefficient on r 8	0.010689
	Coefficient on r 10	-0.00087
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R9	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.01701
	Coefficient on r 6	0.02087
	Coefficient on r 8	-0.00363
	Coefficient on r 10	0.000212
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R10	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.07822
	Coefficient on r 6	0.013989
	Coefficient on r 8	-0.00152
	Coefficient on r 10	6.37E-05

	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0

Table 6: Surface Aspheric Coefficients

Surface	Edge
Object	100
1	0.18
Stop	0.13436
3	0.361345
4	0.208736
5	0.052866
6	0.700429
7	0.0726
8	0.054707
9	0.625532
10	0.494114
11	0.625166
12	0.144313
13	0.505743
14	0.480978
15	0.3
16	0.55
Image	0

Table 7: Edge Thickness Data

Temperature (Temp) in degrees Celsius and pressure (Press) in atmospheres								
Surface	Material	Temp	Press	0.47	0.51	0.555	0.61	0.65
0		20	1	1	1	1	1	
1		20	1	1	1	1	1	
2		20	1	1	1	1	1	
3	APEL55 14ML	20	1	1.552896	1.549574	1.546504	1.543579	1.541977
4		20	1	1	1	1	1	
5		20	1	1	1	1	1	
6	OKP4HT	20	1	1.65642	1.646281	1.637383	1.62927	1.625419
7		20	1	1	1	1	1	
8		20	1	1	1	1	1	
9	APEL55 14ML	20	1	1.552896	1.549574	1.546504	1.543579	1.541977
10		20	1	1	1	1	1	
11	APEL55 14ML	20	1	1.552896	1.549574	1.546504	1.543579	1.541977
12		20	1	1	1	1	1	
13	APEL55	20	1	1.552896	1.549574	1.546504	1.543579	1.541977

	14ML							
14		20	1	1	1	1	1	
15	N-BK7	20	1	1.523605	1.520769	1.518274	1.515909	1.51452
16		20	1	1	1	1	1	
17		20	1	1	1	1	1	

Table 8: Index of Refraction Data

		Wavelengths (µm):					
		0.47		0.51		0.555	
Number	Field (mm)	Tan	Sag	Tan	Sag	Tan	Sag
1	0	2.4569	2.4569	2.4571	2.4571	2.4591	2.4591
2	0.571	2.5045	2.4888	2.5043	2.4886	2.506	2.4902
3	1.142	2.5363	2.5666	2.5363	2.5654	2.538	2.5662
4	1.714	2.6412	2.6707	2.644	2.6687	2.6478	2.6688
5	2.285	3.1763	2.8179	3.1806	2.8155	3.1856	2.8152
6	2.57	3.6191	2.9098	3.6212	2.9074	3.6236	2.907
7	2.856	4.1799	3.0168	4.1688	3.0144	4.1575	3.014
8	2.956	4.4668	3.0594	4.4391	3.0571	4.4113	3.0567

Table 9: F/Number Data

		Wavelengths (µm)			
		0.61		0.65	
Number	Field (mm)	Tan	Sag	Tan	Sag
1	0	2.4624	2.4624	2.4666	2.4666
2	0.571	2.509	2.4932	2.5132	2.4973
3	1.142	2.5408	2.5684	2.5444	2.5721
4	1.714	2.6522	2.6703	2.656	2.6736
5	2.285	3.1911	2.8164	3.1952	2.8194
6	2.57	3.6263	2.908	3.6281	2.911
7	2.856	4.1459	3.0151	4.1376	3.018
8	2.956	4.3835	3.0578	4.3641	3.0606

Table 9A: F/Number Data (Continued)

[0056] Table 1 provides general optical information for an embodiment of optical imaging systems 100 and 200. Table 2 provides image heights in the y axis, measured at the image sensor 106 or image sensor 206, for eight different optical fields, and provides weights for the respective fields. Table 3 includes vignetting data for the eight fields indicated in Table 2. Table 4 depicts wavelengths of respective rays traced in optical imaging systems 100 and 200, depicted at Figures 1 and 2. Table 5 provides a summary of general optical surface characteristics for the lenses of optical elements 102 and optical elements 202, including surface type, radius of curvature, thickness, material (from standard glass and plastic catalogues), diameter, conic constant, and notes regarding vignetting. Table 6 describes even aspheric coefficients for the surfaces of Table 5, whereas Table 7 provides edge thickness information for those surfaces. Table 8 provides index of refraction data for multiple wavelengths for the optical fields identified at Table 2. Tables 9 and 9A provide F/# data for those same wavelengths and optical fields.

[0057] Figure 3 illustrates a diagram of an example injection molded plastic optical system 300 (also referred to as system 300) according to further aspects of the subject disclosure. System 300 can be formed from multiple injection molded plastic components. In one embodiment, two or more of lenses L1, L2, L3, L4 and L5 can be formed from a single mold. In other embodiments, respective lenses can be formed from separate molds and assembled, as depicted, after molding. In other aspects, formation of lenses L1, L2, L3, L4 and L5 can result from another optical fabrication technique, such as wafer-level optic fabrication. In at least one disclosed aspect, system 300 can be substantially similar to optical imaging system 100. In another aspect, system 300 can be substantially similar to optical imaging system 200. According to yet other aspects, system 300 can comprise MEMS hardware configured to displace lens L1 along optical axis 302 to achieve focusing at an image plane 304 of system 300. In a particular embodiment, system 300 can comprise lens surfaces R1 and R2 of lens L1, surfaces R3 and R4 of lens L2, surfaces R5 and R6 of lens L3, surfaces R7 and R8 of lens L4, and surfaces R9 and R10 of lens L5, that are substantially similar to surfaces R1 – R10 described at Figure 1, *supra*.

[0058] Figure 4 illustrates a diagram of field curvature and F-Tan(Theta) Distortion (referred to hereinafter as distortion) for an optical imaging system as described herein. Particularly, Figure 4 illustrates field curvature and distortion for an object distance of 10cm, which can correspond with optical imaging system 100 of Figure 1, *supra*. The field curvature and distortion graphs utilize five wavelengths, having wavelengths of 0.470, 0.510, 0.555, 0.610 and 0.650 μm, respectively, and have a maximum field angle of 33.391 degrees. The left-hand graph depicts field curvature in millimeters along a y-axis at an image plane of an optical imaging system. Field curvature data is depicted for Sagittal rays (delineated as ‘S’ on Figure 4) and Tangential rays (delineated as 'T' on Figure 4). As is clear from the graph, field curvature is minimal for sagittal rays over most of the image plane, and field curvature is within a few microns for tangential rays for most of the image plane, and several microns at the outer edge of the image plane (high y values).

[0059] The distortion graph on the right hand side also includes curves for the above five wavelengths. The distortion data is normalized to 0% at the optical axis. Throughout the image plane, distortion is less than about 1.5%, and less than one percent for low field angles.

[0060] Figure 5 depicts a diagram of field curvature and distortion for an optical imaging system focusing an object at infinity. Thus, the graphs of Figure 5 can correspond with optical imaging system 200 of Figure 2, *supra*. The field curvature and distortion graphs of Figure 5 employ graphs for the same wavelengths as for Figure 4, for a maximum field angle of 34.897 degrees. Field curvature includes lines for sagittal rays (S) for the indicated wavelengths, as well as transverse rays (T) for those same wavelengths. As depicted, field curvature for an object in focus at 10cm is within about +/- 50 microns.

[0061] Distortion at infinity varies a bit more than for the 10cm graph of Figure 4. Distortion is again normalized to 0% on the optical axis. The distortion ranges from about a half percent at medium field angles to about negative one and a half percent at the edge of the image plane. Total distortion for all field angles is about two percent.

[0062] Figure 6 illustrates a graph of primary lateral color for an optical imaging system as described herein. Particularly, the primary lateral color graph of Figure 6 is for an object in focus at 10cm object distance, and therefore can correspond with optical imaging system 100 of Figure 1, *supra*. The maximum field for the primary lateral color graph is 2.9560 mm, and ranges in wavelengths between 0.4700 and 0.6500 μm. As depicted, lateral color variation is well within a half a micron for small field angles, varies to just over negative one microns for medium field angles, and becomes as large as about negative one and a half microns for higher field angles. Overall distortion remains below two microns for the image plane.

[0063] Figure 7 illustrates a graph of primary lateral color for an object in focus at infinity. Accordingly, Figure 7 can correspond with optical imaging system 200 of Figure 2, *supra*. Similar to Figure 6, the maximum field is 2.9560 mm for wavelengths between 0.4700 and 0.6500 μm. For low and medium field angles, primary lateral color remains at or below about one half a micron. Only at larger field angles does the primary lateral color exceed half a micron, reaching a peak at just over about two microns at an edge of the image plane.

[0064] Figure 8 illustrates several transverse ray fan plots at an image plane of an optical imaging system described herein. Particularly, the transverse ray fan plots of Figure 8 correspond with an object in focus at 10cm object distance, and therefore can correspond with optical imaging system 100 of Figure 1, *supra*. The transverse ray fan plots depict transverse ray error (e_y) along a vertical axis, and pupil diameter (P_y) along the horizontal axis, for various image heights. Flatter plots indicate optimal performance and minimal error, whereas greater deviations along the vertical axis indicate greater transverse ray error. As is depicted by Figure 8, transverse ray error is minimal for near the optical axis (small image height), and generally increases with image height. The scale ranges from positive 25 microns to negative 25 microns along the x and y axis, respectively. The transverse ray fan plots include wavelengths between 0.470 and 0.650 wavelengths.

[0065] Figure 9 depicts several transverse ray fan plots for an object in focus at infinity, and therefore can correspond with optical imaging system 200 of Figure 2, *supra*. Similar to Figure 8, the plots exhibit minimal error near the optical axis, and generally low error for small pupil diameters at all field angles. At higher field angles and particularly higher pupil diameters, the transverse ray error increases. Generally, transverse ray error for the object at infinity is less than for the object at 10cm.

[0066] Referring now to the drawings, Figure 10 depicts a cross sectional view of an optical system 1000 for an object at 10cm comprising an arrangement of optical elements 1002 positioned in a like manner relative to an optical axis 1004. Light entering the left side, or object side, of optical elements 1002 can interact sequentially with respective elements 1002 and exit the right side, or image side, of the elements 1002, toward an image sensor 1006. The real image will be formed along the optical axis 1004 a certain distance from the optical elements 1002, called an image distance (ID). Notably, the ID depends primarily on a corresponding object distance (OD – distance between the object and the optical elements 1002 along the optical axis 1004) and a refractive power, or optical power, of the combined optical elements 102.

[0067] Sensor 1006 can be a digital device comprising a multi-dimensional array (*e.g.*, a two dimensional array) of electro-optical sensors, or pixels, which can include a CCD array, or a CMOS array, *etc*. Resolution of a digital image generated by sensor 1006 depends on a number of pixels within the sensor plane array 1008, which in turn is dependent on pixel area and total array area. Thus, for example, for relatively square pixels approximately 1.4 microns per side (1.96 square microns), a 0.4 cm square sensor array can comprise as many as 8.1 megapixels (Mp). Said differently, such a sensor would have resolution of about 8Mp. Because the pixel array generates an electronic reproduction of a real image, data generated by sensor 1006 in the form of electric signals can be saved to memory, projected to a display for viewing (*e.g.*, digital display screen), edited in software, and so on.

[0068] It should be appreciated that the optical imaging arrangement 1000 depicted in Figure 10 (and other optical imaging systems disclosed herein) is not intended to be drawn to scale. For instance, lens thicknesses, positions and heights are not necessarily depicted in proper proportion with actual sizes. Rather, arrangement 1002 is intended to provide a visual context of an imaging system to aid conceptual understanding of other aspects disclosed herein.

[0069] Optical system 1000 comprises a first lens L1, a second lens L2, a third lens L3, a fourth lens L4, and a fifth lens L5 centered upon an optical axis 104. The lenses are numbered starting from the object side to the image side. Thus, lens L1 is closest to the object, and lens L5 is closest to the image. Aperture A1 can be embedded into lens L1, or can be fixed to L1 physically. Accordingly, in this embodiment, aperture A1 does not move relative to lens L1. In certain aspects of the disclosure, the aperture A1 can have a 50μm depth.

[0070] Lenses L1 through L5 each have two opposed refracting surfaces. A radius of curvature for the respective surfaces is denoted by the letter "R" followed by a surface number, starting with the object side surface of lens L1. Thus, the surfaces in order from object side to image side are object side surface R1 and image side surface R2 of lens L1, object side surface R3 and image side surface R4 of lens L2, object side surface R5 and image side surface R6 of lens L3, object side surface R7 and image side surface R8 of lens L4, and object side surface R9 and image side surface R10 of lens L5. The respective surface identifiers (R1, R2, R3, …, R10) are also utilized to represent the radius of curvature for the respective surfaces. Additionally, refractive index n_i denotes the refractive index of the lens medium associated with the i^{th} surface, and v_di is the Abbe number of the lens medium associated with the i^{th} surface.

[0071] Lens L1 can have a large positive refractive power, with both optical surfaces, R1 and R2, being convex. As utilized herein, the terms large or small refractive power (whether positive or negative) are intended to be relative to other lenses of a particular optical system. Thus, for instance, referring to lens L1 as having large positive refractive power implies that lens L1 has greater than average positive refractive power as compared with other positive power lenses of optical system 1000. Conversely, a lens having small positive refractive power for optical system 1000 will have less than the average positive refractive power.

[0072] In an embodiment, L1 can be moveable relative to lenses L2-L5 and the sensor plane 1008. Movement can be achieved using MEMS or other appropriate actuators. In this embodiment, L2-L5 remain fixed relative to the image sensor plane 1008 and image sensor 1006. In some aspects of the disclosure, the range of movement of L1 is around 100μm. The movement of L1 allows optical system 1000 to maintain focus on objects at various distances. In Figure 10, the optical system 1000 is focused on an object at a distance of 10cm from the optical system. In Figure 2, the optical system 1100 is focused on an object at optical infinity.

[0073] In certain embodiments, there is an inverse relationship between the refractive power of L1 and the range of motion required to focus on objects at various distances. An L1 with a higher power requires a shorter range of movement to focus on objects at various distances and vice versa. According to some aspects of the disclosure, the axial gap, or distance between lenses L1 and L2 at the optical axis is around 125μm, with a gap of about 170 μm at the clear aperture.

[0074] L2 can have a meniscus shape (having smaller thickness near the optical axis than away from the optical axis), with optical surface R3 being convex, and optical surface R4 being concave. In some aspects of the disclosure, lens L2 provides most of the chromatic correction for optical system 1000 and has negative refractive power. Lens L3 can be biconvex near the optical axis 1004 as optical surface R5 is convex near the optical axis 1004 and concave away from the optical axis 1004 and image side optical surface R6 is convex. According to some aspects of the disclosure, lens L3 can have a positive refractive power. In certain embodiments, L2 can be mounted on to L3, such that L2 is fixed to L3, and L2 does not touch an optical barrel that arranges lenses L1 – L5 of optical system 1000 along optical axis 1004.

[0075] Lens L4 has a concave object side optical surface R7, and a convex shaped image side optical surface R8. Lens L5 can be meniscus shaped with a convex optical surface R9 near optical axis 1004 and optical surface R10 that is concave near the optical axis 104.

[0076] It should be appreciated that surfaces R1-R10 (as well as other optical surfaces described throughout the subject disclosure, including optical surfaces for system 200 can be of varying shapes. In one aspect, one or more of the surfaces can be spherical surfaces. In other aspects, one or more of the surfaces can be conic surfaces. In yet other aspects, one or more of the surfaces can be aspheric surfaces, according to a suitable aspheric equation, such as the even aspheric equation:

[0077] (1) $z = [\frac{CY^2}{\{1+(1-(1+K)C^2Y^2)^{1/2}\}}] + \sum_i (A_i * Y^i)$, where z is the sag height (in mm) of a line drawn from a point on the aspheric lens surface at a radial distance, Y from the optical axis to the tangential plane of the aspheric surface vertex, C is the curvature of the aspheric lens surface on the optical axis, Y is the radial distance (in mm) from the optical axis, K is the conic constant, and A_i is the i^{th} aspheric coefficient, with the summation over even number i. However, these aspects are not to be construed as limiting the scope of the subject disclosure. Rather, various surfaces can be odd aspheric, or of an aspheric equation comprising even and odd coefficients.

[0078] Further to the above, it should be appreciated that lenses L1-L5 of optical system 1000 (and the optical lenses of optical system 1100) can be made of various suitable types of transparent material, formed according to various suitable processes for generating an optical quality surface. In one aspect, the lenses L1-L5 can be ground and polished glass, where the glass is selected to have an index of refraction resulting in a desired effective focal length for the combined lenses L1-L5. In another aspect, the lenses can be an optical-quality injected molded plastic (or plastic of optical quality formed by another suitable method), wherein the plastic has an index of refraction suitable to provide the desired effective focal length. In at least one other aspect, the lenses L1-L5 can be etched from a transparent glass, crystalline or other suitable structure (*e.g.*, silicon dioxide – SiO_2 wafer) with a lithographic etching process similar to that used to etch semiconductor chips (*e.g.*, solid state memory chip, data processing chip).

[0079] According to various aspects, the lenses L1, L2, L3, L4 and L5 can be made of plastic (*e.g.*, APL5014, OKP4HT, or ZE-330R or another suitable plastic having similar refractive index and Abbe number, or a suitable combination thereof). In one specific aspect, lenses L1, L3, and L5 are made of one plastic (*e.g.*, APL5014) while lenses L2 and L4 are made of different plastics (*e.g.*, OKP4HT and ZE-330R respectively). It should be appreciated, however, that in other aspects the lenses can be of other materials having similar Abbe numbers or refractive indices instead.

[0080] Turning now to Figure 11, a cross-section of a sample optical system focused at infinity according to aspects of the subject disclosure is shown. The optical system 1100 of Figure 11 is similar to optical system 100, although optical system 1100 is focused on an object at infinity as opposed to at 10 cm. A difference between optical system 1100 and optical system 1000 is that L1 is positioned at a different distance from the sensor 1106 relative to lenses L2-L5.

[0081] According to one specific aspect of the subject disclosure, a prescription for the respective lenses L1, L2, L3, L4 and L5 is provided in Tables 10-13, below. Table 10 lists general lens data for the respective lenses, and Table 11 lists surface data including radius of curvature (R) (in mm) near the optical axis, distance between surfaces, diameter of the respective lenses, and material of the respective lenses. Furthermore, Table 12 provides aspheric constants A_i for i = 2, 4, 6, 8, 10, 12, 14, 16 of equation (1), *supra*, for aspheric surfaces of Table 11, where the index "i" is denoted by "r" (*e.g.*, as generated in the optical design software program ZEMAX, available from ZEMAX Development Corporation). Table 13 provides refractive index n_i of the i^{th} lens for a set of wavelengths. Table 14 provides a range of fields versus image height, Table 15 provides vignetting information for optical systems 1000 and 1100, Table 16 provides wavelength and weights used for the raytracing of Figures 10 and 11, Table 17 provides surface data for optical systems 1000 and 1100, including radius, thickness, material, diameter, and conic constant. Additionally, Table 18 provides edge thickness information for optical systems 1000 and 1100.

Surfaces (including apertures)	15
Stops	1
System Aperture	Float by stop size = 0.886727
Apodization	Uniform Factor = 0.00000E+000
Temperature (C)	2.00000E+001
Pressure (ATM)	1.00000E+000
Effective Focal Length	4.28412 (in air at system temp & pressure)
Effective Focal Length	4.28412 (in image space)

Back Focal Length	0.5015793
TTL	5.299934
Image Space F/#	2.415692
Paraxial Working F/#	2.415692
Working F/#	2.40149
Image Space NA	0.202684
Object Space NA	8.867272e-011
Stop Radius	0.8867272
Paraxial Image Height	2.856
Paraxial Magnification	0
Entrance Pupil Diameter	1.773454
Entrance Pupil Position	0
Field Type	Real Image height in mm
Maximum Radial Field	2.856
Primary Wavelength	0.555µm
Lens Units	mm
Angular Magnification	1.39828

Table 10: General Properties for Optical Systems 1000 and 1100

(Optical Properties defined in Optical Design Software Zemax)

Surface	Type	Radius (mm)	Thickness (mm)	Medium	Diameter (mm)
OBJ	Standard	Infinity	Infinity		0
A1	Standard	Infinity	0.05		1.773454
R1	Even_Asph	2.031962	0.545	APL5014	1.774436
R2	Even_Asph	-17.60993	0.1242087		1.867362
R3	Even_Asph	4.178319	0.3	OKP4-HT	1.941112
R4	Even_Asph	1.60308	0.3519566		2.054041
R5	Even_Asph	5.790688	0.6445624	APL5014	2.132792
R6	Even_Asph	-2.417954	0.2002186		2.449247
R7	Even_Asph	-0.9919052	0.3658935	ZE-330R	2.5699
R8	Even_Asph	-1.223582	0.5116968		2.686087
R9	Even_Asph	12.46394	1.123586	APL5014	2.987795
R10	Even_Asph	2.132428	0.3415114		4.646312
14	Standard	Infinity	0.3	D263T	6

15	Standard	Infinity	0.4913		6
IMA	Standard	Infinity			6.4

Table 11: Surface Data for Lens Elements for Optical System 1000 and 1100

Surface	Conic	Note
OBJ	0	
A1	0	stop1
R1	-1	L1-1
R2	-1	L1-2
R3	-1	L2-1
R4	-1	L2-2
R5	-1	L3-1
R6	-1	L3-2
R7	-1	L4-1
R8	-1	L4-2
R9	-1	L5-1
R10	-1	L5-2
14	0	Ir cut-off (D263T)
15	0	
IMA		

Table 11: Continued

Surface	R1	
	Coeff on r2	0
	Coeff on r4	0.021400101
	Coeff on r6	-0.0044229854
	Coeff on r8	-0.00018162551
	Coeff on r10	0
	Coeff on r12	0
	Coeff on r14	0
	Coeff on r16	0
Surface	R2	
	Coeff on r2	0
	Coeff on r4	0.0013366226
	Coeff on r6	0.0044675095

	Coeff on r8	-0.0065254167
	Coeff on r10	0
	Coeff on r12	0
	Coeff on r14	0
	Coeff on r16	0
Surface	R3	
	Coeff on r2	0
	Coeff on r4	-0.15575931
	Coeff on r6	0.11775238
	Coeff on r8	-0.040496241
	Coeff on r10	0
	Coeff on r12	0
	Coeff on r14	0
	Coeff on r16	0
Surface	R4	
	Coeff on r2	0
	Coeff on r4	-0.17899613
	Coeff on r6	0.13165259
	Coeff on r8	-0.041877243
	Coeff on r10	0
	Coeff on r12	0
	Coeff on r14	0
	Coeff on r16	0
Surface	R5	
	Coeff on r2	0
	Coeff on r4	-0.034806957
	Coeff on r6	-0.055196853
	Coeff on r8	-0.0076170308
	Coeff on r10	0
	Coeff on r12	0
	Coeff on r14	0
	Coeff on r16	0
Surface	R6	
	Coeff on r2	0
	Coeff on r4	0.020581236
	Coeff on r6	-0.0065040866
	Coeff on r8	-0.018006387
	Coeff on r10	0
	Coeff on r12	0
	Coeff on r14	0
	Coeff on r16	0
Surface	R7	

	Coeff on r2	0
	Coeff on r4	0.17752822
	Coeff on r6	0.0025820117
	Coeff on r8	0.0073104429
	Coeff on r10	-0.0065708267
	Coeff on r12	0
	Coeff on r14	0
	Coeff on r16	0
Surface	R8	
	Coeff on r2	0
	Coeff on r4	0.03288338
	Coeff on r6	0.076502466
	Coeff on r8	-0.06842281
	Coeff on r10	0.038984099
	Coeff on r12	-0.0076836467
	Coeff on r14	0
	Coeff on r16	0
Surface	R9	
	Coeff on r2	0
	Coeff on r4	-0.1830718
	Coeff on r6	0.075510932
	Coeff on r8	-0.034603365
	Coeff on r10	0.0066539539
	Coeff on r12	-0.00029016159
	Coeff on r14	0
	Coeff on r16	0
Surface	R10	
	Coeff on r2	0
	Coeff on r4	-0.15124446
	Coeff on r6	0.071176496
	Coeff on r8	-0.029255744
	Coeff on r10	0.0080879291
	Coeff on r12	-0.0014220241
	Coeff on r14	0.00014276636
	Coeff on r16	-6.2275295e-006

Table 12: Aspheric Coefficients for Optical System 1000 and 1100

				Index (for given wavelength in μm)				
Surface	**Medium**	**Temp**	**Pressure**	0.47	0.41	0.555	0.61	0.65
L1	APL5014	20	1	1.5518	1.5483	1.5452	1.5424	1.5408

L2	OKP4-HT	20	1	1.6564	1.6458	1.6369	1.6291	1.6248
L3	APL5014	20	1	1.5518	1.5483	1.5452	1.5424	1.5408
L4	ZE-330R	20	1	1.5172	1.5139	1.5111	1.5084	1.5069
L5	APL5014	20	1	1.5518	1.5483	1.5452	1.5424	1.5408

Table 13: Index of Refraction for Optical Systems 1000 and 1100

Field #	X-Value	Y-Value	Weight
1	0	0	1
2	0	0.571	1
3	0	1.142	1
4	0	1.714	1
5	0	2.285	1
6	0	2.57	1
7	0	2.856	1

Table 14: Field Type v. Real Image Height (in mm)

Field / #	VDX	VDY	VCX	VCY	VAN
1	0	0	0	0	0
2	0	-0.00376	0.00001	0.003764	0
3	0	-0.00751	0.00003	0.007509	0
4	0	-0.01125	0.000093	0.011253	0
5	0	-0.01512	0.00015	0.015117	0
6	0	-0.01707	0.000226	0.017069	0
7	0	-0.019	0.000251	0.018997	0
1	0	0	0	0	0

Table 15: Vignetting Factors for Fields of Table 2

Wavelength #	Value (in μm)	Weight
1	0.47	91
2	0.51	503
3	0.555	1000
4	0.61	503
5	0.65	107

Table 16: Wavelengths Used for Raytracing

Surface	Type	Radius	Thickness	Material	Diameter	Conic	Notes

Object	Standard	Infinity	Infinity		0	0	
Stop	Standard	Infinity	0.05		1.773454	0	
2	Standard	Infinity	-0.204		1.773454	0	
3	EvenAsph	2.031962	0.545	APL5014	1.774436	-1	L1
4	EvenAsph	-17.6099	0.124209		1.867362	-1	
5	EvenAsph	4.178319	0.3	OKP4HT	1.941112	-1	L2
6	EvenAsph	1.60308	0.351957		2.054041	-1	
7	EvenAsph	5.790688	0.644562	APL5014	2.132792	-1	L3
8	EvenAsph	-2.41795	0.200219		2.449247	-1	
9	EvenAsph	-0.99191	0.365894	ZE-330R	2.5699	-1	L4
10	EvenAsph	-1.22358	0.511697		2.686087	-1	
11	EvenAsph	12.46394	1.123586	APL5014	2.987795	-1	L5
12	EvenAsph	2.132428	0.341511		4.646312	-1	
13	Standard	Infinity	0.3	D263T	6	0	IRCF
14	Standard	Infinity	0.4913	N-BK7	6	0	
Image	Standard	Infinity	6.4		0	0	

Table 17: Surface Data Summary

Surface	Edge
Stop	0.05
2	0.000726
3	0.315728
4	0.189805
5	0.491449
6	0.078721
7	0.308446
8	0.214072
9	0.303193
10	0.428579
11	1.31122
12	0.662695
13	0.3
14	0.4913
Image	0

Table 18: Edge Thickness Data

[0082] Figure 12 illustrates a graph of field curvature and distortion for optical configuration 1002. Further, the field curvature and distortion values are displayed for several wavelengths ranging from 0.470μm to 0.650μm. Field curvature is within about 10 microns for these wavelengths for low field angles, and is less than 100 microns even at the perimeter of the image plane. Further, distortion is well within the range of two and negative two percent. As would be clear to one of skill in the art, aberrations are well compensated for by the subject optical arrangement 1002.

[0083] Figure 13 illustrates a graph of field curvature and distortion for optical configuration 1102. Further, the field curvature and distortion values are displayed for several wavelengths ranging from 0.470μm to 0.650μm. Field curvature is well within the range of +/- 100 microns, and distortion is well within the range of two and negative two percent. As would be clear to one of skill in the art, aberrations are well compensated for by the subject optical arrangement 1102.

[0084] Figure 14 depicts a graph of lateral color for optical arrangement 1002. A maximum field for the graph is 2.8560mm. Additionally, the lateral color curve is over a range of wavelengths from 0.470μm to 0.650μm. The primary lateral color for an object in focus at 10cm is about -3.5μm as depicted by the graph.

[0085] Figure 15 depicts a graph of lateral color for optical arrangement 1102 for an object in focus at infinity. A maximum field for the graph is 2.8560mm. Additionally, the lateral color curve is over a range of wavelengths from 0.470μm to 0.650μm. The primary lateral color for the object in focus at infinity is about +0.8 microns.

[0086] Figure 16 and Figure 17 depict transverse ray fan plots for optical arrangements 1002 and 1102 respectively. The transverse ray fan plots depict transverse aberration (e_y and e_x) along the y and x axis for pupil diameters P_y and P_x. The transverse ray fan plots are made at image heights 0.000mm (1600 and 1700), 0.5710mm (1602 and 1702), 1.1420mm (1604 and 1704), 1.7140mm (1606 and 1706), 2.2850mm (1608 and 1708), 2.5700mm (1610 and 1710), and 2.8560mm (1612 and 1712). The plots are generally within acceptable ranges for optical imaging and accordingly, the optical arrangements 1002 and 1102 have good imaging quality.

[0087] Figure 18 illustrates a diagram of an example ray plot diagram for an optical system 1800 according to alternative aspects of the subject disclosure. System 1800 comprises an arrangement of optical elements 1802. Optical rays are depicted intersecting optical elements 1802 within a field of view of optical system 1800. On-axis rays are focused onto the optical axis at an image plane or focal plane associated with optical elements 1802, and rays originating at larger field angles are depicted as converging at farther distances from the optical axis at the image plane.

[0088] A left-most side of optical elements 1802 is an object side of optical system 1800, and a right-most side of optical elements 1802 is an image side of optical system 1800. A real image of the object is formed at the image plane of optical elements 1802 when optical elements 1802 are properly in focus. In at least one aspect of the subject disclosure, optical system 1800 can comprise a variable focus optical system, in which a subset of optical elements 1802 can be moved along the optical axis to bring an image of an object into focus at the image plane. In particular aspects, a set of positions of the subset of optical elements 1802 can correspond with a set of object distances having respective images in focus at the image plane. In other words, when the subset of optical elements 1802 is positioned at one of the set of positions, an object at a corresponding one of the set of object distances will be in focus at the image plane. A position of optical elements 1802 as depicted by Figure 18 and Figure 19, *infra*, illustrate an example arrangement in which optical elements of system 1800 are in a position to focus an object located at infinity onto the image plane. A position of optical elements 1802 as depicted by Figures 23 and 24, *infra*, illustrate an example arrangement in which the optical elements are in a position to focus a near-field object onto the image plane.

[0089] Figure 19 depicts a diagram of an example optical system 1900 comprising optical elements and optical surfaces according to additional aspects of the subject disclosure. Optical system 1900 can be substantially similar to optical system 1800. As indicated, optical system 1900 is configured to focus an image of an object located in the far-field (*e.g.*, at infinity).

[0090] Optical system 1900 can comprise a set of optical elements 1902 centered along an optical axis 1904. Optical elements 1902 can be configured to focus an image that can be captured by a sensor 1908. Sensor 1908 can comprise a multi-dimensional array of optical-sensitive pixels located at an image plane of sensor 1908. The optical-sensitive pixels can output electrical signals in response to electro-magnetic energy (*e.g.*, light) focused by optical elements 1902 upon sensor 1908. Moreover, the electrical signals can have characteristics related to optical characteristics of the electro-magnetic energy. These electrical signals can be utilized to re-produce the image focused by optical elements 1902 and captured by sensor 1908, as described herein or known in the art. Optical system 1900 can also comprise a cover plate 1906 for sensor 1908. Cover plate can protect the optical-sensitive pixels of sensor 1908 from dust or other particles that might otherwise absorb or scatter electro-magnetic energy focused by optical elements 1902, thereby distorting the image.

[0091] Optical elements 1902 can comprise five optical lenses, including lens L1, lens L2, lens L3, lens L4 and lens L5 (referred to collectively as lenses L1 – L5). The optical lenses are numbered from left – the object side of optical system 1900 – to right – the image side of optical system 1900. The left-most lens, L1, is therefore also referred to herein as the object-side lens. Alternatively, lens L1 can be referred to as an objective lens of optical system 1900.

[0092] As depicted, lens L1 is a bi-convex lens having positive optical power, and having a convex object-side surface R1 and convex image-side surface R2. Furthermore, lens L1 can have a strong optical power relative to lenses L2, L3, L4 and L5 of optical elements 1902. In particular aspects, lens L1 can have greater positive optical power than either of lenses L2, L3, L4 or L5. In a further aspect, L1 can have greater positive optical power than any subset of lenses L2, L3, L4 and L5. In at least one alternative or additional aspect, lens L1 can have greater positive optical power than the combination of lenses L2, L3, L4 and L5. As depicted, an aperture stop A1 can be located about the object side surface R1 of lens L1.

[0093] Lens 2 can be a lens having a negative optical power. Lens L2 can have an object-side surface R3 and an image-side surface R4. Surface R3 can be mildly convex, in some aspects of the subject disclosure. In other aspects, surface R3 can be substantially flat with no significant optical power. In still other aspects of the subject disclosure, surface R3 can have a complex curvature that is convex for a subset of pupil radii (*e.g.*, a range of distances from optical axis 1904) of surface R3, and concave for a different subset of pupil radii of surface R3. As an example, surface R3 can have a concave curvature from the optical axis 1904 to a first pupil radius, and can have a convex curvature from the first pupil radius to a second pupil radius, where the second pupil radius is larger than the first pupil radius. An image side surface R4 can have a concave curvature, providing the majority of negative optical power of lens L2.

[0094] Lens L3 can be a meniscus lens having a convex curvature toward the object side of lens L3. As depicted, lens L3 comprises an object side surface R5 and image side surface R6. Object side surface R5 can have convex curvature. In particular aspects, convexity of object side surface R5 can be stronger near optical axis 1904 than near a perimeter of lens L3. Said differently, a radius of curvature of object side surface R5 can increase with increasing pupil radius of object side surface R5, and in at least one aspect become infinite near the perimeter of lens L3. Image side surface R6 can have concave curvature. In at least one aspect, a radius of curvature of image side surface R6 can increase with increasing pupil radius of lens L3. In an alternative or additional aspect, image side surface R6 can be convex near the perimeter of lens L3.

[0095] Lens L4 comprises an object side surface R7 and an image side surface R8. Lens L4 can be a meniscus lens toward the image side of optical elements 1902.

Additionally, lens L4 can have mild positive optical power. In one alternative or additional aspect, positive power of lens L4 can be greater near optical axis 1904 as compared with a periphery of lens L4, whereas in other aspects the positive power can be substantially constant over the surface of image side surface R8.

[0096] Lens L5 comprises an object side surface R9 and image side surface R10. Object side surface R9 can have concave curvature for low and medium field angles, and reduced curvature at higher field angles. Image side surface R10 can be concave near optical axis 1904. Further, image side surface R10 can transition from concave to convex for medium and high field angles.

[0097] Optical elements 1902 can have respective spaces (air gaps) between respective lenses L1, L2, L3, L4 and L5. In a particular aspect, an on-axis air distance between lens L4 and lens L5 can be a largest of a set of air distances among lenses L1 – L5. In an alternative or additional aspect, an air distance between lens L3 and lens L4 can be a second largest of the set of air distances among lenses L1 – L5.

[0098] In a further aspect of the subject disclosure, an actuator can be connected to a subset of optical elements 1902. In one example, the actuator can be a MEMS actuator, whereas in other aspects the actuator can be another type of actuator known in the art. The actuator can be configured to reposition the subset of optical lenses along optical axis 1904. Repositioning the subset of optical lenses can cause images of objects at different object distances to come into focus at sensor 1908 of optical system 1900. In particular aspects, optical lenses 1902 can be configured to focus an image of an object located in the far field (*e.g.*, infinity, …) onto sensor 1908. According to further aspects, the subset of optical elements 1902 can be repositioned to focus an object in the near field at sensor 1908. In a specific aspect, the subset of optical elements can include lens L1, and lens L1 can be positioned as depicted by Figure 19 by the MEMS actuator to bring an object located at infinity into focus at sensor 1908, and can be positioned as depicted by Figure 23 by the MEMS actuator to bring an object at an object distance of substantially 12.8 centimeters (cm) into focus at sensor 1908.

[0099] In a further aspect, aperture stop A1 can be fixed relative to optical axis 1904. In another aspect, aperture stop A1 can be fixed relative to a position of lens L1. In the latter aspect, aperture stop A1 can be moved by a MEMS actuator in conjunction with lens L1 when focusing an image of an object onto sensor 1908. According to still other aspects, the MEMS actuator can be configured to move lens L1, either alone or in conjunction with aperture stop A1, a total distance along optical axis 1904. The total distance can, at one end thereof, focus an image of an object at infinity on sensor 1908, and at another end thereof, focus an image of an object at an object distance of substantially 12.8cm at sensor 1908.

[00100] Lenses L1 – L5 can be of various suitable types of suitable optically transparent material, and formed according to a suitable method(s) for generating an optical quality surface. In one aspect, lenses L1 – L5 can be ground or polished glass, where the glass is selected to have an index of refraction resulting in a desired effective focal length for the combined lenses L1 – L5. In another aspect, the lenses can be an optical-quality injection molded plastic (or plastic of optical quality formed by another suitable fabrication method), wherein the plastic has an index of refraction suitable to provide the desired focal length. In another aspect(s), the lenses L1 – L5 can be etched from a transparent glass, crystalline or other suitable structure with a lithographic etching process similar to that used to etch semiconductor chips. In a specific aspect(s), lenses L1 – L5 can be of differing glasses, plastics or suitable optical-transparent medium, by one or more of the above or similar suitable fabrication techniques (note that cover 1908 is a fictional material). In a further aspect, optical elements 1902 can have be described according to the optical prescription of Tables 19 – 27A.

Parameter Description	Value
Effective Focal Length (in air at system temperature and pressure)	4.803702
Effective Focal Length (in image space)	4.803702
Back Focal Length	0.1097044
Total Track Length (TTL)	5.588093
Image Space F/#	2.668723
Paraxial Working F/#	2.668742
Working F/#	2.647852
Image Space NA	0.1841501
Object Space NA	9e-007
Stop Radius	0.9
Paraxial Image Height	3.492
Paraxial Magnification	-4.803736e-006
Entrance Pupil Diameter	1.8
Entrance Pupil Position	0.05

Exit Pupil Diameter	1.214476
Exit Pupil Position	-3.231397
Maximum Radial Field	3.492
Lens Units	Millimeters (mm)
Angular Magnification	1.482119

Table 1: General Optical Properties (Object in Focus at Infinity)

Field #	X-Value	Y-Value	Weight
1	0	0	1
2	0	0.339	1
3	0	0.678	1
4	0	1.018	1
5	0	1.357	1
6	0	1.696	1
7	0	2.035	1
8	0	2.375	1
9	0	2.714	1
10	0	3.053	1
11	0	3.392	1
12	0	3.492	1

Table 20: Field Type v. Real Image Height (in mm)

Field / #	VDX	VDY	VCX	VCY	VAN
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	-0.005032	0.000003	0.005032	0
8	0	-0.018773	0.000041	0.018775	0
9	0	-0.031175	0.000230	0.031178	0
10	0	-0.062274	0.000739	0.062281	0
11	0	-0.154303	0.005254	0.154319	0
12	0	-0.218933	0.013148	0.218954	0

Table 21: Vignetting Factors for Fields of Table 20

Wavelength #	Value (in µm)	Weight
1	0.4358	0.15
2	0.4861	0.45
3	0.5461	1.00

4	0.5876	0.80
5	0.6563	0.10

Table 22: Wavelengths Used for Raytracing

Surface	Type	Radius	Thickness	Material	Diameter	Conic	Notes
Object	Standard	Infinity	1000000		1471328	0	
1	Standard	Infinity	0.05		2.054093	0	Stop1
Stop	Standard	Infinity	-0.176644		1.8	0	A1
3	EvenAsph	2.024203	0.721	ZEONF52R	1.872	-1	R1
4	EvenAsph	-11.83444	0		1.89	0	R2
5	Standard	Infinity	0.1656548		2.013514	0	Stop 2
6	EvenAsph	-250	0.32	EP5000	1.91	0	R3
7	EvenAsph	2.745619	0.3434152		2.093864	0	R4
8	Standard	Infinity	0.0030239		2.284004	0	Stop 3
9	EvenAsph	2.970147	0.3494011	EP5000	2.456709	0	R5
10	EvenAsph	3.958667	0.1844251		2.735497	0	R6
11	Standard	Infinity	0.3353069		2.904996	0	Stop 4
12	EvenAsph	-4.538803	0.5144013	ZEONF52R	3.007844	0	R7
13	EvenAsph	-1.564577	0.2719004		3.349097	-1	R8
14	Standard	Infinity	0.421506		5.022903	0	Stop 5
15	EvenAsph	-3.333743	0.908	ZEONF52R	5.142131	0	R9
16	EvenAsph	3.980869	0.6500583		6.098372	0	R10
17	Standard	Infinity	0.3		6.850686	0	CG 1908
18	Standard	Infinity	0.1		7.016723	0	
Image	Standard	Infinity			7.009976	0	

Table 23: Surface Data Summary

Surface	Parameter Description	Value
R1	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	0.0072492627
	Coefficient on r 6	-0.0011425636
	Coefficient on r 8	-0.026147557
	Coefficient on r 10	0.02892707
	Coefficient on r 12	-0.015728565
	Coefficient on r 14	0
	Coefficient on r 16	0

R2	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.018496708
	Coefficient on r 6	0.041017657
	Coefficient on r 8	-0.14989043
	Coefficient on r 10	0.18705355
	Coefficient on r 12	-0.081043198
	Coefficient on r 14	0
	Coefficient on r 16	0
R3	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.04452888
	Coefficient on r 6	0.1590456
	Coefficient on r 8	-0.32756888
	Coefficient on r 10	0.38155806
	Coefficient on r 12	-0.15580658
	Coefficient on r 14	0
	Coefficient on r 16	0
R4	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.067461498
	Coefficient on r 6	0.16544449
	Coefficient on r 8	-0.23156178
	Coefficient on r 10	0.20660588
	Coefficient on r 12	-0.067541427
	Coefficient on r 14	0
	Coefficient on r 16	0
R5	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.10351059
	Coefficient on r 6	0.083284677
	Coefficient on r 8	-0.073446626
	Coefficient on r 10	0.031355945
	Coefficient on r 12	-0.005953706
	Coefficient on r 14	0

	Coefficient on r 16	0
R6	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.080839736
	Coefficient on r 6	0.05806703
	Coefficient on r 8	-0.042396061
	Coefficient on r 10	0.013117216
	Coefficient on r 12	-0.001392345
	Coefficient on r 14	0
	Coefficient on r 16	0
R7	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.061283862
	Coefficient on r 6	0.056005953
	Coefficient on r 8	-0.023784572
	Coefficient on r 10	0.004382924
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R8	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	0.005176523
	Coefficient on r 6	0.02067126
	Coefficient on r 8	0.001625502
	Coefficient on r 10	-0.001134584
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R9	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	0.019100544
	Coefficient on r 6	-0.000208483
	Coefficient on r 8	5.84E-05
	Coefficient on r 10	-3.36E-06
	Coefficient on r 12	0

	Coefficient on r 14	0
	Coefficient on r 16	0
R10	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.038366245
	Coefficient on r 6	0.004903112
	Coefficient on r 8	-0.000509017
	Coefficient on r 10	1.88E-05
	Coefficient on r 12	1.99E-07
	Coefficient on r 14	0
	Coefficient on r 16	0

Table 24: Surface Aspheric Coefficients

Surface	Edge
Object	1000000
1	0.05
Stop	0.036971
3	0.45386
4	0.053525
5	0.17191
6	0.53351
7	0.123651
8	0.113652
9	0.301427
10	0.121772
11	0.050401
12	0.30346
13	0.767748
14	0.053483
15	0.953242
16	0.972839
17	0.3
18	0.1
Image	0

Table 25: Edge Thickness Data

Temperature (Temp) in degrees Celsius and pressure (Press) in atmospheres								
Surface	Material	Temp	Press	0.4358	0.4861	0.5461	0.5876	0.6563
0		20	1	1	1	1	1	1
1		20	1	1	1	1	1	1
2		20	1	1	1	1	1	1
3	ZEONF5	20	1	1.5467026	1.54130926	1.53688	1.53462	1.531786

	2R							
4		20	1	1	1	1	1	1
5		20	1	1	1	1	1	1
6	EP5000	20	1	1.67140227	1.65459312	1.641717	1.635484	1.628005
7		20	1	1	1	1	1	1
8		20	1	1	1	1	1	1
9	EP5000	20	1	1.67140227	1.65459312	1.641717	1.635484	1.628005
10		20	1	1	1	1	1	1
11		20	1	1	1	1	1	1
12	ZEONF52R	20	1	1.5467026	1.54130926	1.53688	1.53462	1.531786
13		20	1	1	1	1	1	1
14		20	1	1	1	1	1	1
15	ZEON F52R	20	1	1.5467026	1.54130926	1.53688	1.53462	1.531786
16		20	1	1	1	1	1	1
17	MODEL	20	1	1.52670416	1.52237872	1.518719	1.516798	1.514329
18		20	1	1	1	1	1	1
19		20	1	1	1	1	1	1

Table 26: Index of Refraction Data

		Wavelengths (µm):					
		0.4358		0.4861		0.5461	
Number	Field (mm)	Tan	Sag	Tan	Sag	Tan	Sag
1	0	2.6405	2.6405	2.6425	2.6425	2.6479	2.6479
2	0.339	2.6528	2.6499	2.6546	2.6517	2.6597	2.6568
3	0.678	2.681	2.6772	2.6823	2.6783	2.6871	2.683
4	1.018	2.7091	2.7201	2.7106	2.7201	2.7153	2.7239
5	1.357	2.7373	2.7739	2.7401	2.7726	2.7455	2.7753
6	1.696	2.8006	2.8361	2.8059	2.8335	2.8128	2.8352
7	2.035	2.9489	2.9083	2.9563	2.9045	2.9645	2.9052
8	2.375	3.1818	2.9917	3.1891	2.9868	3.196	2.9866
9	2.714	3.5028	3.0817	3.5075	3.076	3.5109	3.075
10	3.053	4.1133	3.1794	4.1121	3.1732	4.109	3.1717
11	3.392	5.1478	3.3011	5.1473	3.2949	5.1404	3.2931
12	3.492	5.7808	3.3568	5.7754	3.3511	5.7637	3.3495

Table 27: F/Number Data

		Wavelengths (µm)			
		0.5876		0.6563	
Number	Field (mm)	Tan	Sag	Tan	Sag
1	0	2.6519	2.6519	2.6583	2.6583
2	0.339	2.6637	2.6608	2.67	2.6671
3	0.678	2.6909	2.6867	2.697	2.6927
4	1.018	2.719	2.7272	2.7249	2.7327

5	1.357	2.7494	2.7781	2.7555	2.7831
6	1.696	2.8173	2.8375	2.824	2.8417
7	2.035	2.9694	2.907	2.9763	2.9106
8	2.375	3.2	2.9879	3.2054	2.9909
9	2.714	3.5125	3.0759	3.5143	3.0782
10	3.053	4.1067	3.1722	4.1033	3.1741
11	3.392	5.1347	3.2934	5.1255	3.295
12	3.492	5.7553	3.3499	5.7426	3.3515

Table 27A: F/Number Data (Continued)

[00101] Table 19 provides general optical information for an embodiment of optical systems 1800, 1900 of Figures 18 and 19, respectively. Table 20 provides image heights in the y axis, measured at the image sensor 1906 for a set of optical fields, and respective weights for the respective fields. Table 21 includes vignetting data for the set of optical fields of Table 20. Table 22 depicts wavelengths of respective rays traced in optical imaging system 1800, depicted at Figure 18. Table 23 provides a summary of general optical surface characteristics for lenses of optical elements 1902, including surface type, radius of curvature, thickness, material (from standard glass and plastic catalogues; not that a fictitious material is used for cover glass 1908), diameter, conic constant and applicable notes. Table 24 describes aspheric coefficients for the surfaces of Table 23, whereas Table 25 provides edge thickness information for those surfaces. Table 26 provides index of refraction data for multiple wavelengths for the optical fields identified at Table 20. Tables 27 and 27A provide F/# data for those same wavelengths and optical fields.

[00102] Figure 20 depicts a diagram of field curvature and distortion for the optical systems 1800, 1900 of Figures 18 and 19, *supra*. Particularly, the field curvature and distortion depicted in Figure 20 correspond with the optical elements 1902 configured to focus an image of an object at infinity onto sensor 1906. The field curvature and distortion graphs utilize five wavelengths, including 0.436, 0.486, 0.546, 0.588 and 0.656 μm respectively. Moreover, the rays are traced with a maximum field of 35.543 degrees. The left-hand graph depicts field curvature in millimeters along a y axis at an image plane of an optical imaging system. Field curvature curves are depicted for Sagittal rays (delineated by an 'S') and Tangential rays (delineated by a 'T'). The range of field curvature over the utilized wavelengths is within a few microns for sagittal and tangential rays. The distortion graphs on the right-hand side of Figure 20 also includes curves for the above five wavelengths. The distortion data is normalized to 0% at the optical axis. Throughout the image plane, distortion is less than about -1%, and for mid to low field angles below about + / - one half a percent.

[00103] Figure 21 illustrates a diagram of longitudinal aberration for a set of wavelengths. Longitudinal aberration of Figure 21 relates to optical elements 1902, configured to image an object located at infinity onto sensor 1906. The listed wavelengths include 0.436, 0.486, 0.546, 0.588 and 0.656 μm. The graph charts longitudinal aberration in millimeters for increasing field angles, for a pupil radius of 0.9mm. At low field angles the longitudinal aberration is generally positive and less than about 0.02 millimeters. At high field angles, the longitudinal aberration is more negative and generally less than about 0.03 millimeters. The longitudinal aberration graph of Figure 21 indicates optical elements 1902 provide reasonably good aberration correction for the identified wavelengths.

[00104] Figure 22 depicts a graph of lateral color for optical elements 1902 of Figure 19, *supra*. Accordingly, the graph of lateral color relates to optical elements 1902 configured to focus an image of an object located at infinity onto sensor 1906. The maximum field for the lateral color graph is 3.3920 millimeters, and wavelengths for the lateral color graph range from 0.4358 through 0.6563 μm. In addition, data is referenced to 0.546100 μm. For most field angles the lateral color is within about + / - 0.5 microns. At high field angles, lower wavelengths exhibit lateral color about -1 micron or greater, and higher wavelengths exhibit lateral color about 1 micron.

[00105] Figure 23 illustrates a diagram of an example optical system 2300 according to still other aspects of the subject disclosure. Optical system 2300 can comprise a set of optical elements 2302, as depicted. In at least one aspect of the subject disclosure, optical elements 2302 can comprise a set of lenses substantially similar to optical elements 1802 and 1902 of Figures 18 and 19, *supra*, but having a different focus position. Specifically, a subset of optical elements 2302 can be positioned in a manner suitable to focus an image of a near-field object at an image plane of optical elements 2302. As depicted, the near-field object position for optical elements 2302 is 12.8cm. By repositioning the subset of optical elements 2302 between the position depicted by Figure 23 and that of optical elements 1902 of Figure 19, optical system 2300 can focus different object distances between the near-field object and an object at infinity.

[00106] Optical system 2300 illustrates a set of ray fans representing light incident upon optical elements 2302 at discrete field angles. A field angle of zero is depicted by rays of light that converge at an optical axis of optical system 2300 at an image plane of optical elements 2302. Light converging at points on the image plane at increasing distances from the optical axis represent rays of light encountering optical elements 2302 at correspondingly larger field angles.

[00107] Figure 24 depicts a diagram of an example optical system 2400 according to still other aspects of the subject disclosure. Optical system 2400 delineates optical lenses and associated optical surfaces of optical system 2300 of Figure 23. Further, in at least one aspect, the optical lenses and associated optical surfaces of optical system 2300 can be substantially similar to the optical lenses and optical surfaces of optical systems 1800 and 1900 of Figures 18 and 19, *supra*. Optical system 2400 can differ from optical systems 1800 and 1900 in that optical elements 2402 can be configured to focus an image of an object located at substantially 12.8cm at a sensor 2408. Other aspects of optical system 2400 and optical elements 2402, including optical surfaces R1 and R2 of lens L1, R3 and R4 of lens L2, R5 and R6 of lens L3, R7 and R8 of lens L4, and R9 and R10 of lens L5. Further, sensor 2408 and cover glass 2406 can be substantially similar to sensor 1906 and cover glass 1908 of optical system 1900.

[00108] According to a particular aspect of the subject disclosure, optical elements 2402 comprise an object lens, lens L1, which is connected to an actuator (*e.g.*, MEMS actuator, …) to facilitate auto-focusing for optical system 2400. In the arrangement of optical elements 2402 depicted by Figure 24, and in particular an air distance $distance_{near}$ between lens L1 and lens L2, optical elements 2402 are configured to focus a real image of an object at an object distance of 12.8cm onto sensor 2408. By moving lens L1 into a position depicted by optical elements 1902 of Figure 19, where the air distance between lens L1 and lens L2 is a $distance_{far}$, optical system 2400 can be configured to focus an image of an object at infinity, instead. In at least one alternative or additional aspect of the subject disclosure, lens L1 can be repositioned to change the air distance between $distance_{near}$ and $distance_{far}$, thereby focusing an image of an object located at points between 12.8cm and infinity at sensor 2408. Optical elements 2402 can have image characteristics as described by the optical characteristics of Tables 28 – 31A.

Parameter Description	Value

Effective Focal Length (in air at system temperature and pressure)	4.673877
Effective Focal Length (in image space)	4.673877
Back Focal Length	-0.05732965
Total Track Length (TTL)	5.668093
Image Space F/#	2.596598
Paraxial Working F/#	2.747179
Working F/#	2.738746
Image Space NA	0.1790633
Object Space NA	0.007028331
Stop Radius	0.9
Paraxial Image Height	3.492
Paraxial Magnification	-0.03861711
Entrance Pupil Diameter	1.8
Entrance Pupil Position	0.05
Exit Pupil Diameter	1.198642
Exit Pupil Position	-3.269722
Maximum Radial Field	3.492
Lens Units	Millimeters (mm)
Angular Magnification	1.501698

Table 28: General Optical Properties (Object in Focus at ~12.8cm)

Field / #	VDX	VDY	VCX	VCY	VAN
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	-0.00588	0.000003	0.005875	0
8	0	-0.02139	0.000058	0.021397	0
9	0	-0.0355	0.00023	0.035498	0
10	0	-0.06623	0.000798	0.066238	0
11	0	-0.16868	0.006487	0.1687	0
12	0	-0.24396	0.016135	0.243989	0

Table 29: Vignetting Factors for Fields of Table 20

Surface	Type	Radius	Thickness	Material	Diameter	Conic	Notes
Object	Standard	Infinity	128		179.1413	0	
1	Standard	Infinity	0.05		2.060591	0	Stop1
Stop	Standard	Infinity	-0.176644		1.8	0	A1
3	EvenAsph	2.024203	0.721	ZEONF52R	1.872	-1	R1
4	EvenAsph	-11.8344	0.08		1.89	0	R2
5	Standard	Infinity	0.1656548		2.015092	0	Stop 2
6	EvenAsph	-250	0.32	EP5000	1.91	0	R3
7	EvenAsph	2.745619	0.3434152		2.093864	0	R4
8	Standard	Infinity	0.00302399		2.284414	0	Stop 3
9	EvenAsph	2.970147	0.3494011	EP5000	2.456709	0	R5
10	EvenAsph	3.958667	0.1844251		2.735497	0	R6
11	Standard	Infinity	0.3353069		2.905287	0	Stop 4
12	EvenAsph	-4.5388	0.5144013	ZEONF52R	3.007844	0	R7
13	EvenAsph	-1.56458	0.2719004		3.349097	-1	R8
14	Standard	Infinity	0.421506		5.039133	0	Stop 5
15	EvenAsph	-3.33374	0.908	ZEONF52R	5.142131	0	R9
16	EvenAsph	3.980869	0.6500583		6.098372	0	R10
17	Standard	Infinity	0.3		6.852322	0	CG 1908
18	Standard	Infinity	0.1		7.029509	0	
Image	Standard	Infinity			7.027898	0	

Table 30: Surface Data Summary

		Wavelengths (µm):					
		0.4358		0.4861		0.5461	
Number	Field (mm)	Tan	Sag	Tan	Sag	Tan	Sag
1	0	2.7277	2.7277	2.7317	2.7317	2.7387	2.7387
2	0.339	2.7368	2.7372	2.7406	2.741	2.7475	2.7479
3	0.678	2.7568	2.7652	2.7602	2.7683	2.7668	2.7746
4	1.018	2.7759	2.8091	2.7796	2.8111	2.7862	2.8166
5	1.357	2.8003	2.8645	2.8054	2.8651	2.8128	2.8695
6	1.696	2.8707	2.929	2.8781	2.9282	2.8869	2.9315
7	2.035	3.0426	3.0048	3.0514	3.0027	3.0608	3.0049
8	2.375	3.3173	3.0938	3.3236	3.0904	3.33	3.0916
9	2.714	3.7043	3.1909	3.7032	3.1866	3.7021	3.1868
10	3.053	4.4104	3.2987	4.3944	3.2936	4.3798	3.2932
11	3.392	5.6482	3.4392	5.6174	3.4339	5.587	3.4329
12	3.492	6.4939	3.5062	6.4341	3.5014	6.3828	3.5006

Table 31: F/Number Data

		Wavelengths (µm)			
		0.5876		0.6563	
Number	Field (mm)	Tan	Sag	Tan	Sag

1	0	2.7437	2.7437	2.7514	2.7514
2	0.339	2.7524	2.7528	2.7599	2.7603
3	0.678	2.7716	2.7793	2.7789	2.7865
4	1.018	2.7909	2.8208	2.7981	2.8276
5	1.357	2.8177	2.8733	2.8251	2.8794
6	1.696	2.8924	2.9347	2.9003	2.9401
7	2.035	3.0664	3.0075	3.0742	3.0122
8	2.375	3.3337	3.0937	3.339	3.0977
9	2.714	3.7016	3.1884	3.701	3.1917
10	3.053	4.372	3.2943	4.3618	3.2971
11	3.392	5.5698	3.4337	5.5469	3.436
12	3.492	6.3558	3.5014	6.3211	3.5037

Table 31A: F/Number Data (Continued)

[00109] Tables 28 – 31A comprise optical characteristics and image characteristics of optical system 2400 that differ from the configuration of optical system 1900. Table 28 provides general optical information for the embodiment of optical system 2400. Table 29 includes vignetting data for the set of optical fields of Table 20. Table 30 provides a summary of general optical characteristics for lenses of optical elements 2402, including surface type, radius of curvature, thickness, material (from standard glass and plastic catalogues, including a fictitious material for cover glass 2408), diameter, conic constant and applicable notes. Tables 31 and 31A provide F/# data for identified wavelengths and optical fields.

[00110] Figure 25 illustrates a diagram of field curvature and distortion for the optical system 2400 of Figure 24, *supra*. Wavelengths employed for the field curvature and distortion graphs include 0.436, 0.486, 0.546, 0.588 and 0.656 μm. Rays traced to generate these graphs have units in field angle with a maximum field of 34.188 degrees. The field curvature for both tangential and sagittal rays are generally positive and less than about 0.05 mm for all field angles. Distortion is less than about 1% for mid to low field angles, and increases to about 1.6% at high field angles.

[00111] Figure 26 illustrates a diagram of longitudinal aberration for optical system 2400. The longitudinal aberration graph is provided for five wavelengths, including 0.436, 0.486, 0.546, 0.588 and 0.656 μm. The graph charts longitudinal aberration in millimeters for increasing field angles, and with pupil radius of 0.9mm. At low field angles the longitudinal aberration is generally positive and less than about 0.04 millimeters. At higher field angles, the longitudinal aberration ranges positive to negative for different field angles, and is generally between positive 0.03 millimeters and about negative 0.035 millimeters.

[00112] Figure 27 depicts a graph of lateral color for optical elements 2402 of Figure 24, *supra*. The graph of lateral color relates to optical elements 2402 configured to focus an image of an object located at about 12.8cm onto sensor 2406. The maximum field for the lateral color graph is 3.3920 millimeters, and wavelengths employed for the graph range from 0.4358 through 0.6563_µm. In addition, data is referenced to 0.546100 µm. For all field angles the lateral color is less than about +3 microns and greater than about -1 microns. At low and mid field angles, the lateral color ranges between about +1 micron and about -0.25 microns.

[00113] Figures 28A – 28D illustrate an example optical system according to one or more additional aspects of the subject disclosure. The optical system is depicted at Figure 28A on the upper left in a configuration to focus an image of an object at infinity onto a sensor of the optical system. Figures 29A – 29D illustrate the example optical system in a configuration to focus an image of a near-field object onto the sensor of the optical system. The latter configuration can be achieved, for instance, by decreasing an air distance between the first left-most lens closest to the object side of the optical system, closer to the second lens on the object side of the optical system.

[00114] Generally, the optical system comprises five lenses, from an object side to image side, including lens L1 (also referred to as an objective lens), lens L2, lens L3, lens L4 and lens L5 (referred to collectively as lenses L1 – L5). Moreover, the optical system of Figures 28A – 28D can comprise two or more lens groups, defined at least in part on an on-axis inter-lens air distance between respective lenses of the two or more lens groups. As an example, the five lenses of the optical system can be arranged into two lens groups, a first of the lens groups comprising a first lens, second lens and third lens from the object side of the optical system, and where the second of the lens groups comprising a fourth lens and fifth lens from the object side of the optical system. The lens groups can be constrained to have on-axis air distances between lenses that is smaller than an on-axis air distance between the first and the second lens groups.

[00115] Figures 28B – 28D illustrate image characteristics for the optical system of Figure 28A configured to focus an image of an object at infinity on a sensor of the optical system (far field focus configuration). Figures 29B – 29D illustrate image characteristics for the optical system of Figure 29A configured to focus a near-field object on the sensor (near field focus configuration). Figure 28B depicts a graph of field curvature and distortion for the far field focus configuration, with a maximum field greater than about 32 degrees for wavelengths between about 0.47 and about 0.65

microns. Figure 28C illustrates a graph of longitudinal aberration for the far field configuration at the above wavelengths, and for a pupil radius of about 0.991mm, and Figure 28D depicts a graph of lateral color for this configuration having a maximum field of about 2.956 millimeters having data referenced to wavelength of about 0.555 microns.

[00116] Figure 29B illustrates field curvature and distortion for the near field configuration of the optical system, depicted at Figure 29A. The field curvature and distortion has a maximum field of about 34.51 degrees for wavelengths between about 0.470 and about 0.650 microns. Figure 29C depicts longitudinal aberration for the near field configuration with pupil radius of about 0.991 millimeters and wavelengths of about 0.470, 0.510, 0.555, 0.610 and 0.650 microns. Figure 29D illustrates a graph of lateral color for the near field configuration, with a maximum field of about 2.9560 millimeters and with data referenced to wavelength of 0.555 microns. The optical system of Figures 28A and 29A are described by the optical and image characteristics provided by Tables 32 – 40A, below.

Parameter Description	Value
Effective Focal Length (in air at system temperature and pressure)	4.309199
Effective Focal Length (in image space)	4.309199
Back Focal Length	0.528864
Total Track Length (TTL)	5.348668
Image Space F/#	2.44563
Paraxial Working F/#	2.44563
Working F/#	2.468005
Image Space NA	0.200303
Object Space NA	8.81E-11
Stop Radius	0.881
Paraxial Image Height	2.956
Paraxial Magnification	0
Entrance Pupil Diameter	1.762
Entrance Pupil Position	0
Exit Pupil Diameter	1.257817
Exit Pupil Position	-3.09729

Maximum Radial Field	2.956
Lens Units	Millimeters (mm)
Angular Magnification	1.400838

Table 32: General Optical Properties (Object in Focus at Infinity)

Field #	X-Value	Y-Value	Weight
1	0	0	1
2	0	0.571	1
3	0	1.142	1
4	0	1.714	1
5	0	2.285	1
6	0	2.57	1
7	0	2.856	0.2
8	0	2.956	0.2

Table 33: Field Type v. Real Image Height (in mm)

Field / #	VDX	VDY	VCX	VCY	VAN
1	0	0	0	0	0
2	0	0.003903	0.00001	0.003903	0
3	0	0.007781	0.000035	0.007783	0
4	0	0.01172	0.000106	0.011721	0
5	0	-0.00257	0.000337	0.034007	0
6	0	-0.04564	0.001626	0.08102	0
7	0	-0.09687	0.005447	0.136263	0
8	0	-0.14243	0.009529	0.183383	0

Table 34: Vignetting Factors for Fields of Table 20

Wavelength #	Value (in µm)	Weight
1	0.47	91
2	0.51	503
3	0.555	1000
4	0.61	503
5	0.65	107

Table 35: Wavelengths Used for Raytracing

Surface	Type	Radius	Thickness	Material	Diameter	Conic	Notes
Object	Standard	Infinity	Infinity		0	0	
Stop	Standard	Infinity	-0.05		1.762	0	Stop
2	Standard	Infinity	-0.05		1.762	0	Vig
3	EvenAsph	1.954112	0.658876	APEL5514ML	1.86811	0	L1
4	EvenAsph	-16.4984	0.123812		1.900083	0	
5	EvenAsph	28.78283	0.537232	EP5000-F	1.936491	0	L2
6	EvenAsph	2.7513	0.242475		2.00919	0	
7	Standard	Infinity	0.05		2.05	0	
8	Standard	Infinity	0.086016		2.05	0	
9	EvenAsph	-34.5053	0.862679	APEL5514ML	2.120461	0	L3
10	EvenAsph	-6.19216	0.424308		2.716502	0	
11	EvenAsph	2.722564	0.509104	APEL5514ML	3.355454	0	L4
12	EvenAsph	-4.26721	-0.19		4.009626	0	
13	Standard	Infinity	0.05		4.16	0	
14	Standard	Infinity	0.389066		4.16	0	
15	EvenAsph	-2.51369	0.426101	APEL5514ML	4.449728	0	L5
16	EvenAsph	2.608397	0.329		4.878517	0	
17	Standard	Infinity	0.3	N-BK7	5.233205	0	CG 1908
18	Standard	Infinity	0.55		5.402932	0	
Image	Standard	Infinity			5.917565	0	

Table 36: Surface Data Summary

Surface	Parameter Description	Value
R1	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.00386
	Coefficient on r 6	0.009055
	Coefficient on r 8	-0.01604
	Coefficient on r 10	0.006453
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R2	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	0.014879
	Coefficient on r 6	-0.02489
	Coefficient on r 8	0.011334
	Coefficient on r 10	0.003758
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0

R3	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	0.001774
	Coefficient on r 6	-0.03857
	Coefficient on r 8	0.035738
	Coefficient on r 10	-0.00277
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R4	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.00027
	Coefficient on r 6	0.001123
	Coefficient on r 8	0.000761
	Coefficient on r 10	0.006183
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R5	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.04891
	Coefficient on r 6	0.029453
	Coefficient on r 8	-0.01911
	Coefficient on r 10	0.004124
	Coefficient on r 12	0
	Coefficient on r 14	0
	Coefficient on r 16	0
R6	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.13503
	Coefficient on r 6	0.048368
	Coefficient on r 8	0.001742
	Coefficient on r 10	-0.00582
	Coefficient on r 12	0.00078
	Coefficient on r 14	5.79E-05

	Coefficient on r 16	0.000106
R7	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.1187
	Coefficient on r 6	0.031933
	Coefficient on r 8	-0.0214
	Coefficient on r 10	0.008804
	Coefficient on r 12	-0.0012
	Coefficient on r 14	-0.00074
	Coefficient on r 16	0.000216
R8	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	0.070788
	Coefficient on r 6	-0.01663
	Coefficient on r 8	-0.00017
	Coefficient on r 10	-0.00047
	Coefficient on r 12	0.000282
	Coefficient on r 14	-1.50E-05
	Coefficient on r 16	-2.54E-06
R9	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	0.019234
	Coefficient on r 6	0.011958
	Coefficient on r 8	-0.00178
	Coefficient on r 10	1.79E-05
	Coefficient on r 12	5.79E-06
	Coefficient on r 14	9.92E-07
	Coefficient on r 16	4.90E-08
R10	Even Asphere	
	Coefficient on r 2	0
	Coefficient on r 4	-0.10214
	Coefficient on r 6	0.027793
	Coefficient on r 8	-0.0071
	Coefficient on r 10	0.000868
	Coefficient on r 12	1.66E-05

	Coefficient on r 14	-1.31E-05
	Coefficient on r 16	7.35E-07

Table 37: Surface Aspheric Coefficients

Surface	Edge
Stop	-0.05
2	0.184732
3	0.400359
4	0.15927
5	0.723662
6	0.044372
7	0.05
8	0.026648
9	0.560283
10	0.571295
11	0.51101
12	0.022871
13	0.05
14	0.126282
15	0.613075
16	0.40481
17	0.3
18	0.55
Image	0

Table 38: Edge Thickness Data

Temperature (Temp) in degrees Celsius and pressure (Press) in atmospheres								
Surface	Material	Temp	Press	0.4358	0.4861	0.5461	0.5876	0.6563
0		20	1	1	1	1	1	1
1		20	1	1	1	1	1	1
2		20	1	1	1	1	1	1
3	APEL5514ML	20	1	1.552896	1.549574	1.546504	1.543579	1.541977
4		20	1	1	1	1	1	1
5	EP5000-F	20	1	1.657924	1.647547	1.638966	1.631351	1.627143
6		20	1	1	1	1	1	1
7		20	1	1	1	1	1	1
8		20	1	1	1	1	1	1
9	APEL5514ML	20	1	1.552896	1.549574	1.546504	1.543579	1.541977
10		20	1	1	1	1	1	1
11	APEL5514ML	20	1	1.552896	1.549574	1.546504	1.543579	1.541977
12		20	1	1	1	1	1	1
13		20	1	1	1	1	1	1
14		20	1	1	1	1	1	1

15	APEL 5514 ML	20	1	1.552896	1.549574	1.546504	1.543579	1.541977
16		20	1	1	1	1	1	1
17	N-BK7	20	1	1.523605	1.520769	1.518274	1.515909	1.51452
18		20	1	1	1	1	1	1
19		20	1	1	1	1	1	1

Table 39: Index of Refraction Data

		Wavelengths (μm):					
		0.4358		0.4861		0.5461	
Number	Field (mm)	Tan	Sag	Tan	Sag	Tan	Sag
1	0	2.4671	2.4671	2.4655	2.4655	2.468	2.468
2	0.571	2.5183	2.4954	2.516	2.4934	2.5179	2.4954
3	1.142	2.5939	2.5672	2.5915	2.564	2.5931	2.5651
4	1.714	2.7124	2.6738	2.7134	2.6698	2.717	2.6702
5	2.285	3.1321	2.8097	3.1364	2.8053	3.1424	2.8052
6	2.57	3.6079	2.8988	3.613	2.8941	3.6195	2.8939
7	2.856	3.8132	3.003	3.8209	2.9987	3.8222	2.9987
8	2.956	4.0285	3.0378	4.0284	3.0345	4.0233	3.0351

Table 40: F/Number Data

		Wavelengths (μm)			
		0.5876		0.6563	
Number	Field (mm)	Tan	Sag	Tan	Sag
1	0	2.4725	2.4725	2.4748	2.4748
2	0.571	2.522	2.4996	2.524	2.5017
3	1.142	2.5966	2.5685	2.5984	2.5702
4	1.714	2.7219	2.6729	2.7244	2.6742
5	2.285	3.1492	2.8075	3.1529	2.8085
6	2.57	3.6267	2.896	3.6307	2.8969
7	2.856	3.8203	3.0009	3.8197	3.0019
8	2.956	4.0151	3.0376	4.0105	3.0389

Table 40A: F/Number Data (Continued)

[00117] Tables 32 – 40A provides optical and image characteristics for the optical system of Figure 28A, having a far field focus configuration. Table 32 provides general optical information for this optical system. Table 33 provides image heights in the y axis, measured at an image sensor of the optical system, for a set of optical fields and respective weights for the respective optical fields. Table 34 includes vignetting data for the set of optical fields of Table 33. Table 35 depicts wavelengths of respective rays traced in the optical imaging system of Figure 28. Table 36 provides a summary of general optical surface characteristics for lenses of this optical system, including surface type, radius of curvature, thickness, material (from standard glass and plastic catalogues), diameter, conic constant and applicable notes. Table 37 describes aspheric coefficients for the surfaces of Table 35, whereas Table 38 provides edge thickness information for those surfaces. Table 39 provides index of refraction data for multiple wavelengths and listed optical fields. Tables 40 and 40A provide F/# data for those same wavelengths and optical fields.

[00118] As utilized herein, the word “exemplary” is intended to mean serving as an example, instance, or illustration. Any aspect or design described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects or designs. Rather, use of the word exemplary is intended to present concepts in a concrete fashion. As used in this application, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or”. That is, unless specified otherwise, or clear from context, “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then “X employs A or B” is satisfied under any of the foregoing instances. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless specified otherwise or clear from context to be directed to a singular form.

[00119] Furthermore, various portions of electronic systems associated with disclosed optical systems described herein may include or consist of artificial intelligence or knowledge or rule based components, sub-components, processes, means, methodologies, or mechanisms (*e.g.*, support vector machines, neural networks, expert systems, Bayesian belief networks, fuzzy logic, data fusion engines, classifiers…). Such components, *inter alia*, and in addition to that already described herein, can automate certain mechanisms or processes performed thereby to make portions of the systems and methods more adaptive as well as efficient and intelligent. For instance, such components can automate optimization of image quality of an optical system, as described above (*e.g.*, see electronic device 500 of Figure 5, *supra*).

[00120] What has been described above includes examples of aspects of the claimed subject matter. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing the claimed subject matter, but one of ordinary skill in the art can recognize that many further combinations and permutations of the disclosed subject matter are possible. Accordingly, the disclosed subject matter is intended to embrace all such alterations, modifications and variations that fall within the spirit and scope of the appended claims. Furthermore, to the extent that the terms “includes,” “has” or “having” are used in either the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term “comprising” as “comprising” is interpreted when employed as a transitional word in a claim.

CLAIMS

What is Claimed is:

1. An optical imaging system arranged along an optical axis, comprising:

a set of optical lenses including a first lens group and a second lens group, wherein the second lens group is fixed in position along the optical axis;

a micro electromechanical system (MEMS) actuator mechanically connected to the first lens group and configured to adjust a position of the first lens group along the optical axis, wherein a first adjusted position is configured to focus an image of an object positioned far from the optical imaging system onto an image plane associated with the optical imaging system, and wherein a second adjusted position is configured to focus an image of an object positioned near to the optical imaging system onto the image plane;

wherein:

the set of optical lenses comprising five lenses;

the MEMS actuator is configured to adjust a position of the first lens group along the optical axis up to between 50 and 150 micrometers;

the first optical lens group comprising a biconvex object-side lens; and

a ratio of the focal length of the biconvex object-side lens to a combined focal length of the five lenses is greater than one half.

2. The optical imaging system of claim 1, further comprising an aperture stop positioned at an object-side of the biconvex object-side lens.

3. The optical imaging system of claim 2, wherein the aperture stop is fixed in position along the optical axis.

4. The optical imaging system of claim 2, wherein the aperture stop is fixed in position relative to the first lens group.

5. The optical imaging system of claim 4, wherein the MEMS actuator is configured to reposition the first lens group and the aperture stop along the optical axis and maintain the fixed position between the aperture stop and the first lens group at least at the first adjusted position and at the second adjusted position.

6. The optical imaging system of claim 1, the second lens group comprising four lens elements, including a second lens, a third lens, a fourth lens and a fifth lens.

7. The optical imaging system of claim 6, the second lens having a concave image-side surface and a flat or a weak convex curvature on an object-side surface.

8. The optical imaging system of claim 7, the second lens having a negative optical power, and formed of an OKP4HT plastic.

9. The optical imaging system of claim 6, the third lens having a concave object-side surface and a convex image-side surface, a positive optical power, and formed of an APEL5514ML glass.

10. The optical imaging system of claim 6, the fourth lens having an object-side surface that is convex near the optical axis and transitions to concave away from the optical axis, and an image-side surface having convex curvature.

11. The optical imaging system of claim 10, the fourth lens having positive optical power near the optical axis, and having small negative optical power, small positive optical power, or no optical power away from the optical axis, and the fourth lens is formed of an APEL5514ML plastic.

12. The optical imaging system of claim 6, the fifth lens having an object-side surface that is concave near the optical axis and that transitions to convex away from the optical axis, and an image-side surface that is concave near the optical axis and transitions to convex away from the optical axis.

13. The optical imaging system of claim 12, the fifth lens having large negative optical power near the optical axis, and positive optical power away from the optical axis, and the fifth lens is formed of an APEL5514ML plastic.

14. The optical imaging system of claim 1, the biconvex object-side lens is formed of an APEL5514ML plastic.

15. The optical imaging system of claim 1, wherein an optical power of the biconvex object-side lens is at least in part a function of a distance along the optical axis between the first adjusted position and the second adjusted position.

16. The optical imaging system of claim 1, wherein the ratio of the focal length of the biconvex object-side lens to a combined focal length of the five lenses is about three quarters.

17. The optical imaging system of claim 1, wherein the ratio of the optical power of the biconvex object-side lens to a combined optical power of the five lenses is at least in part a function of a distance along the optical axis between the first adjusted position and the second adjusted position.

18. The optical imaging system of claim 1, wherein the object positioned far from the optical system is positioned substantially at infinity, and wherein the object positioned near to the optical system is positioned at substantially 10cm from an aperture stop of the optical imaging system.

19. An optical system comprising:

a plurality of optical elements arranged along a common optical axis for forming a real image of an object, said optical elements including:

a first lens having a positive refractive power, with both surfaces, one facing an object side and another facing an image side, having convex shape;

a second lens having negative refractive power and a meniscus shape, with the surface facing the object side having a convex shape and the surface facing the image side having a concave shape;

a third lens having positive refractive power, and a biconvex shape near the optical axis, and the surface facing the object side is concave away from the optical axis;

a fourth lens, with the surface facing the object side having a concave shape, and the surface facing the image side having a convex shape; and

a fifth lens having a meniscus shape with the surface facing the object side having a convex shape and the surface facing the image side having a concave shape near the optical axis and a convex shape away from the optical axis; and

an actuator configured to move the first lens along the optical axis.

20. The optical system of claim 19, wherein the motor is a microelectromechanical system.

21. The optical system of claim 19, wherein the second lens performs a majority of chromatic correction for the optical system.

22. The optical system of claim 19, further comprising an aperture that is embedded into the first lens and moves with the first lens, wherein the aperture having a depth of 50μm.

23. The optical system of claim 19, wherein the F-number of the optical system is approximately 2.4.

24. The optical system of claim 19, wherein one or more of the lenses are made of plastic.

25. The optical system of claim 19, wherein the surfaces of the lenses are aspheric.

26. The optical system of claim 19, wherein the refractive index of the lenses is within a range of about 1.5 to about 1.66.

27. The optical system of claim 19, wherein the range of movement for the first lens is between about 0μm and about 100μm.

28. The optical system of claim 19, wherein an amount of movement to focus an image of an object is inversely proportional to the positive refractive power of the first lens.

29. The optical system of claim 19, wherein the primary lateral color range for the optical system focused on an object at infinity is equal to or less than approximately 1μm.

30. The optical system of claim 19, wherein the primary lateral color range for the optical system focused on an object at 10cm is equal to or less than approximately 4μm.

31. An optical imaging system arranged along an optical axis, comprising:

a set of optical lenses including a first lens group and a second lens group, wherein the second lens group is fixed in position along the optical axis and comprises a majority of the optical lenses of the set of optical lenses; and

an actuator mechanically connected to the first lens group and configured to adjust a position of the first lens group along the optical axis, wherein a first adjusted position is configured to focus an image of an object positioned far from the optical imaging system onto an image plane associated with the optical imaging system, and wherein a second adjusted position is configured to focus an image of an object positioned near to the optical imaging system onto the image plane;

wherein:

the set of optical lenses comprising five lenses;

the actuator is configured to adjust a position of the first lens group along the optical axis up to between 50 and 150 micrometers;

the second optical lens group comprising a third lens of the set of optical lenses that is third in sequence from an object side of the set of optical lenses, the third lens having a meniscus shape that is convex toward the object side of the set of optical lenses.

32. The optical imaging system of claim 31, wherein the actuator comprises a micro electromechanical system (MEMS) actuator.

33. The optical imaging system of claim 31, the first optical lens group comprising a biconvex objective lens that provides a majority of the positive optical power of the set of optical lenses.

34. The optical imaging system of claim 33, wherein the biconvex objective lens has greater positive refractive power than a combined refractive power of the set of optical lenses.

35. The optical imaging system of claim 31, wherein an effective focal length of the set of optical lenses is between about 4.5 and about 5.0 millimeters.

36. The optical imaging system of claim 31, wherein a ratio of total track length to effective focal length of the optical system is between about 1.1 and about 1.2.

37. The optical imaging system of claim 31, wherein the first lens group comprises a single lens of the set of optical lenses.

38. The optical imaging system of claim 37, wherein the single lens is an objective lens of the optical system.

39. The optical imaging system of claim 37, wherein the second adjusted position focuses an image of an object at an object distance of about 12.8 centimeters onto the image plane.

40. The optical imaging system of claim 31, wherein an air distance between a third lens and a fourth lens of the set of optical lenses, numbered from an object side of the set of optical lenses, is a largest of air distances between respective ones of the set of optical lenses.

41. The optical imaging system of claim 31, wherein an air distance between a fourth lens and a fifth lens of the set of optical lenses, numbered from an object side of the set of optical lenses, is a largest of air distances between respective ones of the set of optical lenses.

42. The optical imaging system of claim 31, further comprising an aperture stop about an object side surface of a first lens of the set of optical lenses, numbered from an object side of the set of optical lenses.

43. The optical imaging system of claim 42, further comprising a stop between a second and third lens of the set of optical lenses, numbered from an object side of the set of optical lenses.

44. The optical imaging system of claim 43, further comprising a second stop between the third lens and a fourth lens of the set of optical lenses.

45. The optical imaging system of claim 44, further comprising a third stop between the fourth lens and a fifth lens of the set of optical lenses.

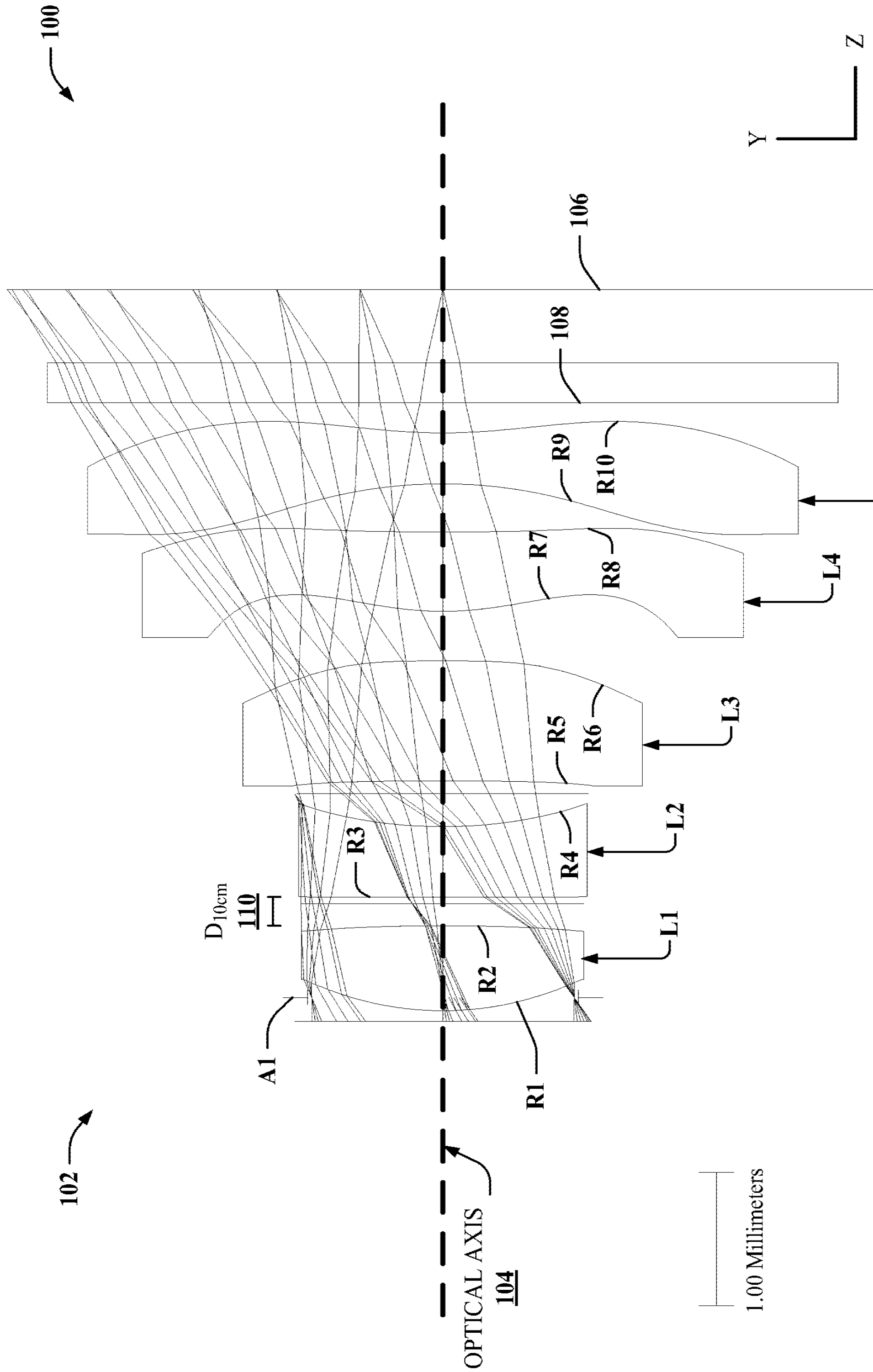


FIG. 1

OPTICAL LAYOUT; OBJECT FOCUSED AT 10CM

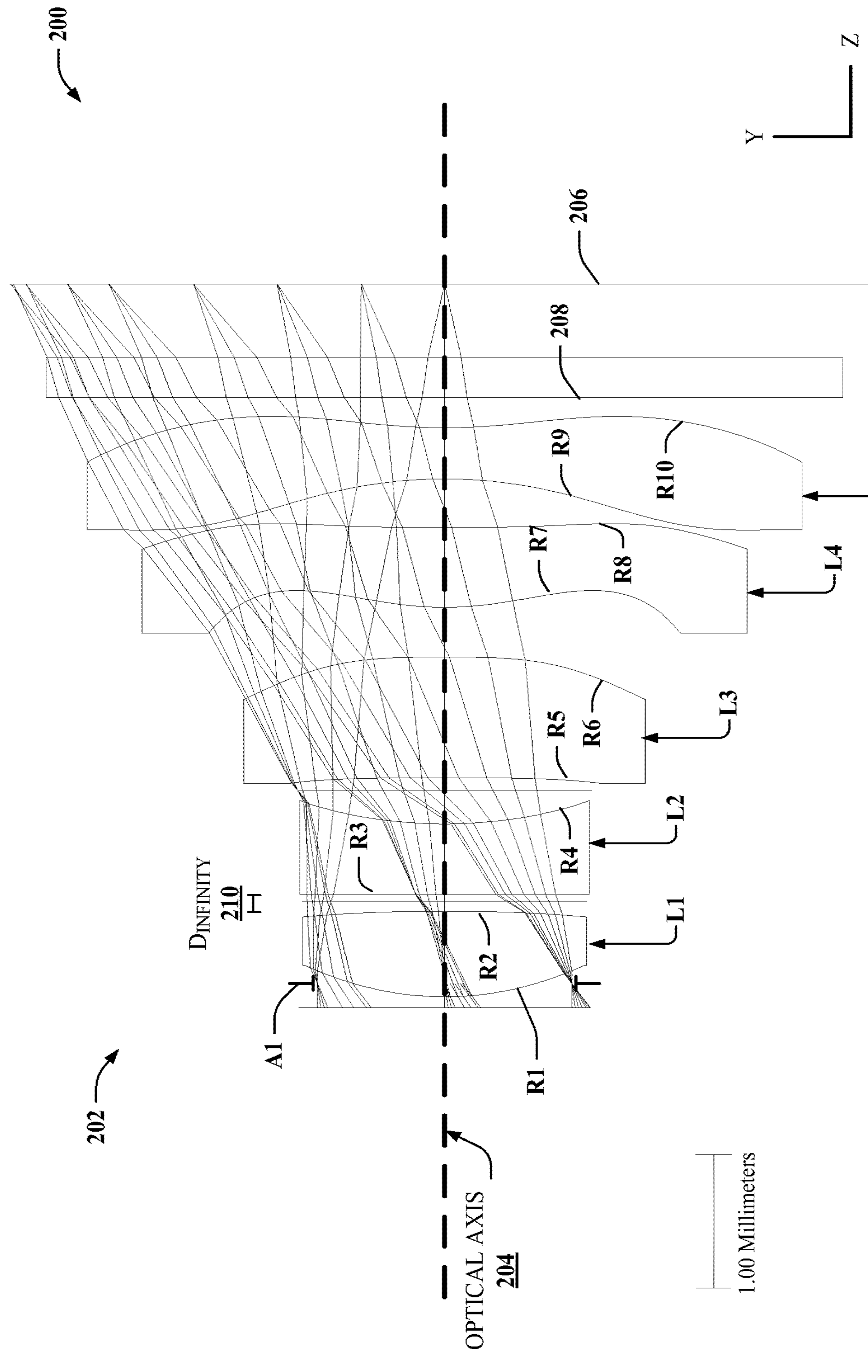


FIG. 2

OPTICAL LAYOUT; OBJECT FOCUSED AT INFINITY

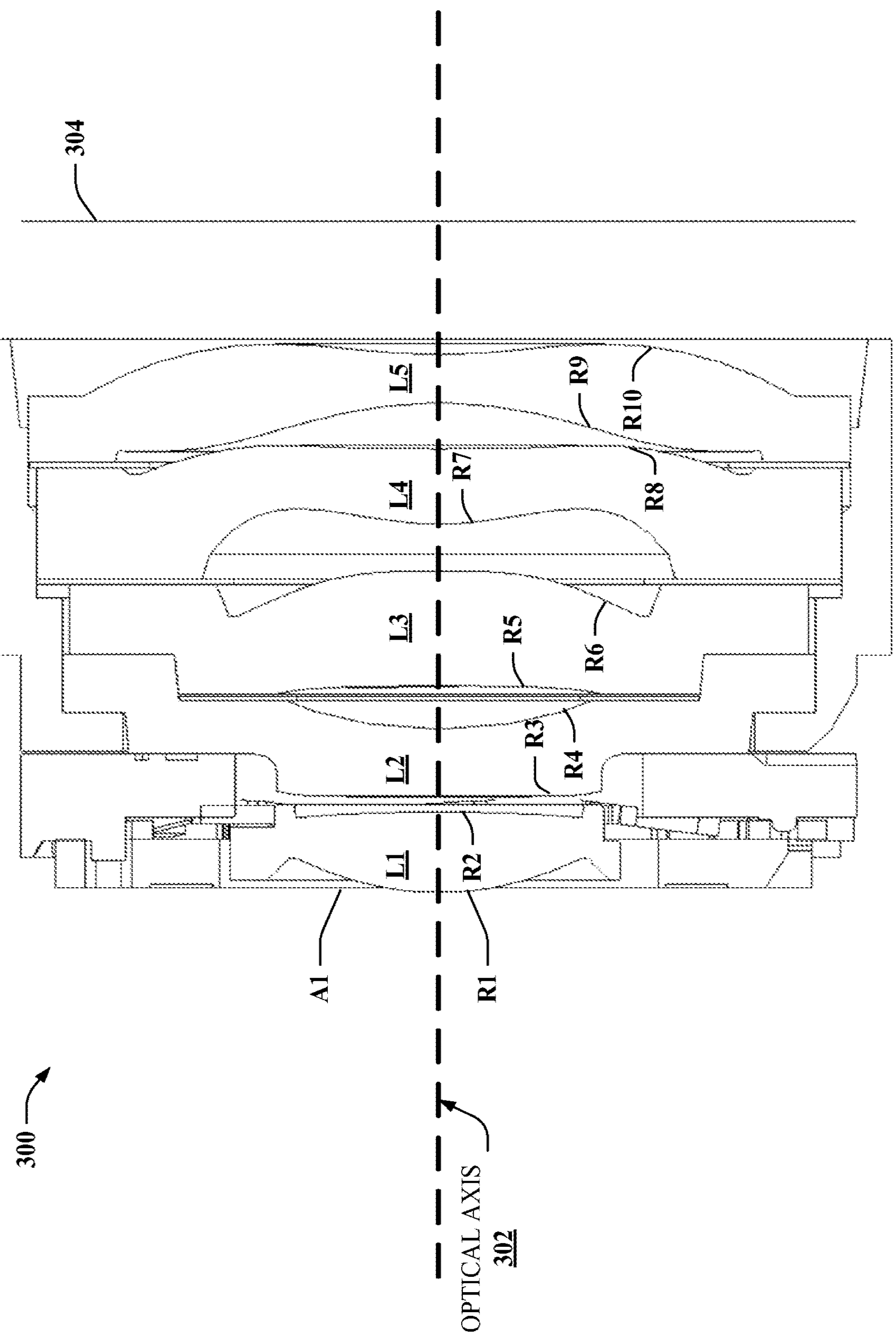

304
L5
R9
R10
R7
R8
L4
L3
R5
R6
R3
R4
L2
L1
R2
A1
R1
300
OPTICAL AXIS
302

FIG. 3

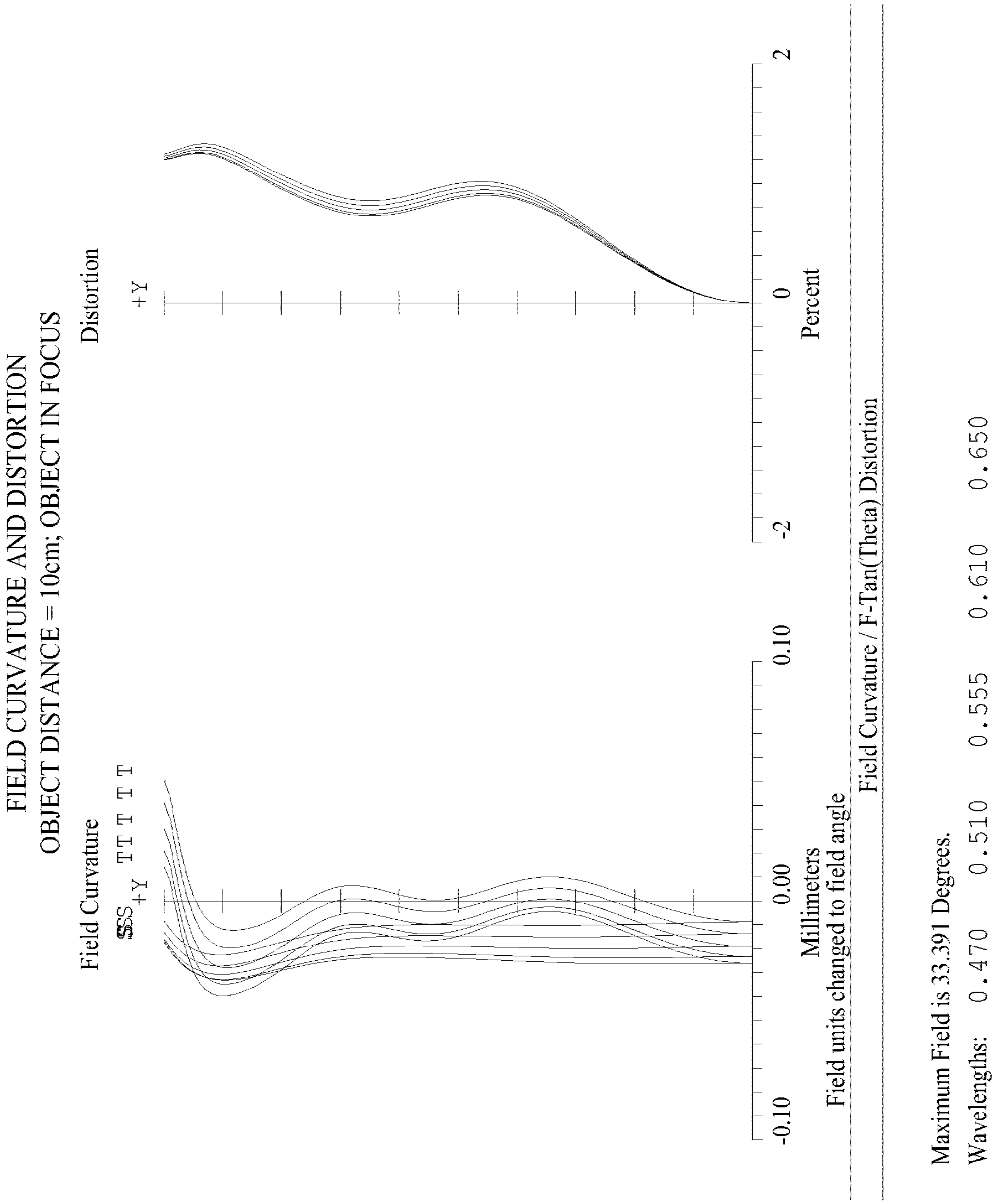

FIELD CURVATURE AND DISTORTION
OBJECT DISTANCE = 10cm; OBJECT IN FOCUS
Field Curvature
Distortion
S S S
T T T T T
+Y
+Y
-0.10
0.00
0.10
Millimeters
Field units changed to field angle
-2
0
2
Percent
Field Curvature / F-Tan(Theta) Distortion
Maximum Field is 33.391 Degrees.
Wavelengths: 0.470 0.510 0.555 0.610 0.650

FIG. 4

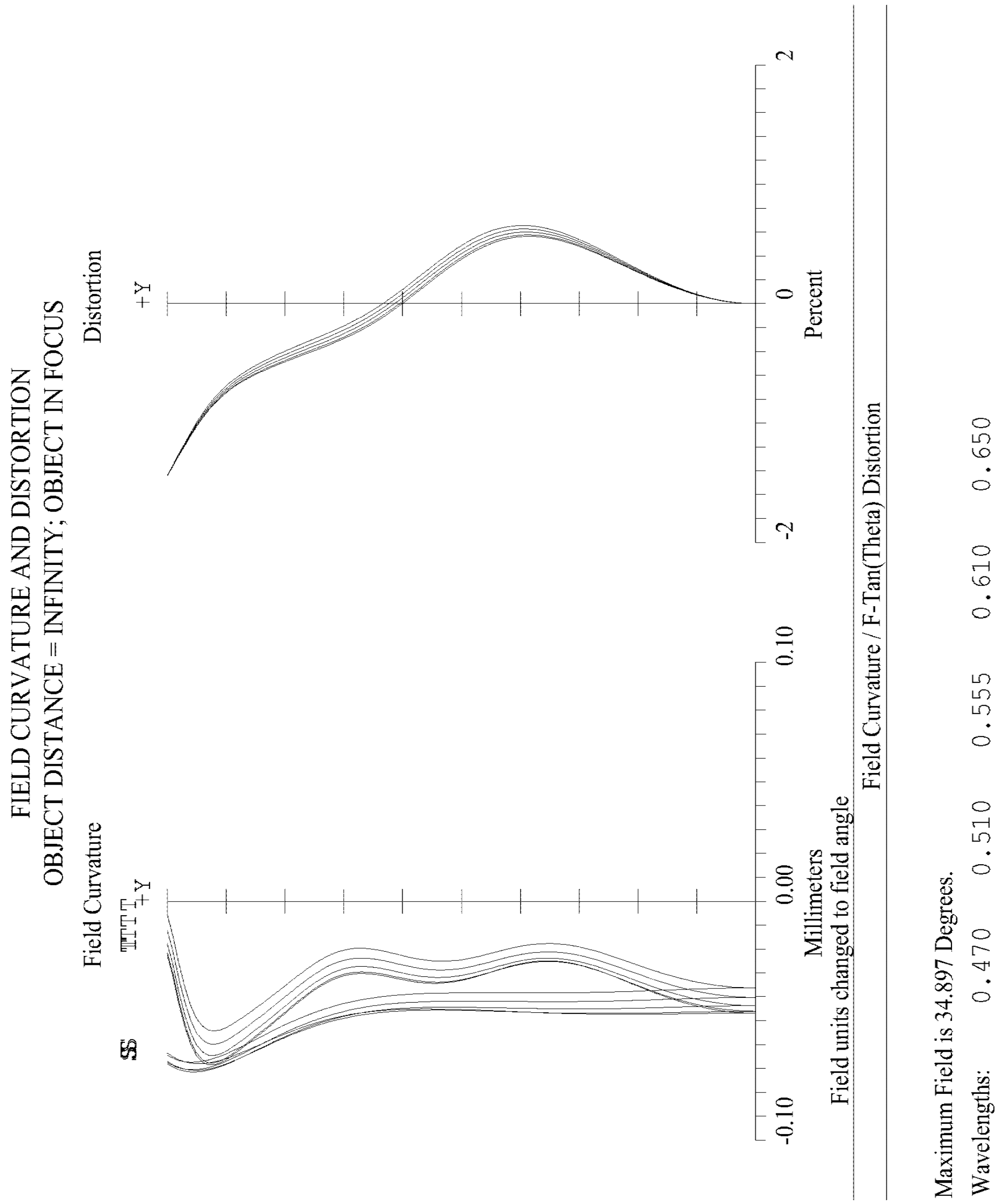

FIELD CURVATURE AND DISTORTION
OBJECT DISTANCE = INFINITY; OBJECT IN FOCUS
Field Curvature
Distortion
+Y
+Y
-0.10
0.00
0.10
Millimeters
Field units changed to field angle
-2
0
2
Percent
Field Curvature / F-Tan(Theta) Distortion
Maximum Field is 34.897 Degrees.
Wavelengths: 0.470 0.510 0.555 0.610 0.650

FIG. 5

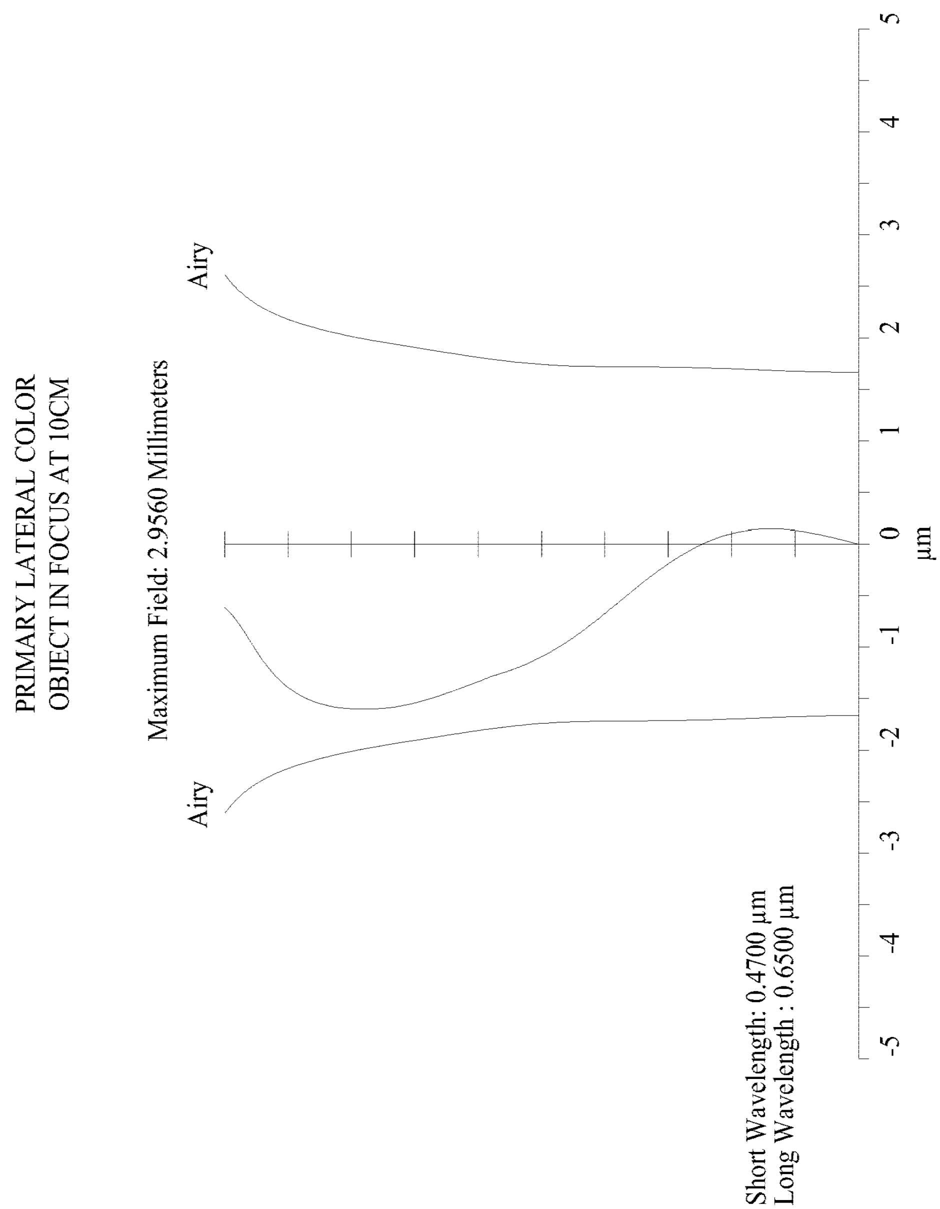

PRIMARY LATERAL COLOR
OBJECT IN FOCUS AT 10CM
Maximum Field: 2.9560 Millimeters
Airy
Airy
Short Wavelength: 0.4700 µm
Long Wavelength : 0.6500 µm
5
4
3
2
1
0
-1
-2
-3
-4
-5
µm

FIG. 6

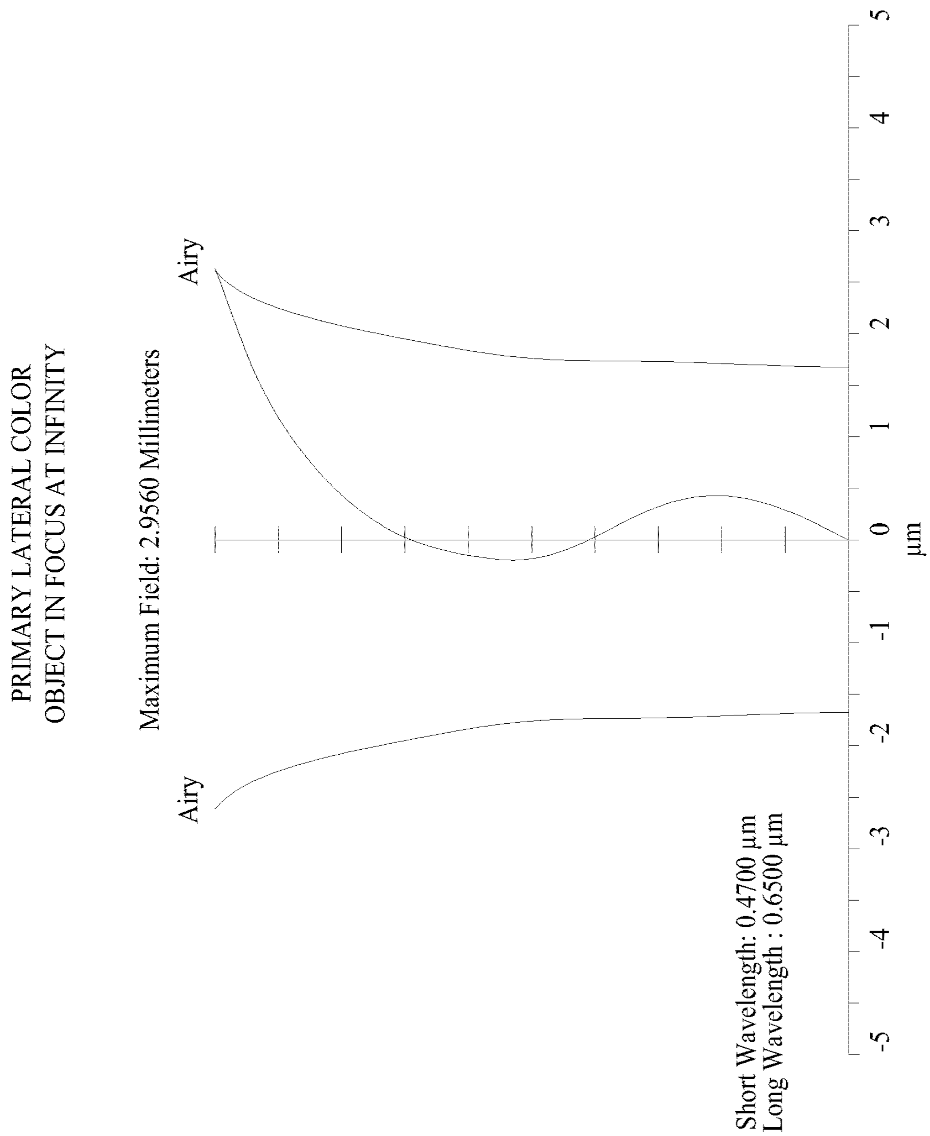

PRIMARY LATERAL COLOR
OBJECT IN FOCUS AT INFINITY
Maximum Field: 2.9560 Millimeters
Airy
Airy
Short Wavelength: 0.4700 µm
Long Wavelength : 0.6500 µm
-5
-4
-3
-2
-1
0
1
2
3
4
5
µm

FIG. 7

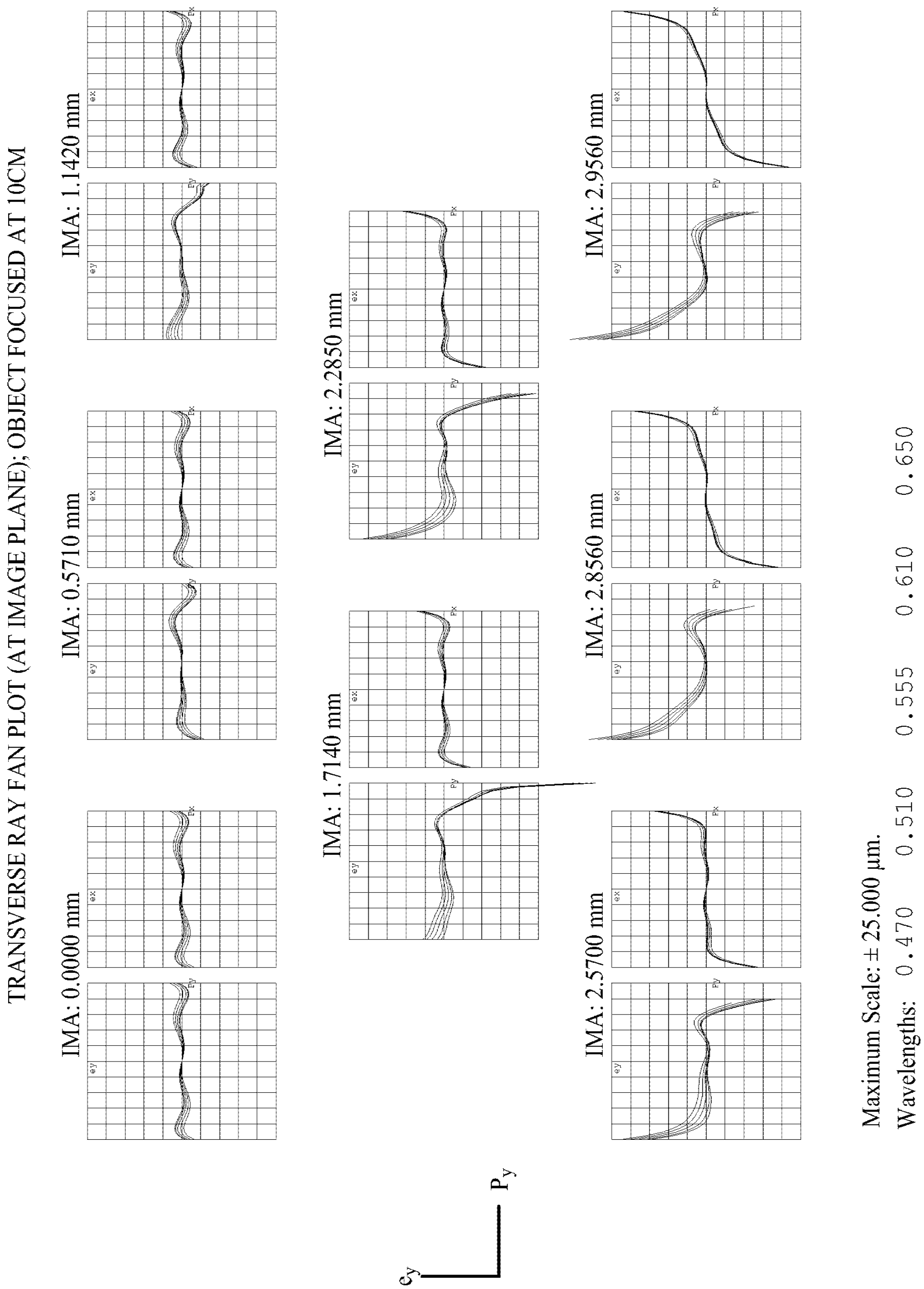

TRANSVERSE RAY FAN PLOT (AT IMAGE PLANE); OBJECT FOCUSED AT 10CM
IMA: 0.0000 mm
IMA: 0.5710 mm
IMA: 1.1420 mm
IMA: 1.7140 mm
IMA: 2.2850 mm
IMA: 2.5700 mm
IMA: 2.8560 mm
IMA: 2.9560 mm
ey
ex
Py
Px
Maximum Scale: ± 25.000 µm.
Wavelengths: 0.470 0.510 0.555 0.610 0.650
e_y
P_y

FIG. 8

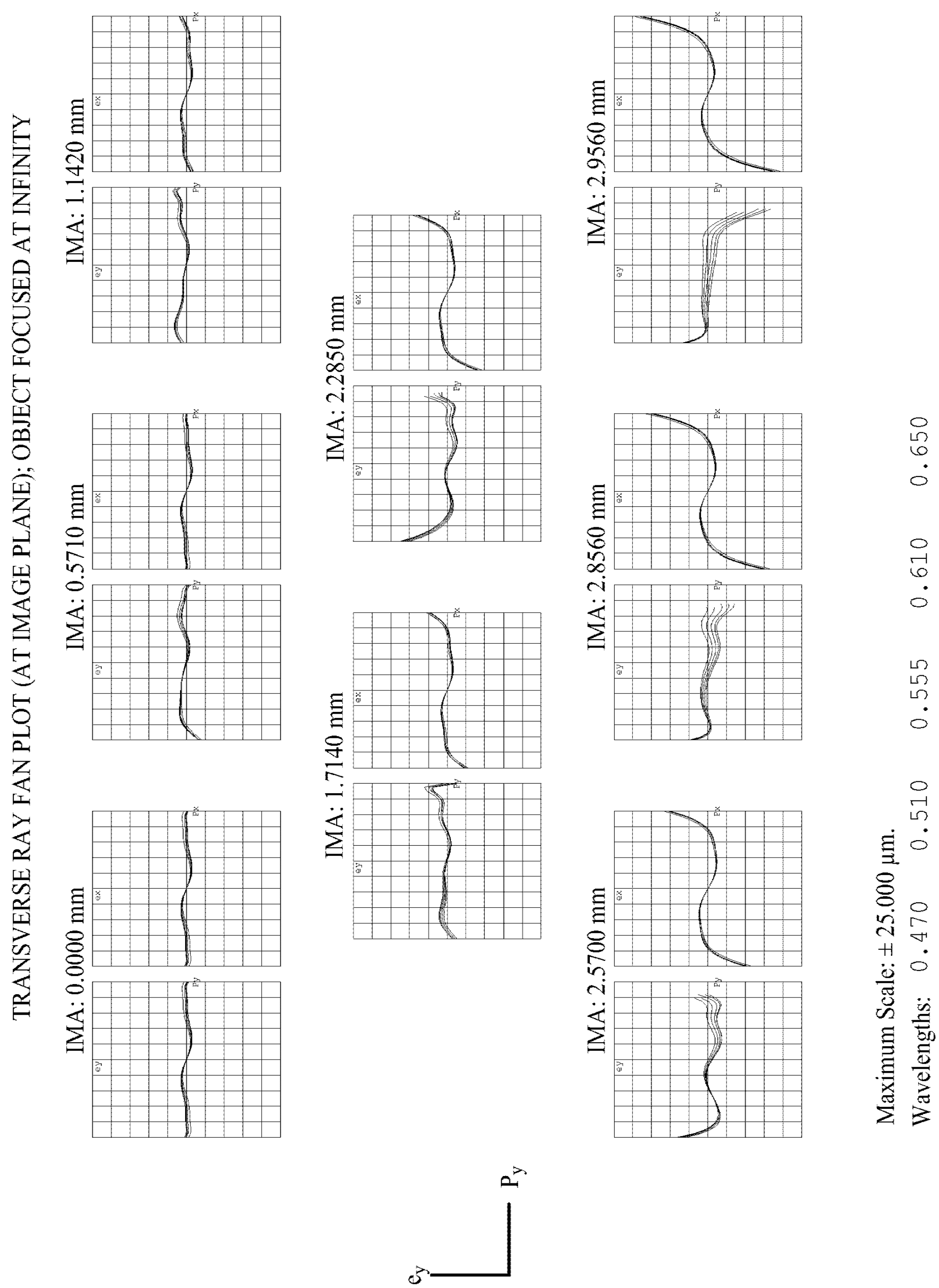

TRANSVERSE RAY FAN PLOT (AT IMAGE PLANE); OBJECT FOCUSED AT INFINITY
IMA: 0.0000 mm
IMA: 0.5710 mm
IMA: 1.1420 mm
IMA: 1.7140 mm
IMA: 2.2850 mm
IMA: 2.5700 mm
IMA: 2.8560 mm
IMA: 2.9560 mm
Maximum Scale: ± 25.000 µm.
Wavelengths: 0.470 0.510 0.555 0.610 0.650
P_y
e_y

FIG. 9

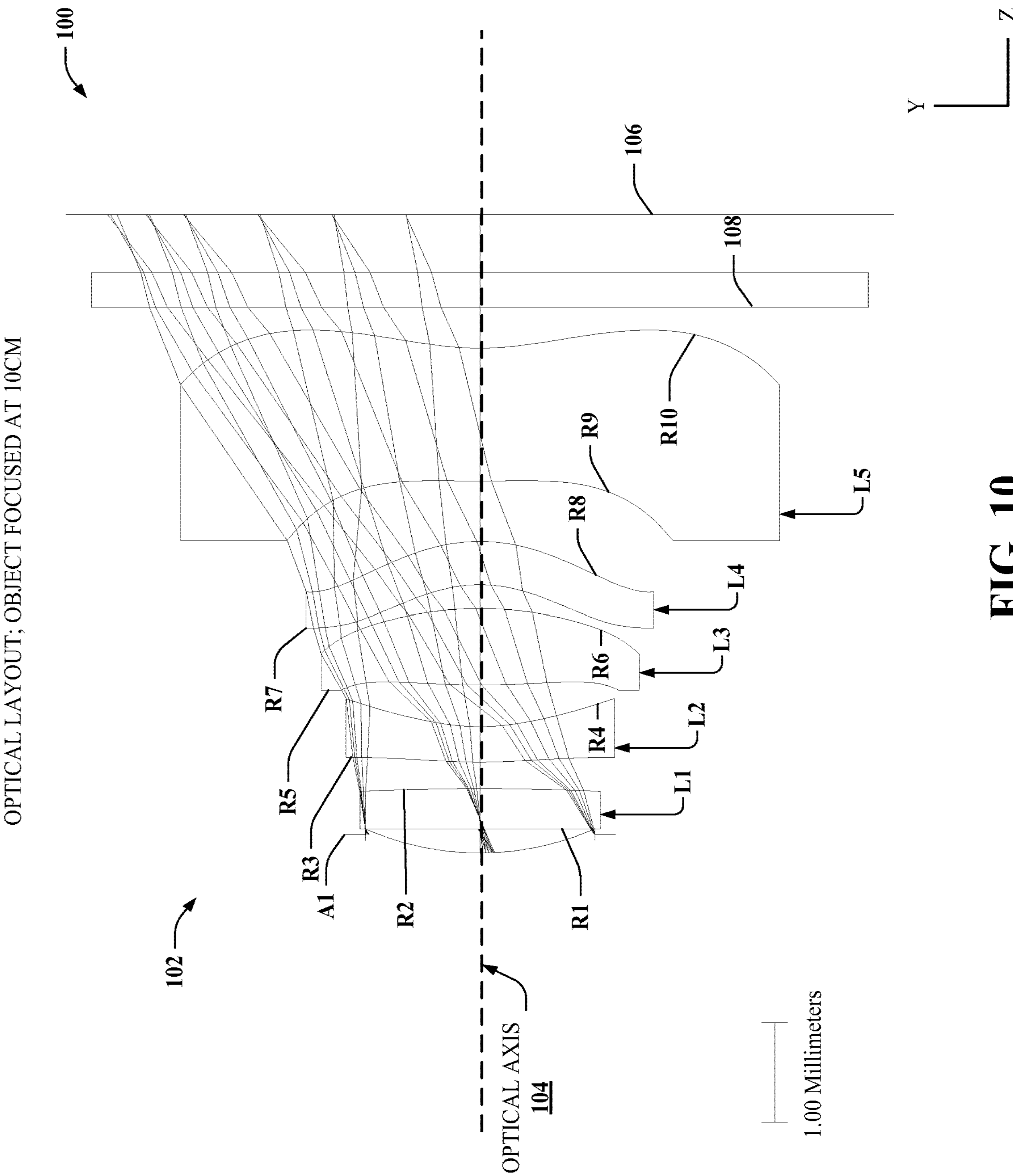

OPTICAL LAYOUT; OBJECT FOCUSED AT 10CM
100
102
106
108
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
A1
L1
L2
L3
L4
L5
OPTICAL AXIS
104
1.00 Millimeters
Y
Z

FIG. 10

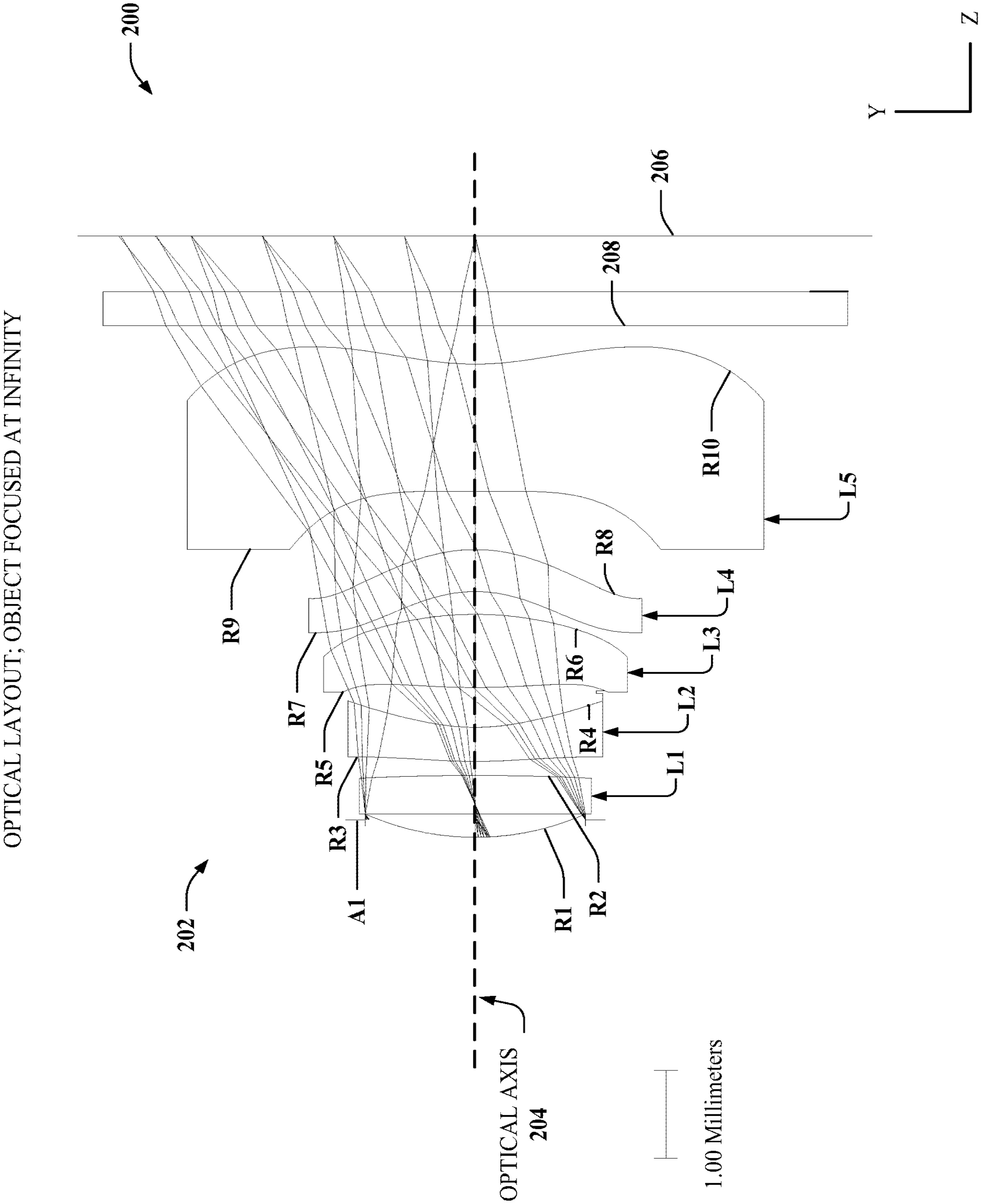

OPTICAL LAYOUT; OBJECT FOCUSED AT INFINITY
200
202
206
208
Y
Z
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
A1
L1
L2
L3
L4
L5
OPTICAL AXIS
204
1.00 Millimeters

FIG. 11

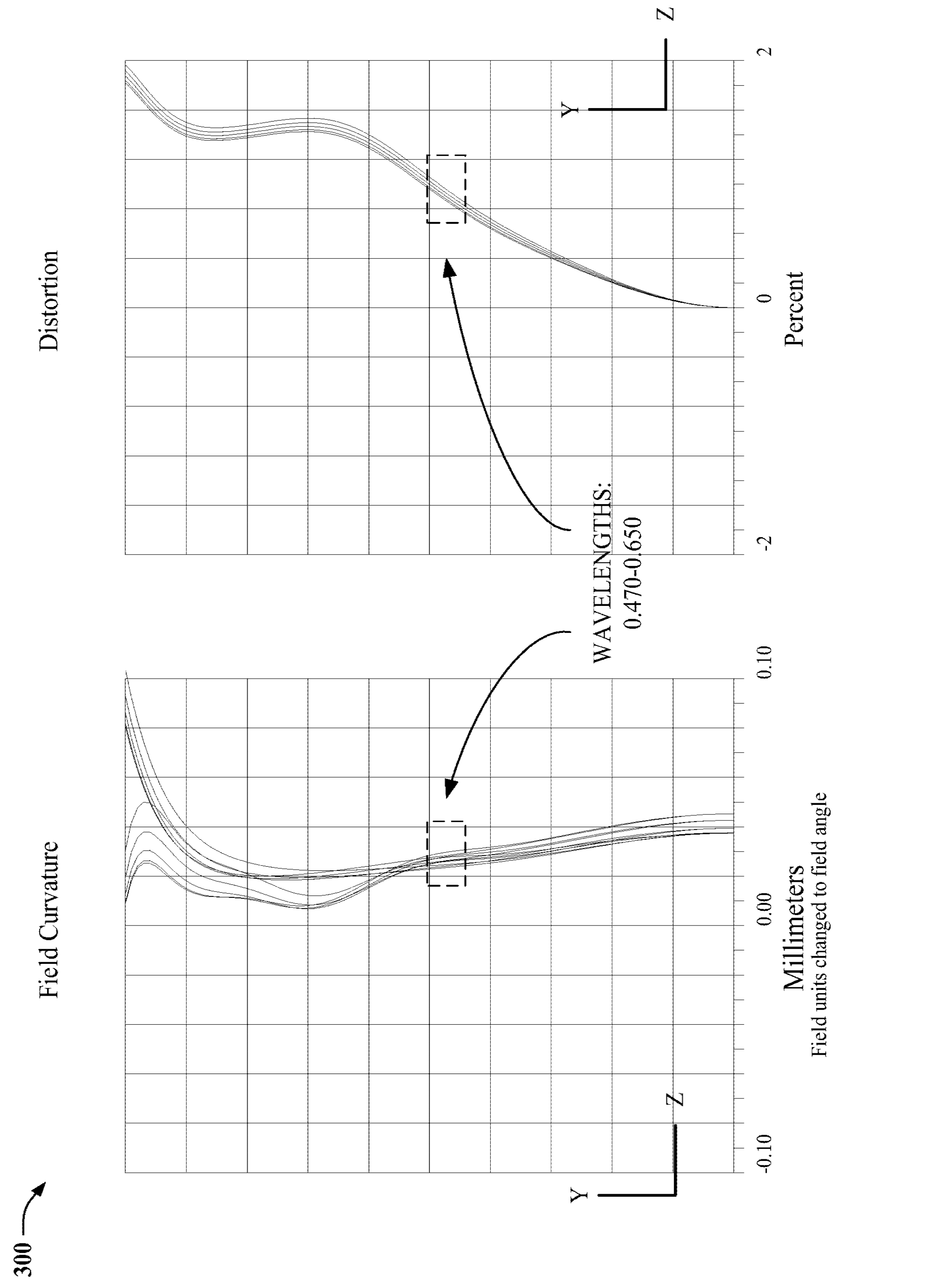

300
FIELD CURVATURE: 10cm - Infinity
Field Curvature
Distortion
Y
Z
-0.10
0.00
0.10
Millimeters
Field units changed to field angle
WAVELENGTHS:
0.470-0.650
-2
0
2
Percent
Y
Z

FIG. 12

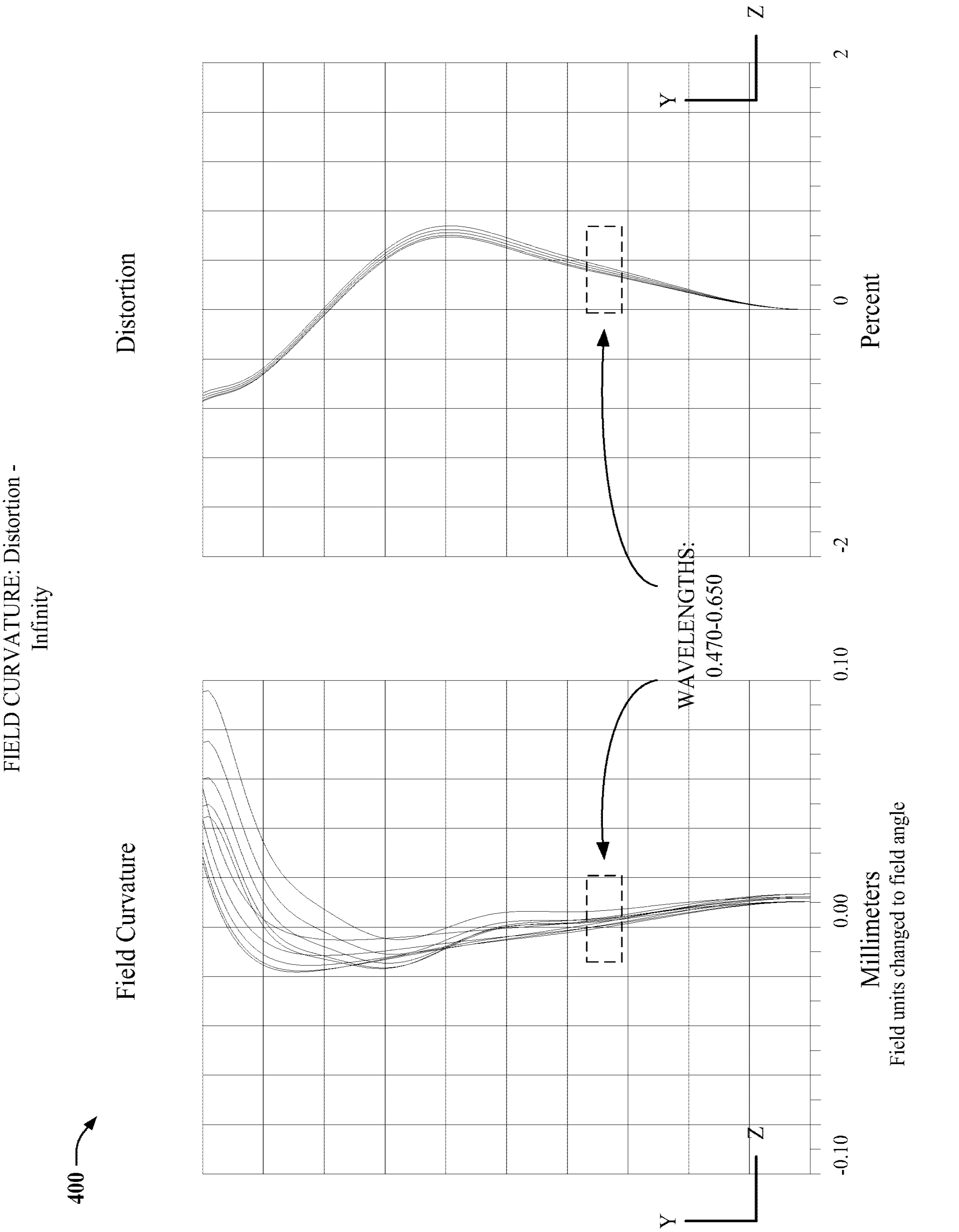

400
FIELD CURVATURE: Distortion -
Infinity
Field Curvature
Distortion
WAVELENGTHS:
0.470-0.650
-0.10
0.00
0.10
Millimeters
Field units changed to field angle
-2
0
2
Percent
Y
Z
Y
Z

FIG. 13

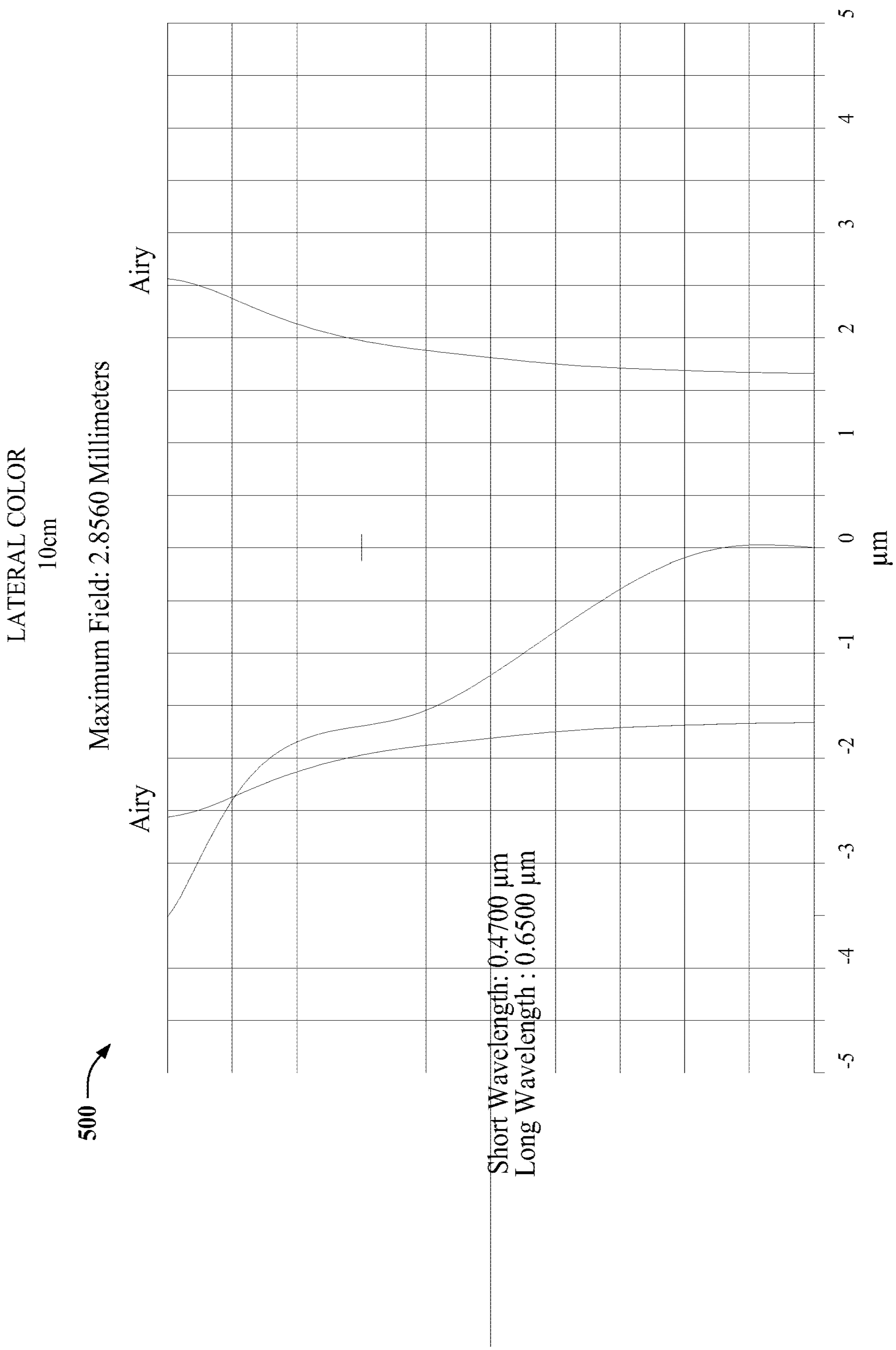

500
LATERAL COLOR
10cm
Maximum Field: 2.8560 Millimeters
Airy
Airy
Short Wavelength: 0.4700 µm
Long Wavelength : 0.6500 µm
-5
-4
-3
-2
-1
0
1
2
3
4
5
µm

FIG. 14

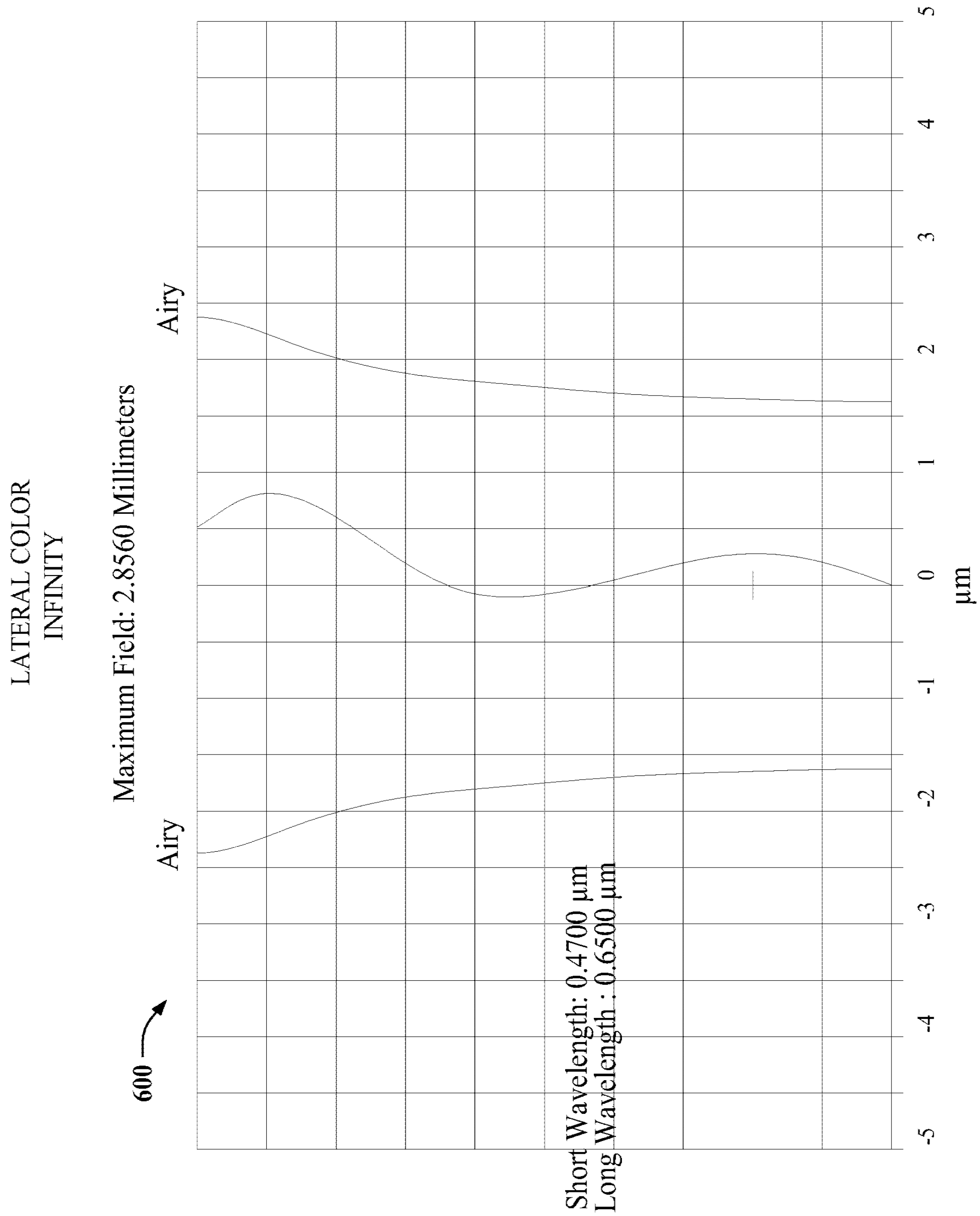

LATERAL COLOR
INFINITY
Maximum Field: 2.8560 Millimeters
Airy
Airy
600
Short Wavelength: 0.4700 µm
Long Wavelength : 0.6500 µm
-5
-4
-3
-2
-1
0
1
2
3
4
5
µm

FIG. 15

TRANSVERSE RAY FAN PLOT 10cm

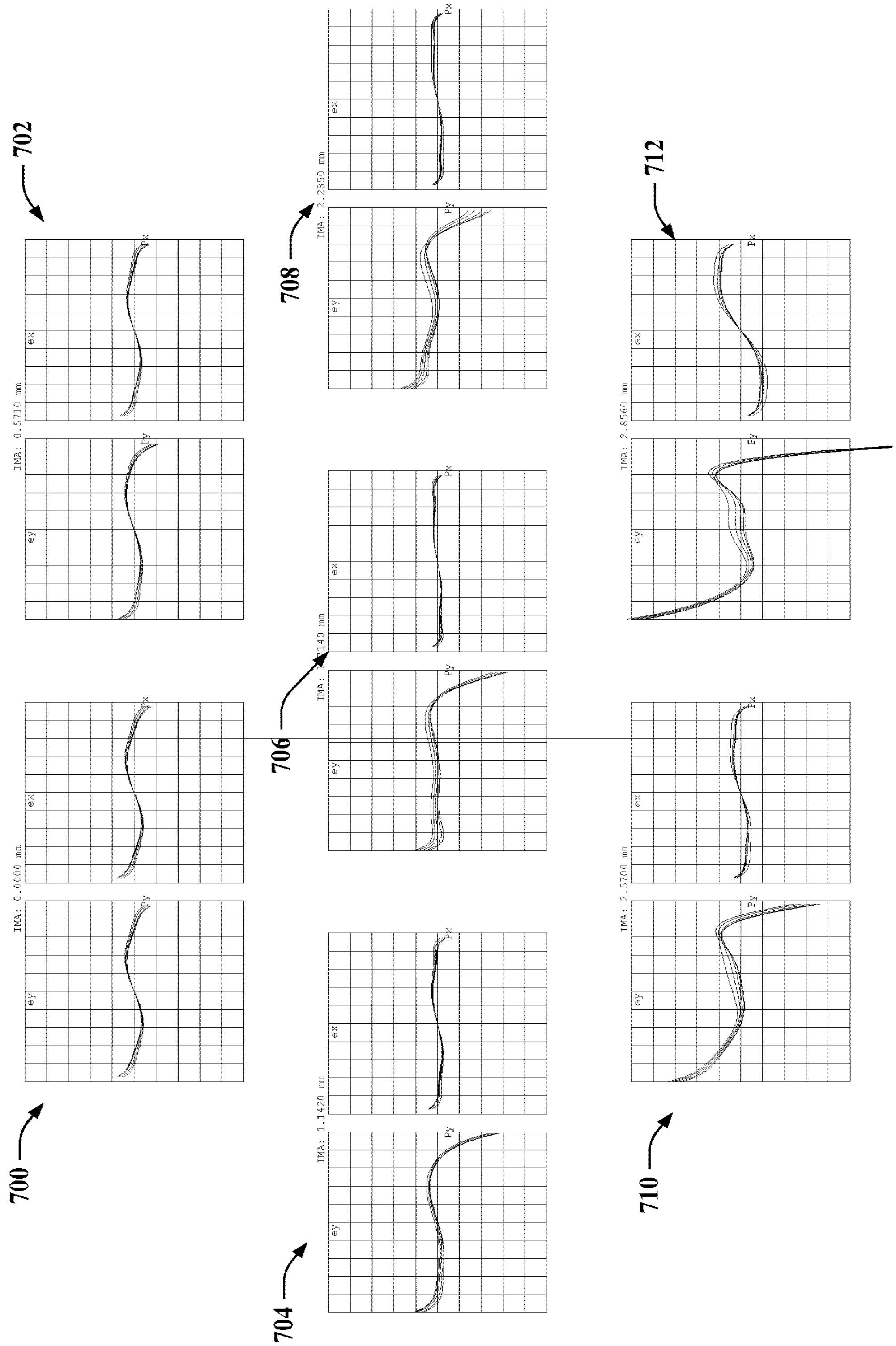


FIG. 16

TRANSVERSE RAY FAN PLOT: INFINITY

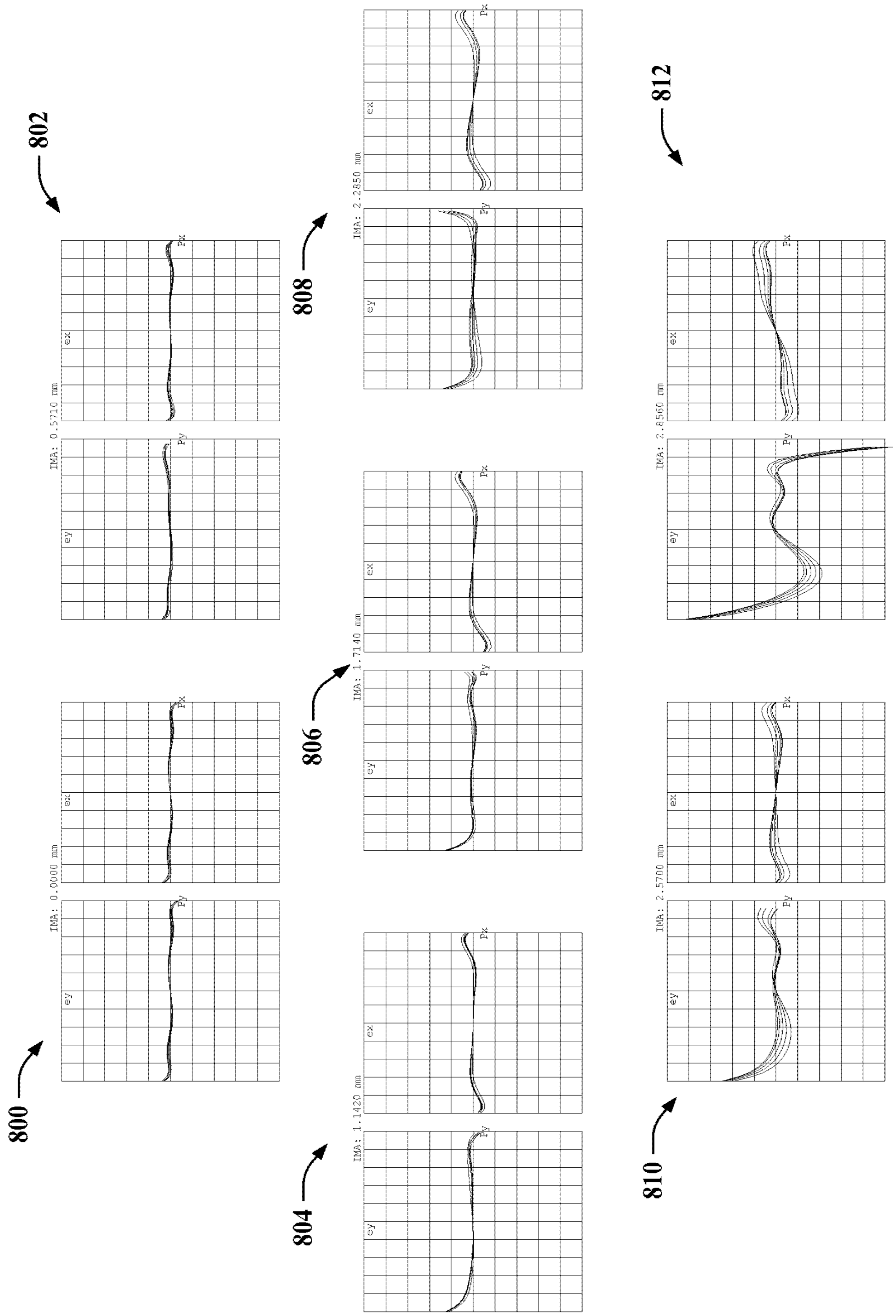


FIG. 17

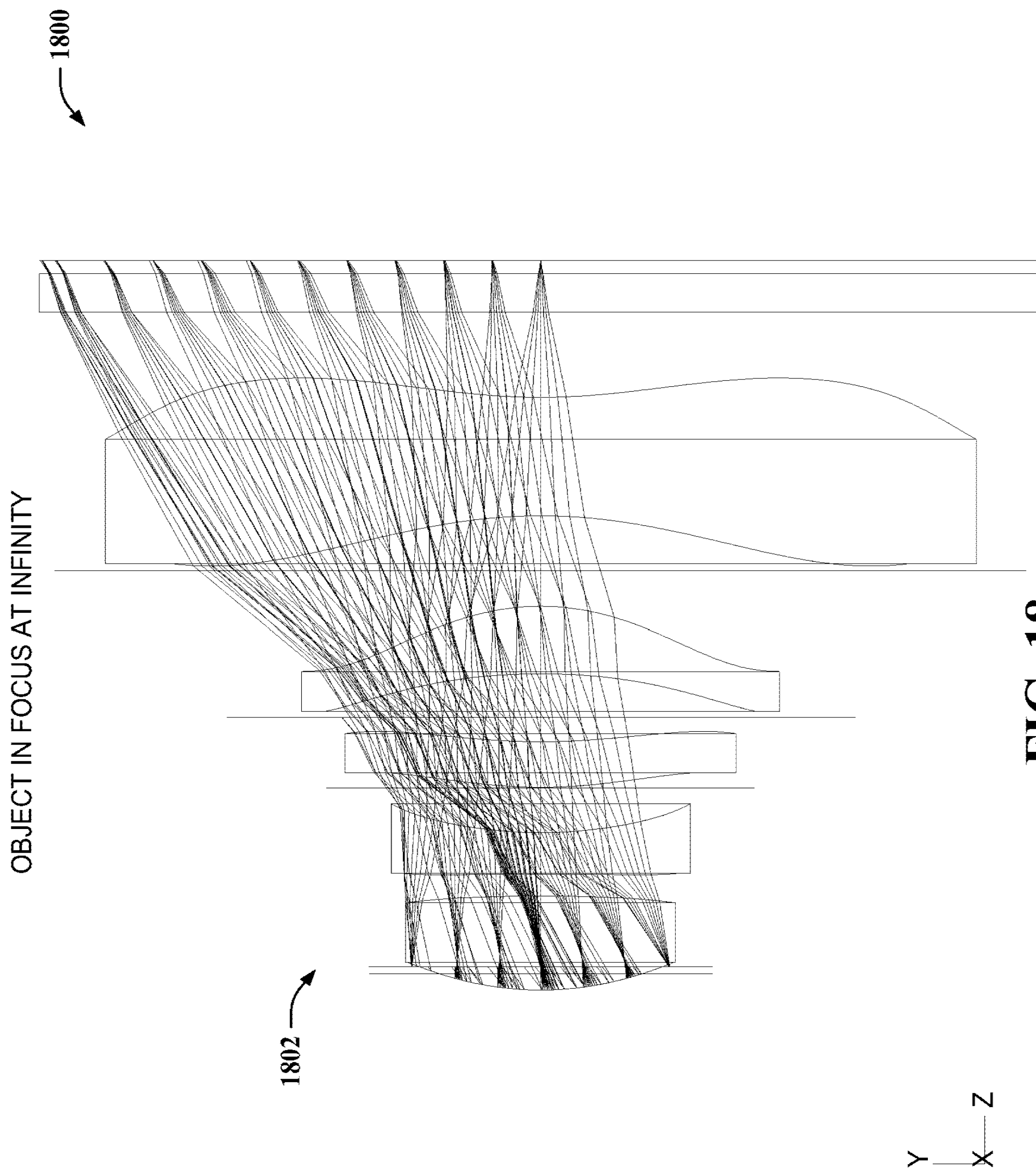


FIG. 18

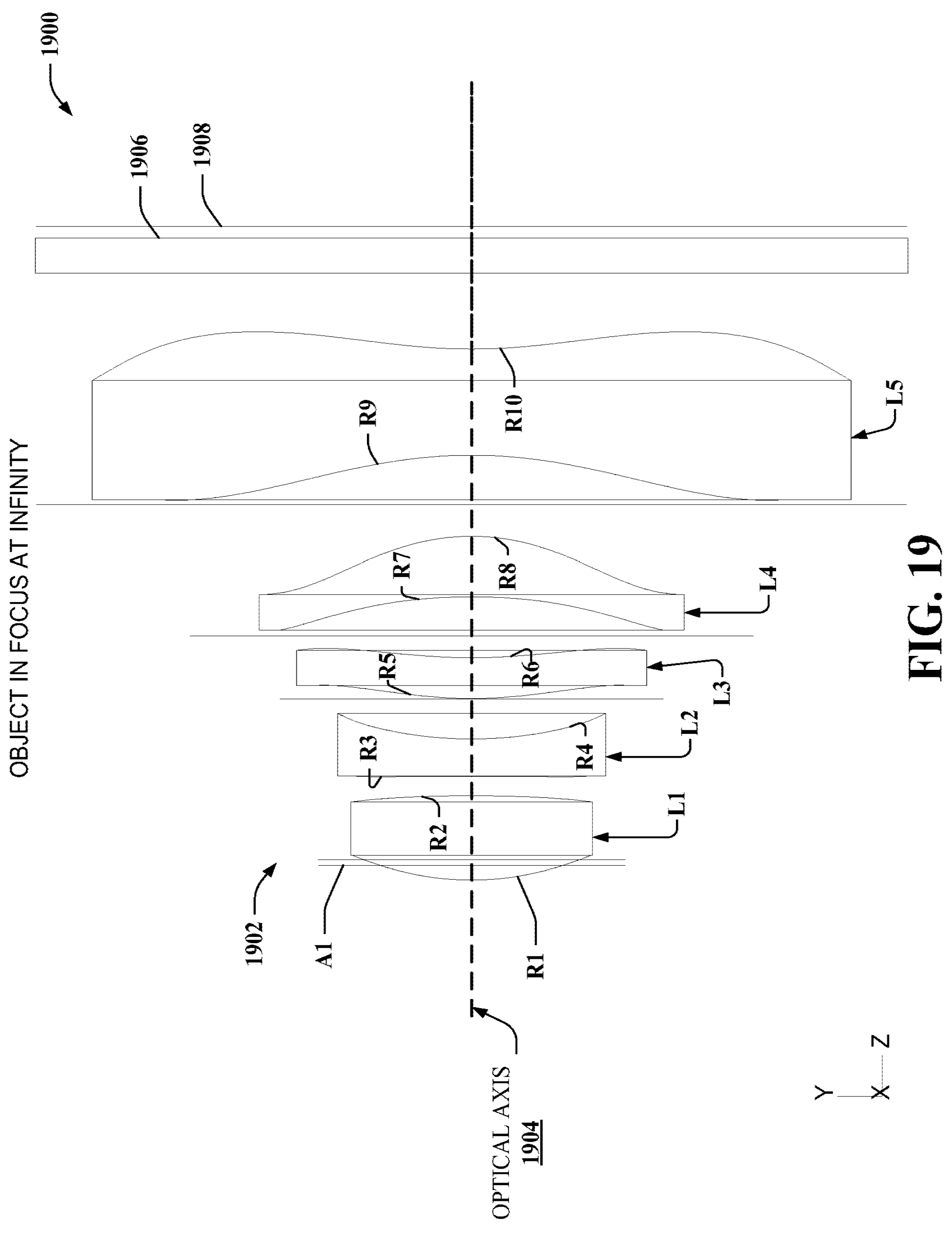

1900
1906
1908
OBJECT IN FOCUS AT INFINITY
R9
R10
L5
R7
R8
L4
R5
R6
L3
R3
R4
L2
R2
L1
1902
A1
R1
OPTICAL AXIS
1904
Y
Z

FIG. 19

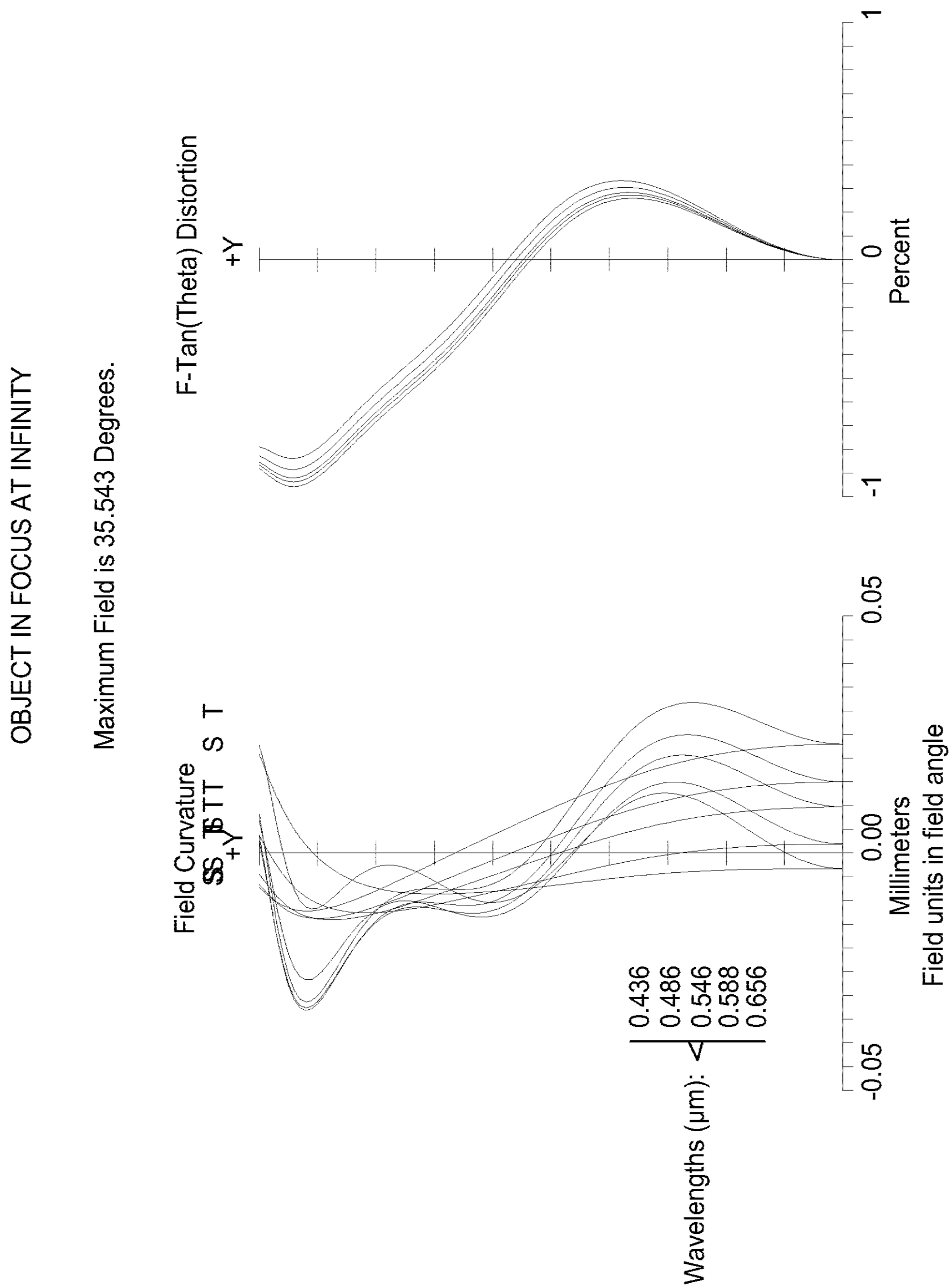

OBJECT IN FOCUS AT INFINITY
Maximum Field is 35.543 Degrees.
Field Curvature
S T
+Y
F-Tan(Theta) Distortion
+Y
Wavelengths (µm):
0.436
0.486
0.546
0.588
0.656
-0.05
0.00
0.05
Millimeters
Field units in field angle
-1
0
1
Percent

FIG. 20

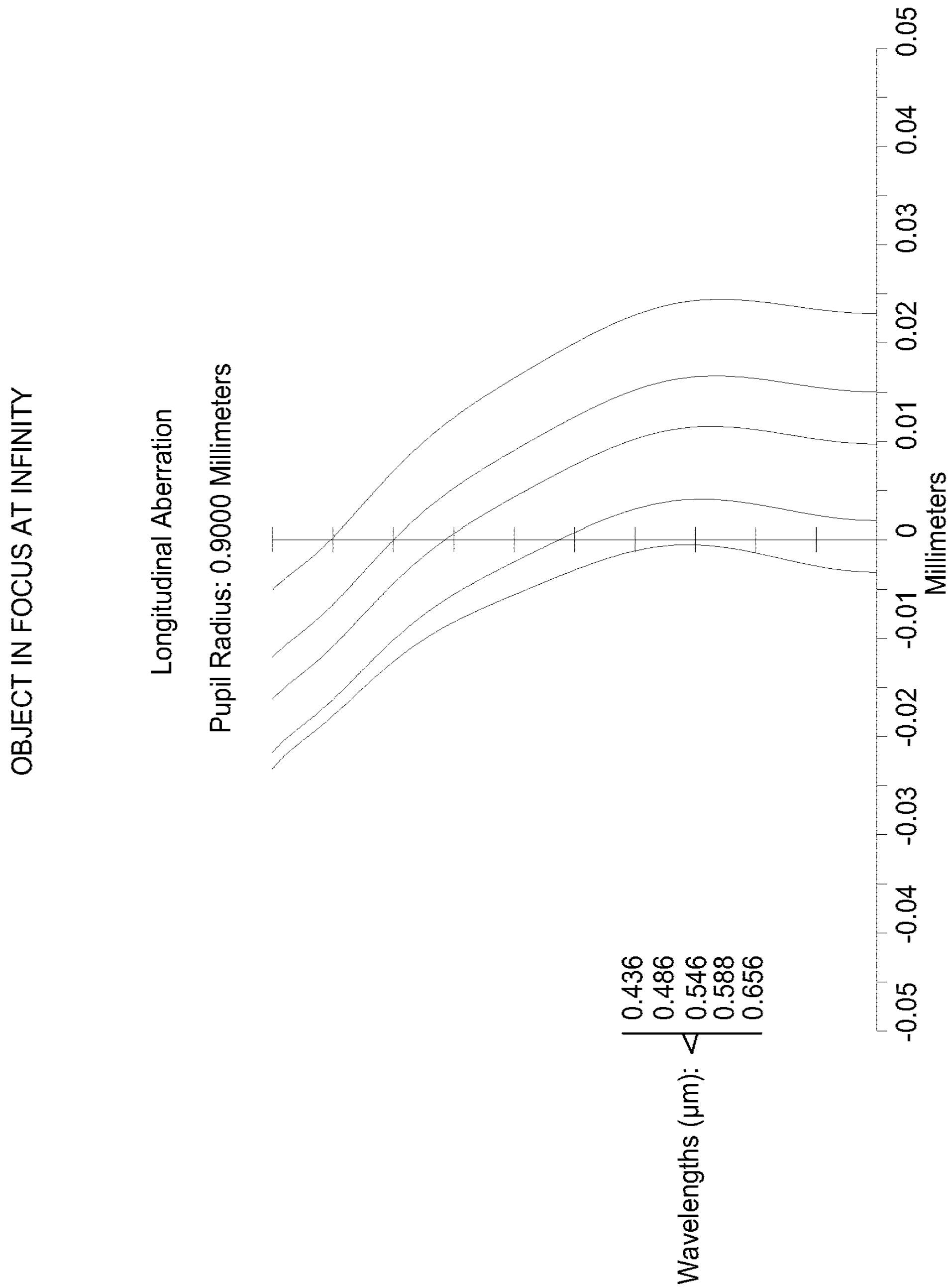

OBJECT IN FOCUS AT INFINITY
Longitudinal Aberration
Pupil Radius: 0.9000 Millimeters
-0.05
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04
0.05
Millimeters
Wavelengths (µm):
0.436
0.486
0.546
0.588
0.656

FIG. 21

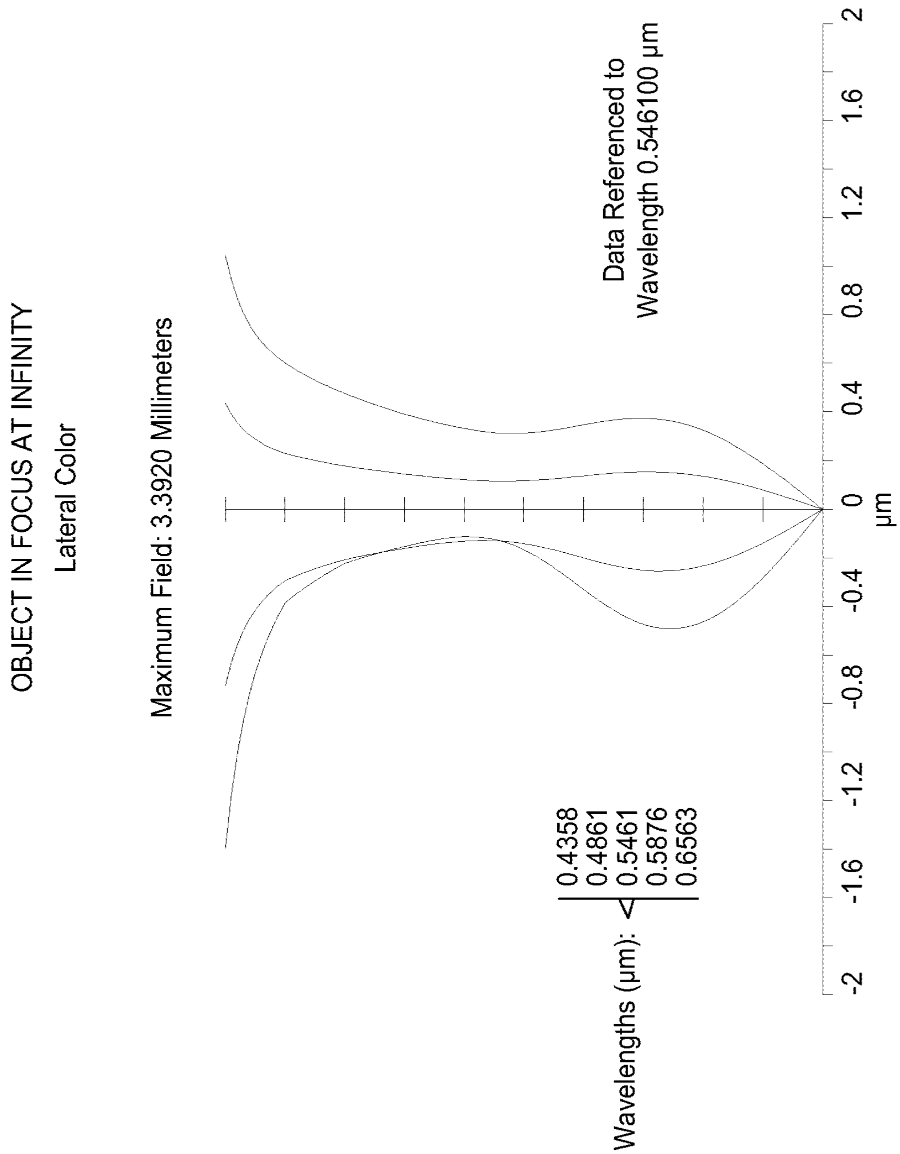

OBJECT IN FOCUS AT INFINITY
Lateral Color
Maximum Field: 3.3920 Millimeters
Data Referenced to
Wavelength 0.546100 µm
Wavelengths (µm):
0.4358
0.4861
0.5461
0.5876
0.6563
-2
-1.6
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
1.6
2
µm

FIG. 22

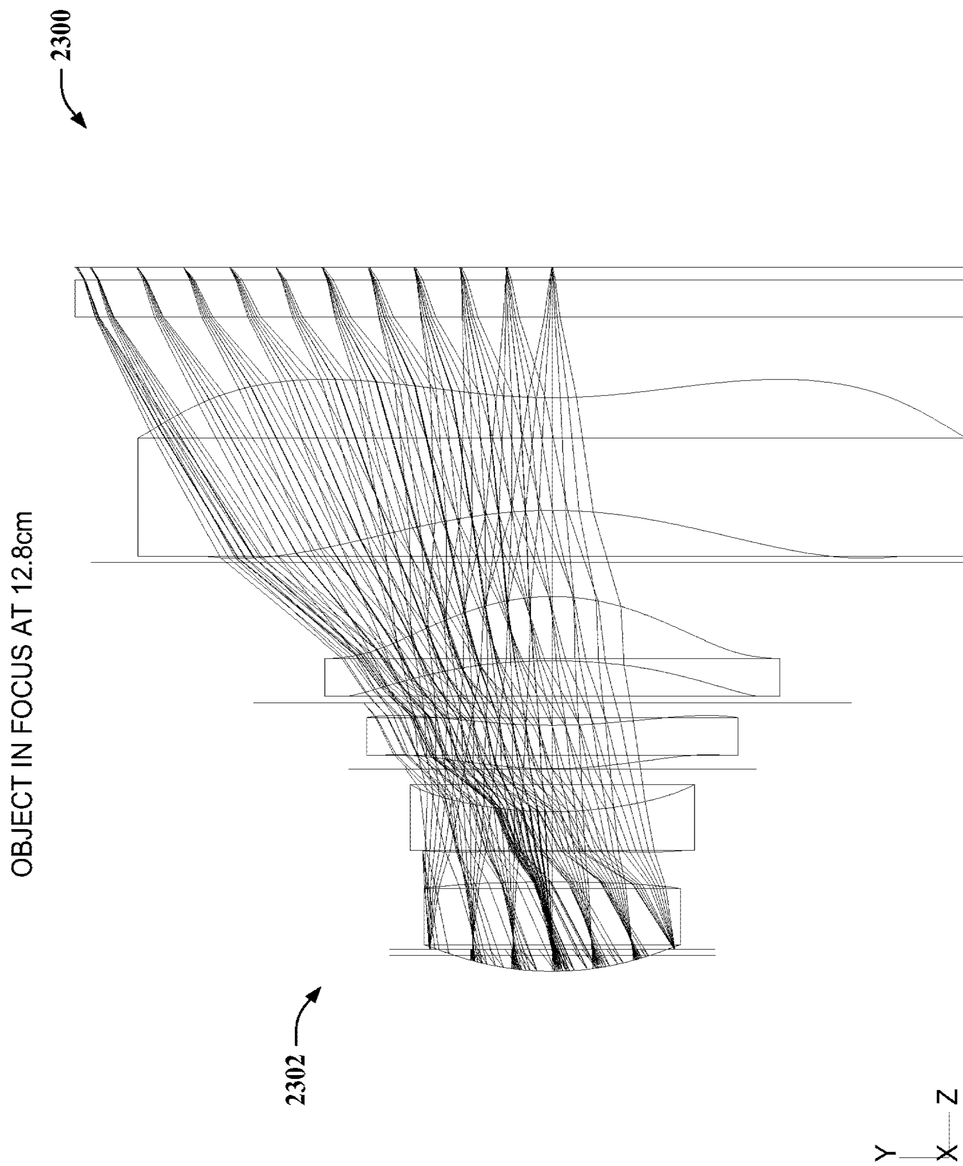
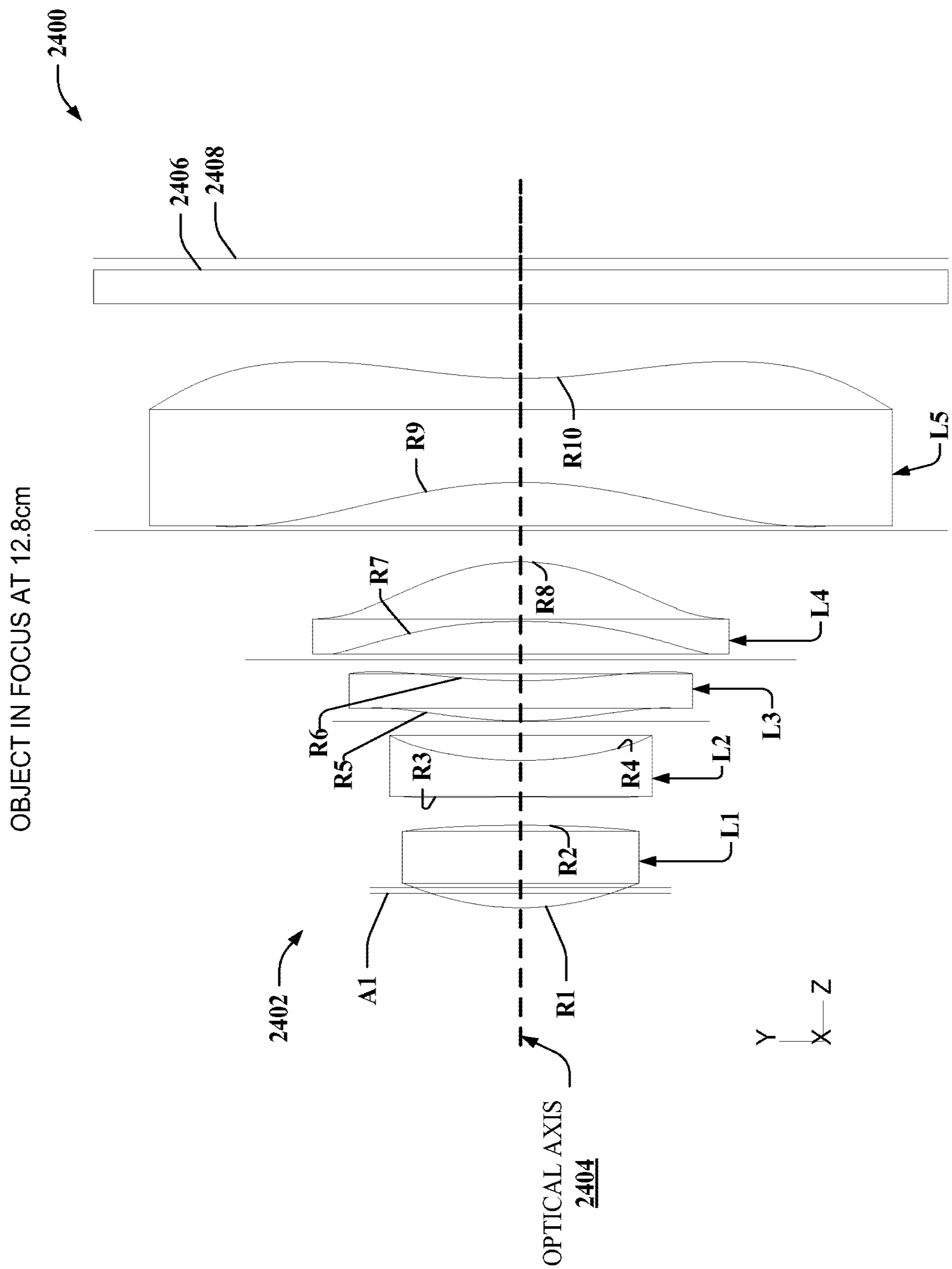


FIG. 23



2400
2406
2408
OBJECT IN FOCUS AT 12.8cm
R9
R10
L5
R7
R8
L4
R6
R5
R3
R4
L2
L3
L1
R2
2402
A1
R1
Y
Z
X
OPTICAL AXIS
2404

FIG. 24

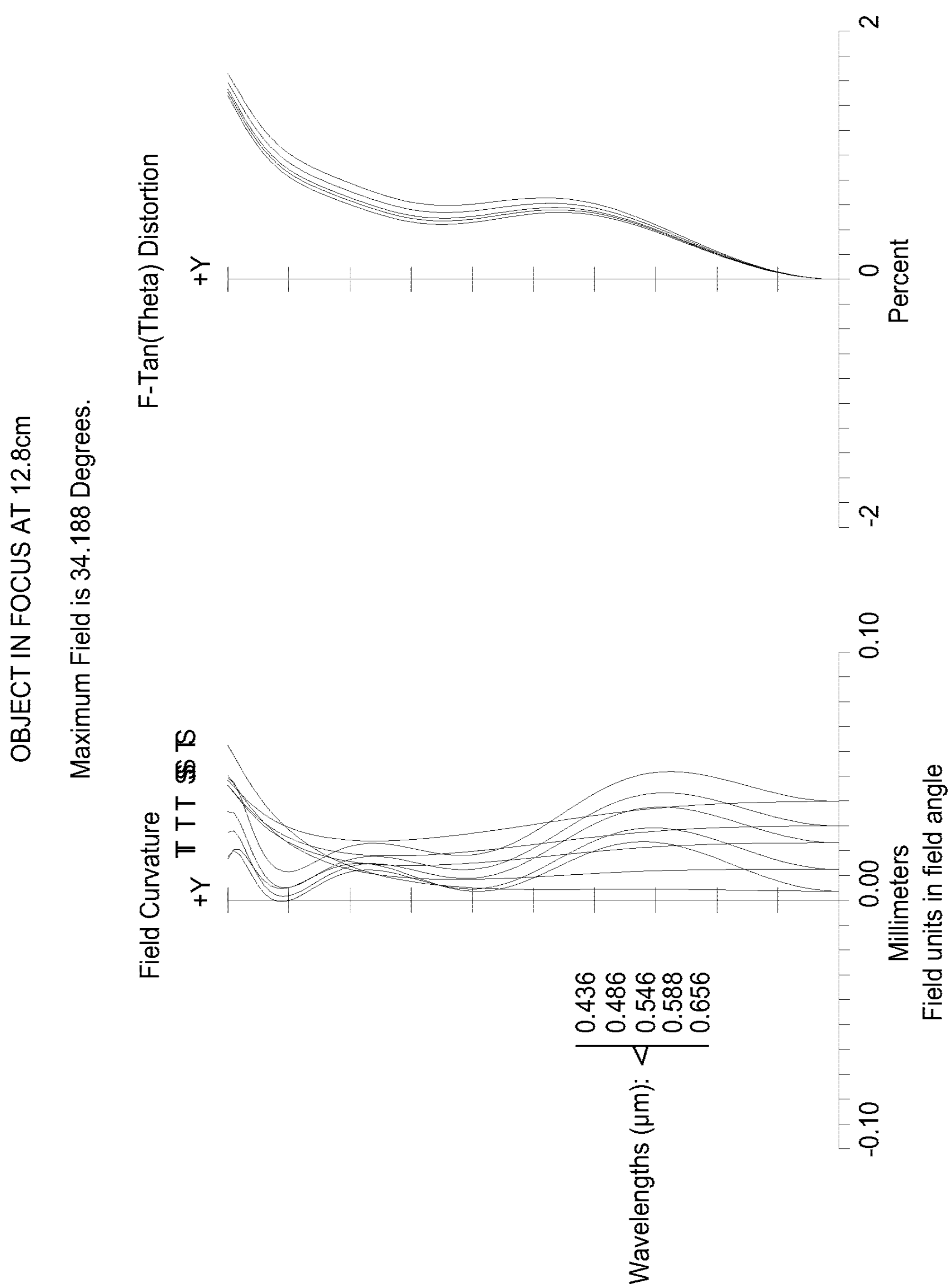

OBJECT IN FOCUS AT 12.8cm
Maximum Field is 34.188 Degrees.
Field Curvature
+Y
T T T S S S
Millimeters
Field units in field angle
-0.10
0.00
0.10
Wavelengths (µm):
0.436
0.486
0.546
0.588
0.656
F-Tan(Theta) Distortion
+Y
Percent
-2
0
2

FIG. 25

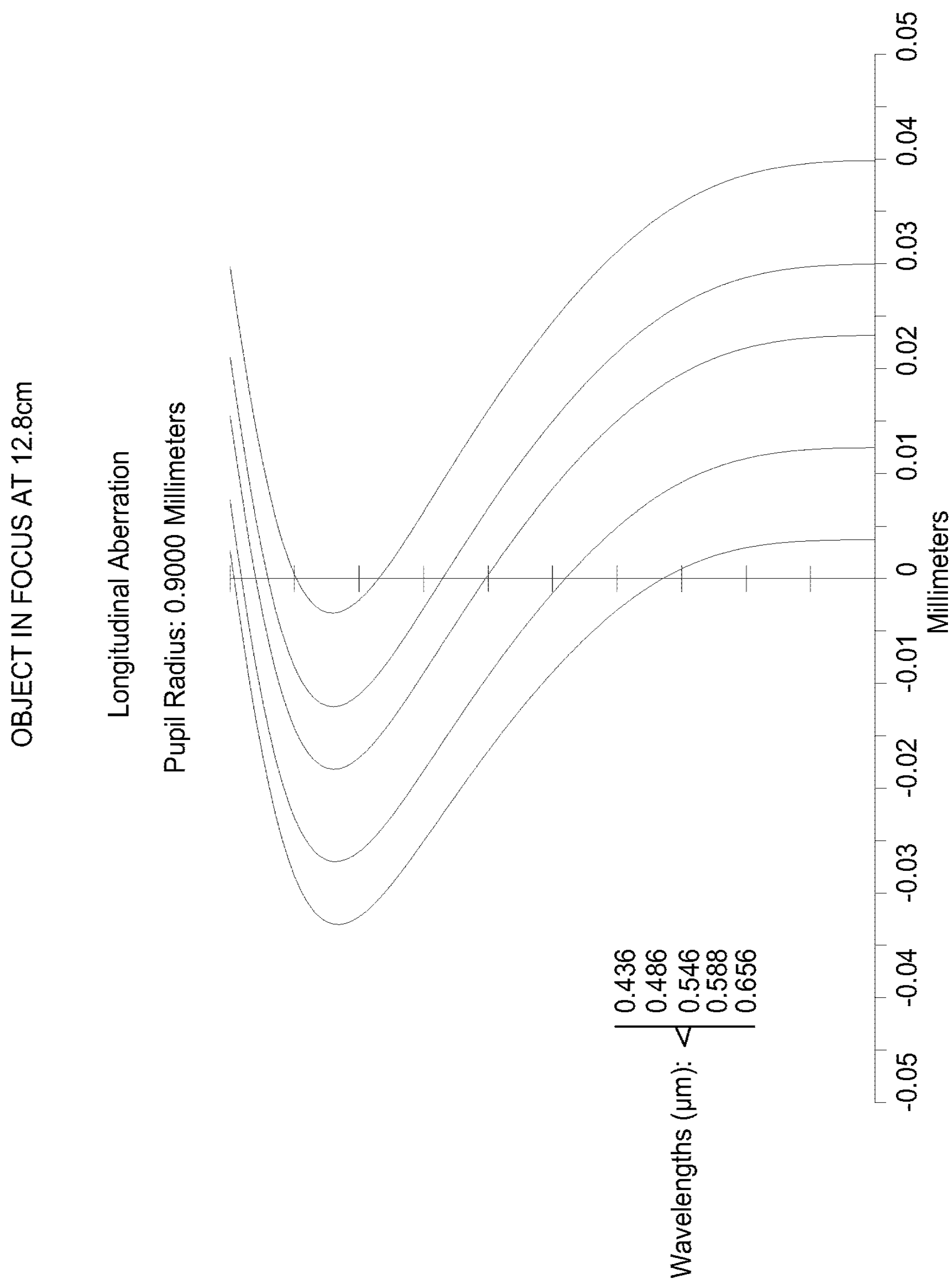

OBJECT IN FOCUS AT 12.8cm
Longitudinal Aberration
Pupil Radius: 0.9000 Millimeters
Wavelengths (µm):
0.436
0.486
0.546
0.588
0.656
-0.05
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04
0.05
Millimeters

FIG. 26

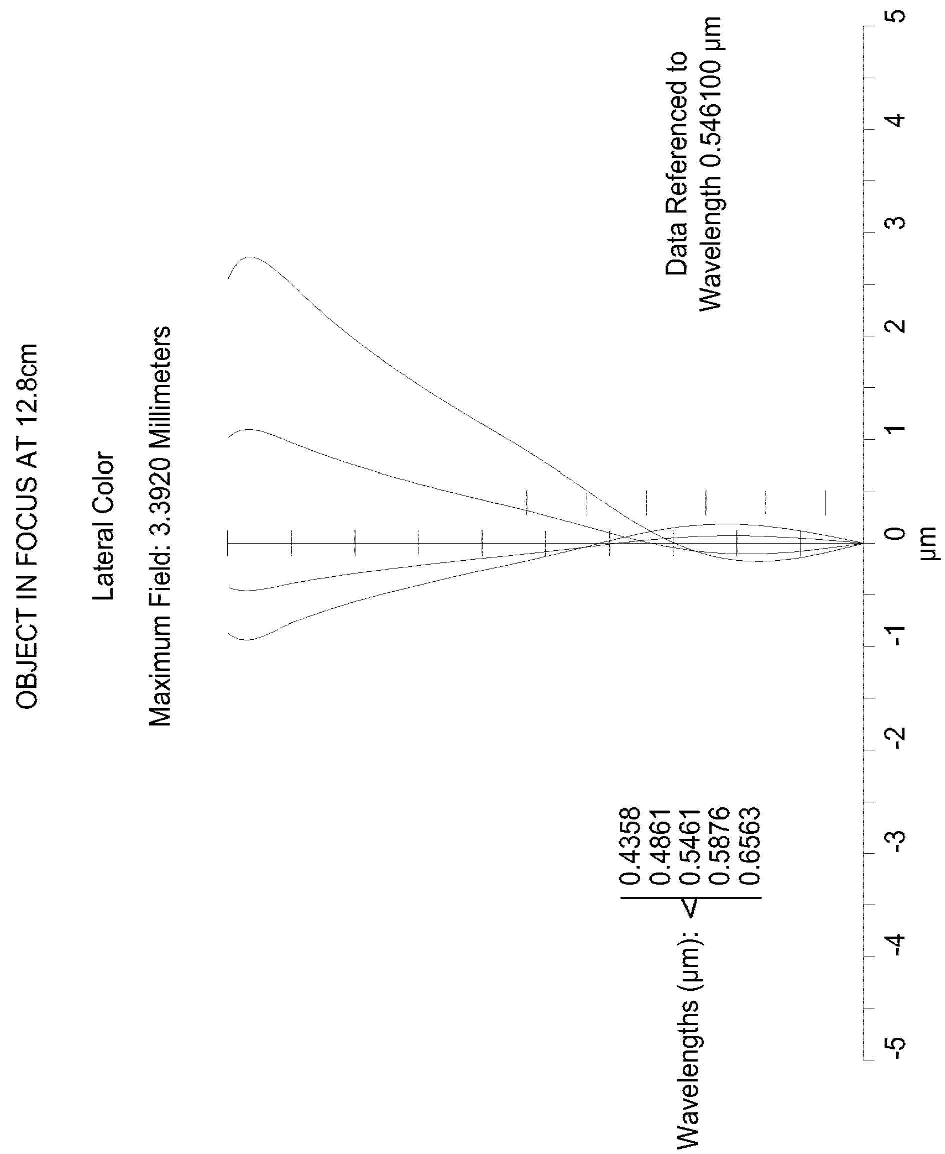

OBJECT IN FOCUS AT 12.8cm
Lateral Color
Maximum Field: 3.3920 Millimeters
Data Referenced to
Wavelength 0.546100 µm
Wavelengths (µm):
0.4358
0.4861
0.5461
0.5876
0.6563
-5
-4
-3
-2
-1
0
1
2
3
4
5
µm

FIG. 27

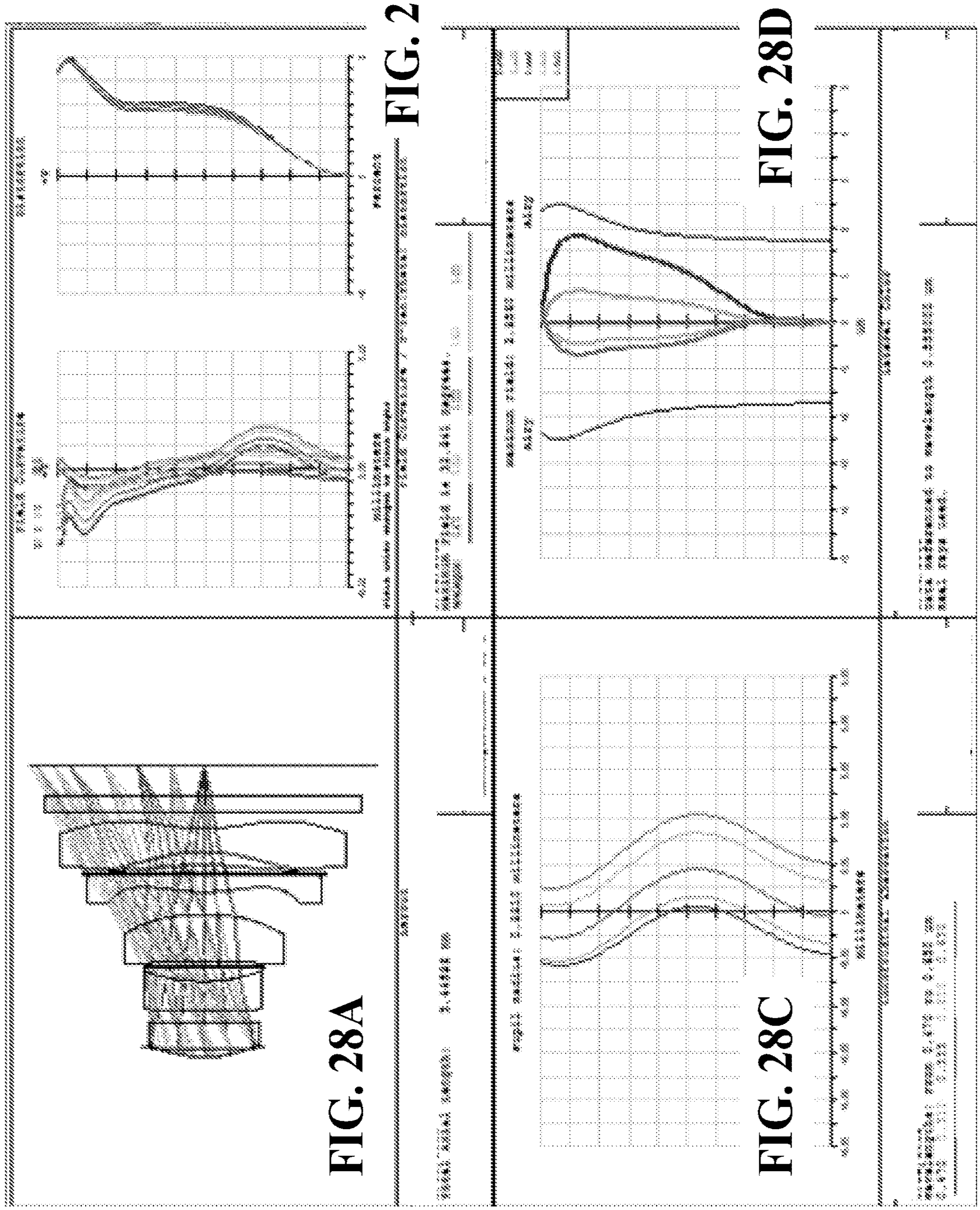


FIG. 28A

FIG. 28B

FIG. 28C

FIG. 28D

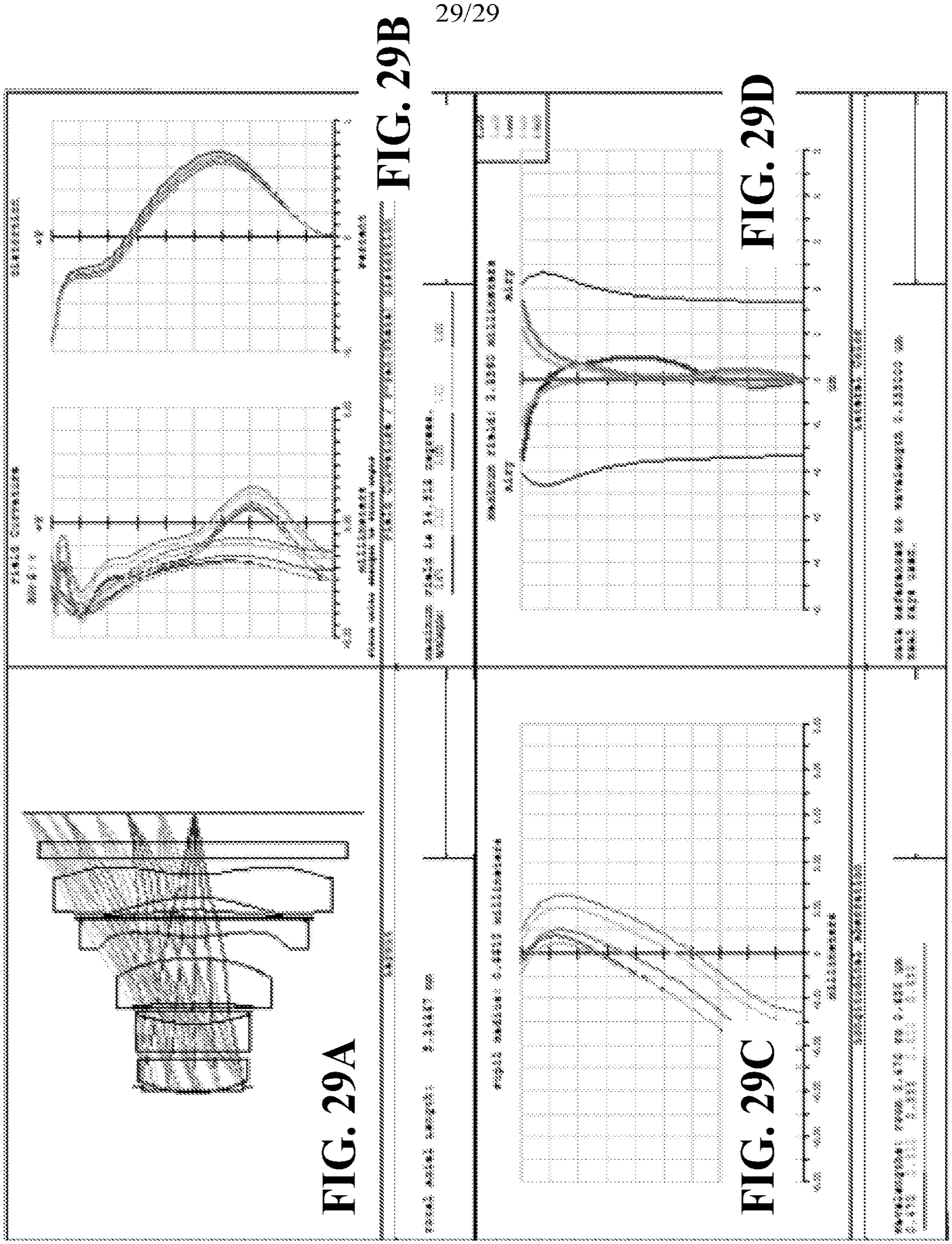


FIG. 29A

FIG. 29B

FIG. 29C

FIG. 29D

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/061668

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B13/00 H04N5/232
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)
G02B 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	JP 2010 224521 A (KONICA MINOLTA OPTO INC) 7 October 2010 (2010-10-07)	1,14-18
Y	abstract; figure 5	6-13
Y	US 5 598 299 A (HAYAKAWA) 28 January 1997 (1997-01-28) figure 1	6-13
A	JP 2011 209554 A (Y. SHINOHARA) 20 October 2011 (2011-10-20) figures 4,11; tables 7,19	19-30
X	JP 7 181389 A (MINOLTA CO LTD) 21 July 1995 (1995-07-21) abstract; figure 1 paragraph [0023]; table 1	31-35, 40-42

[ ] 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
14 March 2013	21/03/2013

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	Michel, Alain

4

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/061668

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.:
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:

3. ☐ Claims Nos.:
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:

see additional sheet

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 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.

Form PCT/ISA/210 (continuation of first sheet (2)) (April 2005)

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-18

   Claim 1 relates to an imaging system having two lens groups, five lenses and front-focusing carried out by a MEMS actuator. Claims 2-18 depend on claim 1.
   The underlying problem to be solved is how to enable a small lens displacement during focusing.
   The special feature is the first lens group comprising a biconvex object-side lens, the focal length of which being greater than half of the focal length of the whole imaging system.

---

2. claims: 19-30

   Independent claim 19 relates to an optical system having five lenses, focusing being carried out by moving the first lens. Claims 20-30 depend on claim 19.
   The underlying problem to be solved is how to reduce field curvature and distortion.
   The special feature is the lens constitution of the optical system, the first and the fourth lenses being biconvex, the second and the fifth lenses being menisci and the third lens being concave-convex.

---

3. claims: 31-45

   Independent claim 31 relates to an imaging system having two lens groups, the first lens group for focusing and consisting of two lenses and the second lens group having three lenses. Claims 32-45 depend on claim 31.
   The underlying problem to be solved is how to reduce primary lateral colour.
   The special feature is the second lens group comprising a fore-front lens being a meniscus that has a convex surface towards the object side.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2012/061668

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2010224521 A	07-10-2010	CN 101819315 A	01-09-2010
		JP 2010224521 A	07-10-2010
		JP 2011138175 A	14-07-2011
		US 2010220229 A1	02-09-2010
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		JP 7294853 A	10-11-1995
		US 5598299 A	28-01-1997
JP 2011209554 A	20-10-2011	NONE	
JP 7181389 A	21-07-1995	NONE	

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

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18 July 2013 (18.07.2013)

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(74) **Agent**: **NATHAN & ASSOCIATES PATENT AGENTS**; P.O.Box 10178, 61101 Tel Aviv (IL).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title**: ELECTROMAGNETIC ACTUATORS FOR DIGITAL CAMERAS

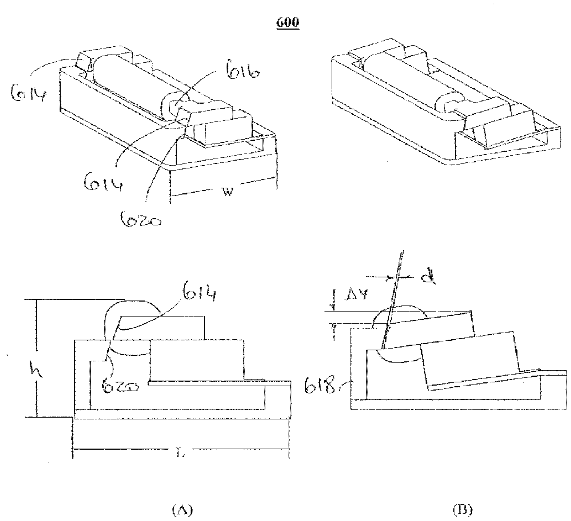


FIG. 6

(57) **Abstract**: Electromagnetic actuators for digital cameras, in particular miniature cell- phone and tablet cameras, include an electromagnet with a first elongated ferromagnetic member surrounded coaxially in part by a conductive coil along a first longitudinal axis, and a elongated second ferromagnetic member with a second longitudinal axis. The first and second ferromagnetic members have respective first and second operative surfaces and are aligned such that their longitudinal axes are parallel and such that respective operative surfaces overlap each other across a gap. The two members are mechanically coupled to respective frames. A frame hinge connects the frames and enables a relative tilt motion between the ferromagnetic members when current passes through the coil. The tilt motion is convertible into a linear displacement along an optical axis of an optical element coupled to the actuator. Two actuators can be combined into an assembly capable of providing double-axis tilt.

WO 2013/105012 A2

ELECTROMAGNETIC ACTUATORS FOR DIGITAL CAMERAS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to and claims priority from US Provisional Patent Application No. 61/585,795 titled “Magnetic Actuator” and filed January 12, 2012, which is incorporated herein by reference in its entirety.

FIELD

Embodiments disclosed herein relate in general electromagnetic (EM) actuators having ferromagnetic members and conductive coils and more particularly to EM actuators used in miniature cameras.

BACKGROUND

In its basic form, an electronic camera, such as digital still camera or a camera embedded in a mobile (cell) phone or in a tablet computer includes two components: (1) a lens module comprising a set of one or more plastic or glass lens elements and used to create an optical image of the viewed scene, and (2) an image sensor (e.g., CMOS or CCD), which converts the optical image to the electronic domain, where the image can be processed and stored. There are different types of electronic (or digital) cameras ranging by application (e.g., regular SLR, camera-phone, automotive, security and medical) and by functionality (e.g., with or without auto-focus). The simplest cameras are those in which the lens module is fixed in position with respect to the image sensor. These cameras are often called fixed-focus cameras, where the camera is focused to a pre-determined distance. Objects that fall within the depth of field of the camera can be captured sharply and those which fall beyond the depth of field will be blurred. In more advanced cameras, the position of the lens module (or at least one lens element in the lens module) can be changed by means of an actuator and the focus distance can be changed in accordance with the captured object or scene. In these cameras it is possible to capture objects from a very short distance (e.g., 10cm) to infinity.

Some advanced camera designs may include different groups of lenses that can move with respect to each other and hence change the effective focal length of the camera, which results in optical zoom capability. The trend in digital still cameras is to increase the zooming capabilities (e.g. to 5x, 10x or more) and, in cellphone cameras, to decrease the pixel size and increase the pixel count. These trends result in greater sensitivity to hand-shake or in a need for longer exposure time. This has created a need for optical image stabilization (OIS), which now appears in advanced cameras. In OIS-enabled cameras, the lens or camera module can change its lateral position or tilt angle in a fast manner to cancel the hand-shake during the image capture.

In compact (miniature) camera modules, the most ubiquitous form of an actuator is the Voice-Coil Motor (VCM), which includes a coil (wire turned on a cylinder), fixed (or “permanent” or "hard") magnets and springs. When current is driven through the coil, an electro-magnetic (EM) force is applied and the lens module changes position. While the VCM is considered a mature technology, it is costly, large in size, uses rare-earth magnets, is slow in operation and consumes high power. Therefore, there is a need for, and it would be advantageous to have technical advances which overcome the shortcomings of VCM and related technologies.

SUMMARY

In various embodiments, there are disclosed EM actuators which can be used in digital (including cell-phone and tablet) cameras where at least one lens element in a lens module and/ or an image sensor move to adjust camera focus, stabilize an image, create a super-resolution effect or provide enhanced user experience.

Embodiments disclosed herein teach semi-planar geometry EM actuators for miniature camera auto-focus (AF) and OIS, as well as for any other functionality that can be obtained by tilting or moving a camera module or elements therewithin. The actuator’s thickness may be less than half of its large dimension. The actuator moves along the thickness axis. The actuation force is magnetic, using ferromagnetic materials ("soft" magnets). The structure is inspired by the basic reluctance motor scheme. Actuator structures disclosed herein are designed to reduce the magnetic reluctance of the actuator and thereby provide a large EM force. Further, actuators disclosed herein are designed to allow solely one dimensional (1D) tilt of parts within

the actuator, thereby enabling accurate and smooth motion while avoiding jamming. Assemblies of two such actuators allow 2D tilts.

In some embodiments, there is provided an EM actuator used to linearly move an optical element along an optical axis, the actuator comprising: a first elongated ferromagnetic member surrounded partially by a conductive coil, the first ferromagnetic member having a first longitudinal axis and a first operative surface; a second elongated ferromagnetic member having a second longitudinal axis parallel to the first longitudinal axis and a second operative surface, the first and second ferromagnetic members disposed such that a gap and an overlap are formed between the first and second operative surfaces; and a frame hinge having a third longitudinal axis parallel to the first and second longitudinal axes, the frame hinge used to enable one ferromagnetic member to undergo a tilt motion relative to the other ferromagnetic member when a magnetic force is generated by current in the coil, the tilt motion convertible into a linear displacement of the optical element from a first position to a second position.

In some embodiments, the operative surface includes two operative surface sections disposed at two opposing ends of each ferromagnetic member.

In some embodiments, the movement between the first and second positions is continuous and provides a third, intermediate position for the optical element.

In some embodiments, the first position corresponds to a maximal overlap and the second position corresponds to a minimal overlap.

In some embodiments, each ferromagnetic member has an extension along its respective longitudinal axis, the extension of the second ferromagnetic member being greater than the extension of the first ferromagnetic member along the first longitudinal axis, so that the first ferromagnetic member is configured for being at least partially contained within the second ferromagnetic member.

In some embodiments, each ferromagnetic member is formed with two operative surfaces spaced and facing away from one another so that when the first ferromagnetic member is at least partially contained within the second ferromagnetic member, the operative surfaces of the first ferromagnetic member face the operative surfaces of the second ferromagnetic member.

In some embodiments, each operative surface is in the form of a fork having a plurality of portions spaced apart by respective gaps, each portion being formed with an operative sub-surface.

In some embodiments, the gap and the overlap are formed between first and second operative surface sections defined by flat planes perpendicular to an axis originating at the hinge.

In some embodiments, the gap and the overlap are formed between first and second operative surface sections defined by curved planes having a common radius originating at the hinge.

In some embodiments, one ferromagnetic member is fixedly attached to a first platform, the other ferromagnetic member is fixedly attached to a second platform, and one of the two platforms is movable.

In some embodiments, the platforms are non-ferromagnetic.

In some embodiments, at least one platform is in the form of a frame.

In some embodiments, at least one of the first longitudinal axis and the second longitudinal axis is oriented parallel to the frame.

In some embodiments, at least the movable platform is made of a flexible material which is used to form the common hinge as an integral hinge.

In some embodiments, two actuators are combined to form an actuator assembly which provides a double-axis tilt capability.

In some embodiments, an actuator assembly is configured for controlling focus of the optical device

In some embodiments, an actuator assembly is configured for controlling vibration compensation of the optical device.

In some embodiments, an actuator or actuator assembly are implemented in a digital camera.

In some embodiments, the actuator has a height h and the digital camera has a height H wherein $H/h > 3$.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting embodiments are herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. 1 shows a known EM actuator in isometric and frontal views in: (A) a relaxed (open) state and (B) a final (closed) operative state;

FIG. 2 shows an embodiment of an EM actuator disclosed herein in an isometric view in: (A) a relaxed state and (B) an operative state;

FIG. 3 shows another embodiment of an EM actuator disclosed herein in isometric and frontal views in: (A) a relaxed state and (B) closed operative state;

FIG. 4 shows another embodiment of an EM actuator disclosed herein in isometric and frontal views in: (A) a relaxed state and (B) closed operative state;

FIG. 5 shows yet another embodiment of an EM actuator disclosed herein in: (A) isometric and side views of a relaxed state, (B) isometric and side views of a closed operative state, and (C) side view of an intermediate operative state;

FIG.6 shows yet another embodiment of an EM actuator disclosed herein in: (A) isometric and side views of a relaxed state and (B) isometric and side views of a final operative state;

FIG. 7 shows yet another embodiment of an EM actuator disclosed herein in: (A) isometric and side views of a relaxed state and (B) isometric and side views of a final operative state;

FIG.8 shows isometric views of yet another embodiment of an EM actuator disclosed herein in: (A) a relaxed state and (B) final operative state;

FIG. 9 shows isometric views of an embodiment of an EM actuator assembly disclosed herein and capable of θ-φ (double-axis) tilting in: (A) an open-open state; (B) an open-closed state; (C) a closed-open state; (D) a closed-closed state;

FIG. 10 shows isometric views of another embodiment of an EM actuator assembly disclosed herein and which can provide double-axis tilting in: (A) an open-open state and (B) a closed-closed state;

FIG. 11 shows schematically an embodiment of a camera module which includes an actuator assembly coupled to a lens module: (A) isometric view in a first position, (B) isometric view in a second position, (C) a frontal view in the first position, (D) a frontal view in the second position, (E) a flexible band coupling the actuator assembly and the lens module in the first position, and (F) the flexible band in the second position;

FIG. 12 shows results of a simulation related to the actuator of FIG. 6.

DETAILED DESCRIPTION

FIG. 1 shows a known EM actuator numbered **100** in isometric and frontal views in: (A) a relaxed (open) state, and (B) a closed operative state. The frontal view is along the -Z axis in an orthogonal X-Y-Z reference frame, which is used throughout the description below. Actuator **100** includes a first elongated ferromagnetic member (also referred to as "core") **102** surrounded partially by a conductive coil **104** and a second elongated ferromagnetic member **106.** Core **102** and coil **104** form an electromagnet. The core and coil are coaxial along a first longitudinal axis **108**. Member **106** is elongated along a second longitudinal axis **110** which is parallel to axis **108**. Core **102** has two end sections **112a** and **112b** which extend along axis **106** beyond the area covered by the coil. The core end sections are exemplarily similar. End sections **112a** and **112b** have planar horizontal (X-Z) "operative" surfaces **114a** and **114b**. Second ferromagnetic member **106** has two end sections **116a** and **116b** with respective planar horizontal operative surfaces **118a** and **118b** which face surfaces **114a** and **114b** across a gap **120** of size "d" and overlap over an area "A". The operative surfaces are shown exemplarily as having rectangular shapes. Other shapes are possible.

In an operative state, FIG. 1B, current applied to the coil develops an EM force F in the Y direction. F is approximately proportional to $A(IxN)^2/(B + d)^2$ where I is the current, N is the number of coil wire turns and B is a constant which depends on the geometry and material of the device. The magnetic force pulls the two ferromagnetic members toward each other, reducing the gap size and thereby minimizing the magnetic reluctance. Evidently, when the gap is small, F is very large. However, for larger gaps, e.g. gaps satisfying d > B, F decreases quickly as d increases. A counterforce S may be provided by a spring **122.** For a particular current, an equilibrium formed between the EM force and the spring force leads to a particular gap size. However, while F is approximately proportional to $1/d^2$, S proportional to 1-d (i.e. is linear). The different dependencies on d lead to two major problems: the range of significant EM force is small, and the gap can collapse. Therefore, the use of such an actuator would be problematic in camera applications.

The problems mentioned may be somewhat alleviated by introducing a ferromagnetic fluid to fill the gap. This can result in a significant reduction in the constants A and C, which in turn reduces the maximal F (when $d \rightarrow 0$) but increases the usable gap (displacement) range.

FIG. 2 shows an embodiment of an EM actuator disclosed herein and numbered **200** in an isometric view in: (A) a relaxed state, and (B) a closed operative state. Also shown are details of a "gap and hinge" region. Actuator **200** comprises a ferromagnetic frame **202** includes a U-shaped section **204** having an elongated base member **206** extending along a first longitudinal axis **208** and arms **210a** and **210b.** Frame **202** further includes a second section **212** which includes arms **212a** and **212b.** All arms have cross sections A (in essentially the X-Y plane). Arms **212a** and **212b** are connected through an elongated ferromagnetic member (core) **214** surrounded partially by a coil **216.** Core **214** and coil **216** extend along a second longitudinal axis **218** which is parallel with axis **206**. Arms **208a** and **208b** and **212a** and **212b** are separated by respective V-shaped gaps **220a** and **220b** except at hinges **222a** and **222b** which extend along a third longitudinal axis **224**, parallel to axes **206** and **218**. Each gap **220** is characterized by an angle θ and a top opening of size d'. The gap determines the reluctance of the magnetic circuit. The gap is shaped to allow a relative tilt (pivoting) motion between sections **204** and **210** around hinges **222** through a tilt angle which can vary exemplarily between 0 degrees (for a relaxed or "open" state) and 5 degrees for a closed (minimal reluctance) state. When current passes through coil **216**, a "folding" EM force develops in the frame such that member **206** undergoes a displacement Δy in the Y direction relative to core **214** (FIG. 2B). Δy may be along an optical axis. The EM force F is approximately proportional to $A(IxN)^2/ (B + d')^2$. The material in the hinge region has elastic properties and serves as a spring. This configuration has an advantage in that even if the maximal d' is small (which results in a high force) one can achieve a large lateral movement of base member **204**.

FIG. 3 shows another embodiment of an EM actuator numbered **300** in isometric and frontal views in: (A) a relaxed (open) state, and (B) a closed operative state. Actuator **300** comprises a U-shape structure with a first planar frame **302,** a base section **304,** and a second planar frame **306**. The two frames are non-ferromagnetic and joined at a frame hinge **308,** which may be integral to the structure (see below). The base section and /or hinge material have elastic properties that enable them to act as a spring. Frame **302** is stationary and has attached thereto a first elongated ferromagnetic member (core) **310** surrounded partially by a conductive coil **312.** The core and coil extend and are coaxial along a first longitudinal axis **314**. The core has two end sections **310a** and **310b** which extend beyond the area covered by the coil. End sections **310a** and **310b** have planar vertical (X-Y) operative surfaces **316a** and **316b** with an overlap depth S (in the Z direction). Exemplarily, S may be about 1 mm. Frame **306** has attached thereto a second ferromagnetic member **318** which extends along a second longitudinal axis **324** and has two end sections **318a** and **318b.** These end sections have respective planar vertical operative surfaces **320a** and **320b.** Essentially, the extension of second ferromagnetic member **318** is greater than the extension of first ferromagnetic member **310**, so that the first ferromagnetic member is configured for being at least partially contained within the second ferromagnetic member. The pairs of vertical operative surfaces **316a** and **320a** and **316b** and **320b** thus face each other across constant gaps **322** of size d.

Frame **306** is movable (can tilt or pivot) around frame hinge **308.** Note that hinge **308** (positioned here at ends of "arms" of the frames, arms which are perpendicular to the ferromagnetic members) extends along a third longitudinal axis **326**. Axis **326** is parallel to axes **314** and **324**. An overlap area between operative surfaces is defined by depth S multiplied by a displacement Δy in the Y direction, i.e. by SΔy. Δy may vary exemplarily between 0 and 500μm. In a typical application involving cameras, actuator **300** and others disclosed below may be connected to an optical lens which will in turn undergo a similar displacement upon actuation.

Note that a U-shape shown is exemplary. Other shapes which allow a relative tilt between two frames around a common frame hinge (such as a V-shape, an intermediate shape between a U-shape and a V-shape, and more generally partially curved frame shapes which keep the longitudinal axes of the two ferromagnetic members parallel) may be used for purposes set forth herein. Also note that the use of frames to support the ferromagnetic members and to provide the tilt movement capability through their connection to a common hinge is exemplary, and that full plates (see FIG. 10) or other types of platforms may replace the frames. Further note that a hinge may be formed by local structural or mechanical changes in the same material used for the frames. That is, a frame may be locally (in a narrow area around the hinge longitudinal axis) thinned or its mechanical/elastic properties changed so that it becomes more flexible in that area. Such a hinge is referred to as an "integral" hinge.

All following actuator embodiments have first and second ferromagnetic members and hinges with parallel longitudinal axes. Also, electromagnet core end sections with operative surfaces extend beyond the coil in all embodiments. Therefore, these facts are not described further but can be seen in the drawings.

A current applied to coil **308** develops an EM force F in the Y direction approximately proportional to $S(IxN)^2/(B + d)$. The force causes the operative surfaces to slide relative to each other, changing the overlap area but leaving d constant. The overlap is minimal in the relaxed ("open") state, FIG. 3A, and, in an operative state, increases with I to a maximal overlap (FIG. 3B) which represents a "closed" state. To a first approximation, the EM force in this configuration depends essentially only on the current (i.e. is independent of position). This provides easier control of the position (actuation state) than for example in actuator **100**.

FIG. 4 shows another embodiment of an EM actuator disclosed herein and numbered **400** in isometric and frontal views in: (A) a relaxed (open) state, and (B) a closed operative state. Actuator **400** is similar to actuator **300**, i.e. it has exemplarily a U-shape structure with a first fixed planar frame **402**, a base section **404,** and a second movable planar frame **406**. Frames **402** and **406** are joined at a common hinge **408**. Actuator **400** differs from actuator **300** in that a first elongated ferromagnetic member **410** has end sections **410a** and **410b** with "forked" vertical surfaces **414a** and **414b**. End sections **416a** and **416b** in a second ferromagnetic member **416** have respective forked vertical surfaces **418a** and **418b**. Each forked surface has two "prongs" (each prong having an operative "sub-surface"). Respective operative sub-surfaces of opposite members (**414** and **418**) are separated by gaps of size d. Opposing (across the gap) operative surfaces overlap over a depth S. For two-prong forks, the overlap area between operative surfaces is $2S\Delta y$, i.e. double the one obtained with actuator **300**. The fork geometry provides effectively two operative sub-surfaces for each ferromagnetic member, and this allows having doubled force (and magnetic reluctance) compared to that in actuator **300** for the same vertical displacement.

FIG. 5 shows yet another embodiment of an EM actuator disclosed herein and numbered **500** in: (A) isometric and side views of a relaxed state, (B) isometric and side views of a final operative state, and (C) a side view of an intermediate operative state. In principle, actuator **500** is similar to actuators **300** and **400** in that it is based on a framed structure capable of tilting around a hinge**.** However, in actuator **500**, the movable member includes the electromagnet, in contrast with actuators **300** and **400** in which the tilting member is the opposite ferromagnetic member. Also, operative surfaces in actuator **500** (as well as others below) are in planes substantially parallel to the longitudinal axes, in contrast with actuators **300** and **400**, in which they are substantially perpendicular to such axes. Actuator **500** includes exemplarily a U-shape structure with a first frame **502**, a base section **504** and a second planar frame **506.** The frames and base section are non-ferromagnetic. Frame **506** has attached thereto a first surface of a non-ferromagnetic spacer **510.** Spacer **510** has attached thereto at a second, opposite surface, two ferromagnetic arms **512a** and **512b** with respective operative end surfaces **514a** and **514b**. Arms **512a** and **512b** are connected through an elongated ferromagnetic member (core) **514** surrounded partially by a coil **516.** Frame **502** has attached thereto a vertical ferromagnetic member **518** (similar to member **316** in FIG. 3) with two end sections **518a** and **518b.** End sections **518a** and **518b** have respective operating end surfaces **520a** and **520b**. Surfaces **520a** and **520b** face respectively surfaces **514a** and **514b** across constant gaps of size d. Operative surfaces **514a** and **514b** have a curvature with radius R, where R originates at common hinge **508**. Exemplarily, R is 3 mm. Operative surfaces **520a** and **520b** have a matching curvature with respectively radii R and (R+d). Opposing (across the gap) operative surfaces overlap over a depth S. A relative tilt movement between the operative surfaces of opposing ferromagnetic members keeps the gap constant while changing an overlap area.

As in actuator **300**, a current applied to coil **516** develops an EM force which depends essentially only on the current. The operative surfaces slide relative to each other with a displacement Δy occurring in the Y direction. In some camera embodiments, Δy may vary between 0 and 500μm or between 0 and 1000μm. In other embodiments, Δy may vary between 0 and 1000μm. The displacement provides an overlap area SΔy. The overlap area is minimal in the relaxed state, FIG. 5A, and increases in an operative state to a maximal overlap, FIG. 5B, which represents a "closed state".

FIG. 6 shows yet another embodiment of an EM actuator disclosed herein and numbered **600** in: (A) isometric and side views of a relaxed state, and (B) isometric and side views of a final operative state. Actuator **600** is shown with exemplary dimensions of length L of 3.5 mm, width W of 8mm, height h (along an optical axis) of 2 mm, radius R of 3mm and a gap d of 15μm for the position in which the operative surfaces are parallel. In this embodiment, opposing operative surfaces overlap over a depth S which is exemplarily 0.9 mm. Actuator **600** is similar to actuator **500**, except that operative surfaces **614** (on a moving ferromagnetic member **616**) and operative surfaces **620** (on a stationary ferromagnetic member **618**) approximate flat planes instead of arcs. Surfaces **614** and **620** actually represent two operative surfaces of the same ferromagnetic member, as in FIG. 5. In contrast with gaps in actuator **500**, the gap between opposing operative surfaces **614** and **620** is not constant over the range of Δy displacements between a relaxed (open) state (FIG. 6A) and a fully operative (closed) state (FIG. 6C). Nevertheless, the change in gap width is tolerable over an operating range of displacements (for example, d varies from a minimum of 15μm to a maximum of 25μm).

FIG. 7 shows yet another embodiment of an EM actuator disclosed herein and numbered **700** in: (A) isometric and side views of a relaxed state, and (B) isometric and side views of a final operative state. Actuator **700** is similar to actuators **500** or **600** (i.e. it can have either flat or curved operative surfaces), except that its operative surfaces **714** and **720** are forked as in actuator **300** (and thus provide similar sub-surfaces). Its operation is similar to that of actuators **500** and **600**, with the sub-surfaces providing doubled force (and magnetic reluctance) compared to that in actuators **500** or **600** for the same vertical displacement.

FIG. 8 shows isometric views of yet another embodiment of an EM actuator disclosed herein and numbered **800** in: (A) a relaxed state and (B) a final operative state. Actuator **800** is similar to previously described actuators disclosed herein, having two frames **802** and **806** with respective arms **830a, 830b** and **832a** and **832b.** The frames are coupled at frame hinges **808** positioned at some point (e.g. centered) along of the length of the arms. The ferromagnetic members (e.g. a first member **810** with surrounding coil **812** and a parallel second member **814**) are perpendicular to the arms. The displacement Δy depends on the hinge position and on the length of the arms L. The frames can tilt around the hinges in a range of angles ± θ (exemplarily ± 5 degrees).

FIG. 9 shows isometric views of an embodiment of an EM actuator assembly numbered **900** and capable of θ-φ (double-axis) tilting in: (A) an open-open state, (B) an open-closed state, (C) a closed-open state, and (D) a closed-closed state**.** Assembly **900** includes two actuators **800** (numbered. **800'** and **800"**) arranged such that their respective ferromagnetic members are orthogonal. This provides double-axis tilting. One tilt motion (θ) is around hinges **808'** and the other tilt motion (φ) is around hinges **808".** Each actuator can provide at least "end" two positions, i.e. "open" and "closed" (as well as a range of intermediate positions).

FIG. 10 shows isometric views of another embodiment of an EM actuator assembly numbered **1000** which can provide double-axis tilting in: (A) an open-open state and (B) a closed-closed state. Assembly **1000** includes two actuators similar to actuator **400** (numbered. **400'** and **400"**) coupled so as to provided θ-φ (double-axis) tilting. In contrast with the actuators in assembly **900,** actuators **400'** and **400"** are arranges such that their ferromagnetic members are parallel. Note that here plates **1002** and **1004** are used instead of frames to support the ferromagnetic members. FIG. 10A shows the assembly in a relaxed state while FIG. 10B shows it in an operational state. An optical element may be coupled to the assembly at points **1004** and **1006** and each actuator may provide a different displacement Δy along axes **1008** and **1010** such that the result is tilt in two directions. Note that other actuators disclosed above can be similarly combined into two-actuator assemblies.

Single actuators or actuator assemblies disclosed above can be used as drive mechanisms in digital cameras, and in particular in small cameras like those in cellphones. Assemblies such as **900** and **1000** can provide tilt movement of various optical components. They can for example implement OIS by tilting an entire camera module, and/or lateral movement of various components to implement camera Auto Focus (AF) by changing a lens-to-sensor distance.

FIG. 11 shows schematically an embodiment of a camera module **1100** which includes an actuator assembly coupled to a lens module **1101**: (A) isometric view in a first position, (B) isometric view in a second position, (C) a frontal view in the first position, (D) a frontal view in the second position, (E) a flexible band **1102** coupling the actuator assembly and the lens module in the first position, and (F) the flexible band in the second position. The actuator assembly is similar to that in FIG. 10 in the sense that two (first and second) actuators **1104'** and **1104"** have respective electromagnets **1104a** and **1104b** arranged in parallel on opposite sides of the lens module. Actuators **1104'** and **1104"** are exemplarily similar to actuator **600.** The total module height (along an optical axis) is indicated by "H" while "h" indicates an actuator height (as in FIG. 6). Exemplarily, H/h > 3. Actuator **1104'** includes a first ferromagnetic member **1106** and a second ferromagnetic member **1108** partly surrounded coaxially by a coil **1110** and fixedly attached to flexible band **1102** through spacers **1114**. Actuator **1104"** includes a first ferromagnetic member **1116** and a second ferromagnetic member **1118** partly surrounded coaxially by a coil **1120** and fixedly attached to flexible band **1102.** Flexible band **1102** may be made of a flexible material (e.g. hard rubber) and provides two spring-like "integral hinges" **1102a** and **1102b** for each actuator. The ferromagnetic members and hinges have parallel longitudinal axes. A lens barrel **1126** is fixedly attached to the band at two opposite (along a barrel radius) lens holders (or "shoulders") **1128.** The band is attached at four corners by spring sections **1129** to pillars **1124**, which may be made of hard rubber or similar material. The pillars may tilt slightly to allow tilt by integral hinges 1102. The two hinges allow both Y-displacement and tilt of the second ferromagnetic members (in the electromagnet) of an actuator, as well as displacement of the lens barrel along the Y axis and tilt of the lens barrel around the Z axis.

In use, when both actuators are operated to provide the same displacement, the overlap between opposite operative surfaces of each actuator changes. Exemplarily, in first position (A) shows no overlap between operative surfaces **1130** and **1132** while second position (B) shows a maximal overlap between these surfaces. In the move from the first to the second position, the band flexes around the two hinges, such that it changes shape from a planar state (E) to a flexed state (F). Hinges **1102a** are kept stationary in the Y direction by the fixed attachment of the band to the pillars, but allow tilt of the spacers (and of operative surfaces **1130**). The two hinges **1102b** and the band section therebetween (attached to the lens holder) are therefore displaced along the Y axis and tilting spacers **1114** as well as displacing the lens barrel along the Y axis. The action just described can be used for miniature camera AF, with AF functionality achieved without an increase of the camera module's total height.

In an OIS application, an actuator assembly as described in FIGS. 9 or 10 is placed under the camera module so that it can tilt the entire camera module and achieve pitch and yaw correction. Alternatively (for one-axis tilt) this can be done by providing a different displacement by each actuator in an actuator assembly such as that of FIG. 11.

FIG. 12 shows results of a simulation related to the actuator of FIG. 6. The figure shows the EM force as function of the position (and gap size) for N=580 and illustrates that at least for certain currents (e.g. for 40 mA), the force is approximately constant over a large part of an operating range of 500 μm.

While this disclosure has been described in terms of certain embodiments and generally associated methods, alterations and permutations of the embodiments and methods will be apparent to those skilled in the art. The disclosure is to be understood as not limited by the specific embodiments described herein, but only by the scope of the appended claims.

CLAIMS

1. An electro-magnetic actuator used to provide a linear movement of an optical element along an optical axis, the actuator comprising:

a) a first elongated ferromagnetic member surrounded partially by a conductive coil, the first ferromagnetic member having a first longitudinal axis and a first operative surface;

b) a second elongated ferromagnetic member having a second longitudinal axis parallel to the first longitudinal axis and a second operative surface, the first and second ferromagnetic members disposed such that a gap and an overlap are formed between the first and second operative surfaces; and

c) a frame hinge having a third longitudinal axis parallel to the first and second longitudinal axes, the frame hinge used to enable one ferromagnetic member to undergo a linear tilt motion relative to the other ferromagnetic member when a magnetic force is generated by current in the coil, the linear tilt motion convertible into a linear displacement of the optical element from a first position to a second position.

2. The actuator of claim 1, wherein each operative surface includes two operative surface sections disposed at two opposing ends of each ferromagnetic member.

3. The actuator of claim 1, wherein the movement between the first and second positions is continuous and provides a third, intermediate position for the optical element.

4. The actuator of claim 1, wherein the first position corresponds to a maximal overlap and wherein the second position corresponds to a minimal overlap.

5. The actuator of claim 1, wherein each ferromagnetic member has an extension along its respective longitudinal axis, the extension of the second ferromagnetic member being greater than the extension of the first ferromagnetic member along the first longitudinal axis, so that the first ferromagnetic member is configured for being at least partially contained within the second ferromagnetic member.

6. The actuator of claim 5, wherein each ferromagnetic member is formed with two operative surfaces spaced and facing away from one another so that when the first ferromagnetic member is at least partially contained within the second ferromagnetic member, the operative surfaces of the first ferromagnetic member face the operative surfaces of the second ferromagnetic member.

7. The actuator of claim 6, wherein each operative surface is in the form of a fork having a plurality of portions spaced apart by respective gaps, each portion being formed with an operative sub-surface.

8. The actuator of claim 2, wherein the gap and the overlap are formed between first and second operative surface sections defined by flat planes perpendicular to an axis originating at the hinge.

9. The actuator of claim 2, wherein the gap and the overlap are formed between first and second operative surface sections defined by curved planes having a common radius originating at the hinge.

10. The actuator of any of claims 1 to 9, wherein one ferromagnetic member is fixedly attached to a first platform, wherein the other ferromagnetic member is fixedly attached to a second platform, and wherein one of the two platforms is movable.

11. The actuator of claim 10, wherein the platforms are non-ferromagnetic.

12. The actuator of claim 11, wherein at least one platform is in the form of a frame.

13. The actuator of claim 12, wherein at least one of the first longitudinal axis and the second longitudinal axis is oriented parallel to the frame.

14. The actuator of claim 13, wherein at least the movable platform is made of a flexible material which is used to form the common hinge as an integral hinge.

15. The actuator of claim 10, wherein the displacement ranges between 0 and approximately 500μm.

16. The actuator of claim 10, wherein the tilt is in an angle between 0 and approximately 5°.

17. The actuator of claim 10, wherein the optical element is a lens assembly.

18. The actuator of claim 10, combined with another such actuator to form an actuator assembly which provides a double-axis tilt capability.

19. The actuator of claim 18, wherein the two actuators have first ferromagnetic members and coils orthogonal to each other.

20. The actuator of claim 18, wherein the two actuators have first ferromagnetic members and coils parallel to each other.

21. The actuator of claim 18, wherein the actuator assembly is configured for controlling a focus of the optical device.

22. The actuator of claim 18, wherein the actuator assembly is configured for controlling vibration compensation of the optical device.

23. The actuator of claim 10, implemented in a digital camera.

24. The actuator of any of claims 11-17, implemented in a digital camera.

25. The actuator of claim 18, implemented in a digital camera.

26. The actuator of claim 23, wherein the actuator has a height h, wherein the digital camera has a height H, and wherein $H/h > 3$.

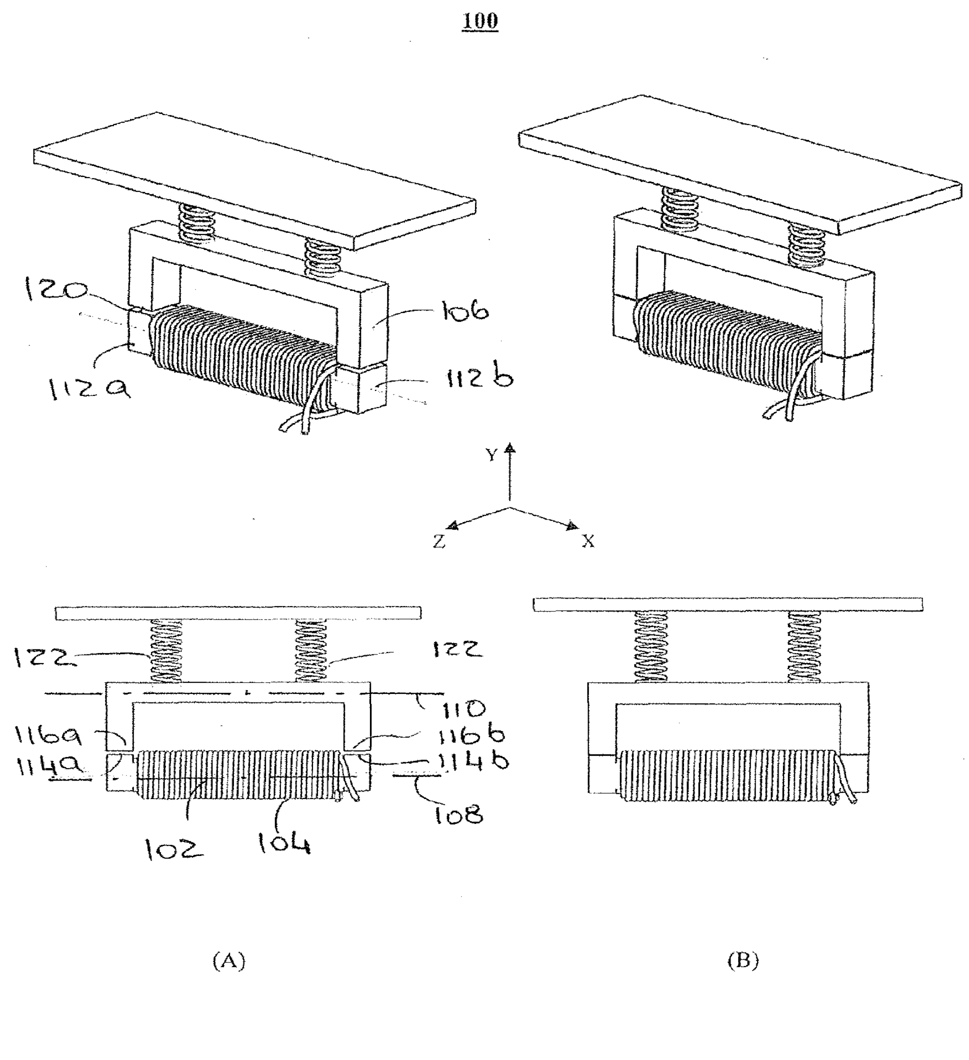

100
120
106
112a
112b
Y
Z
X
122
122
110
116a
116b
114a
114b
108
102
104
(A)
(B)

FIG. 1

200

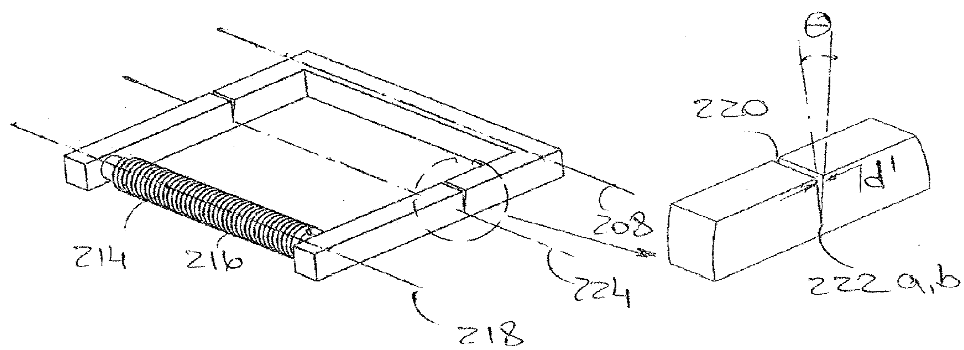


FIG. 2A

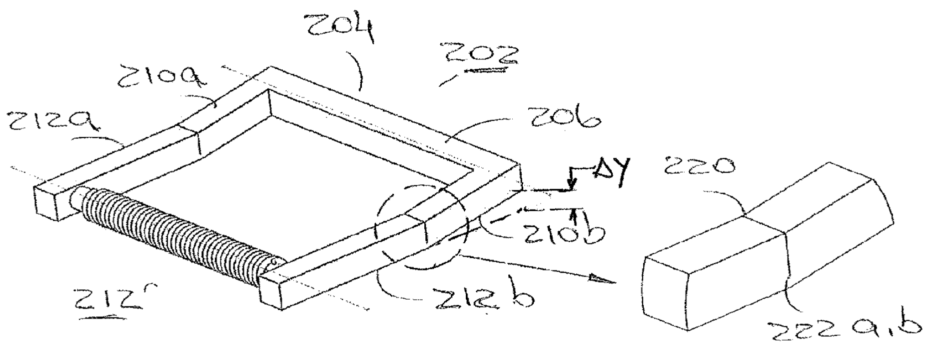


FIG. 2B

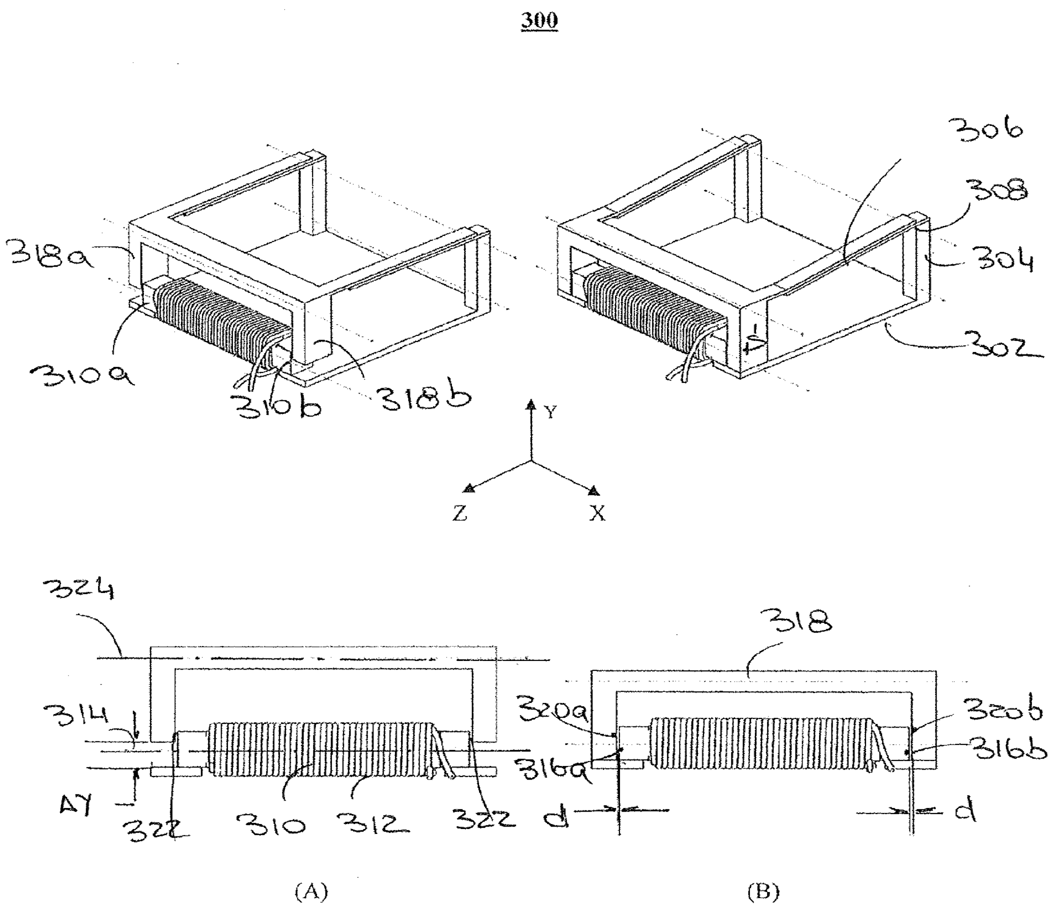

300
306
308
318a
304
302
310a
310b
318b
Y
Z
X
324
318
314
320a
320b
316b
316a
ΔY
322
310
312
322
d
d
(A)
(B)

FIG. 3

400

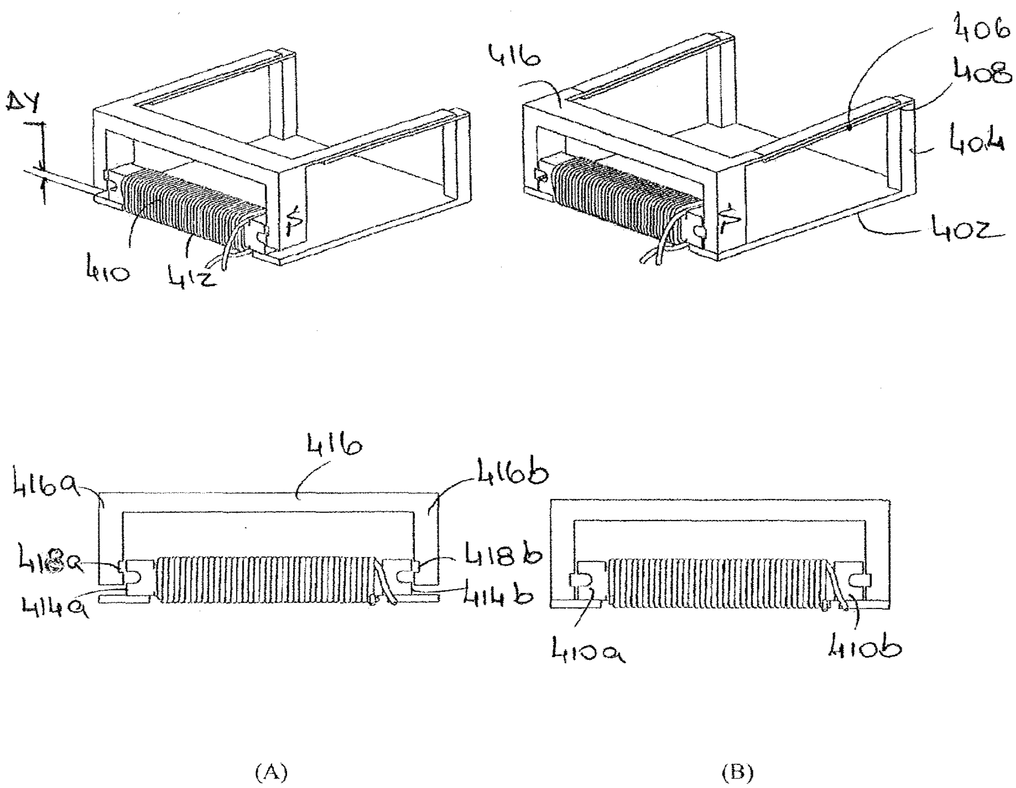

ΔY
416
406
408
404
402
410
412
416
416a
416b
418a
418b
414a
414b
410a
410b
(A)
(B)

FIG. 4

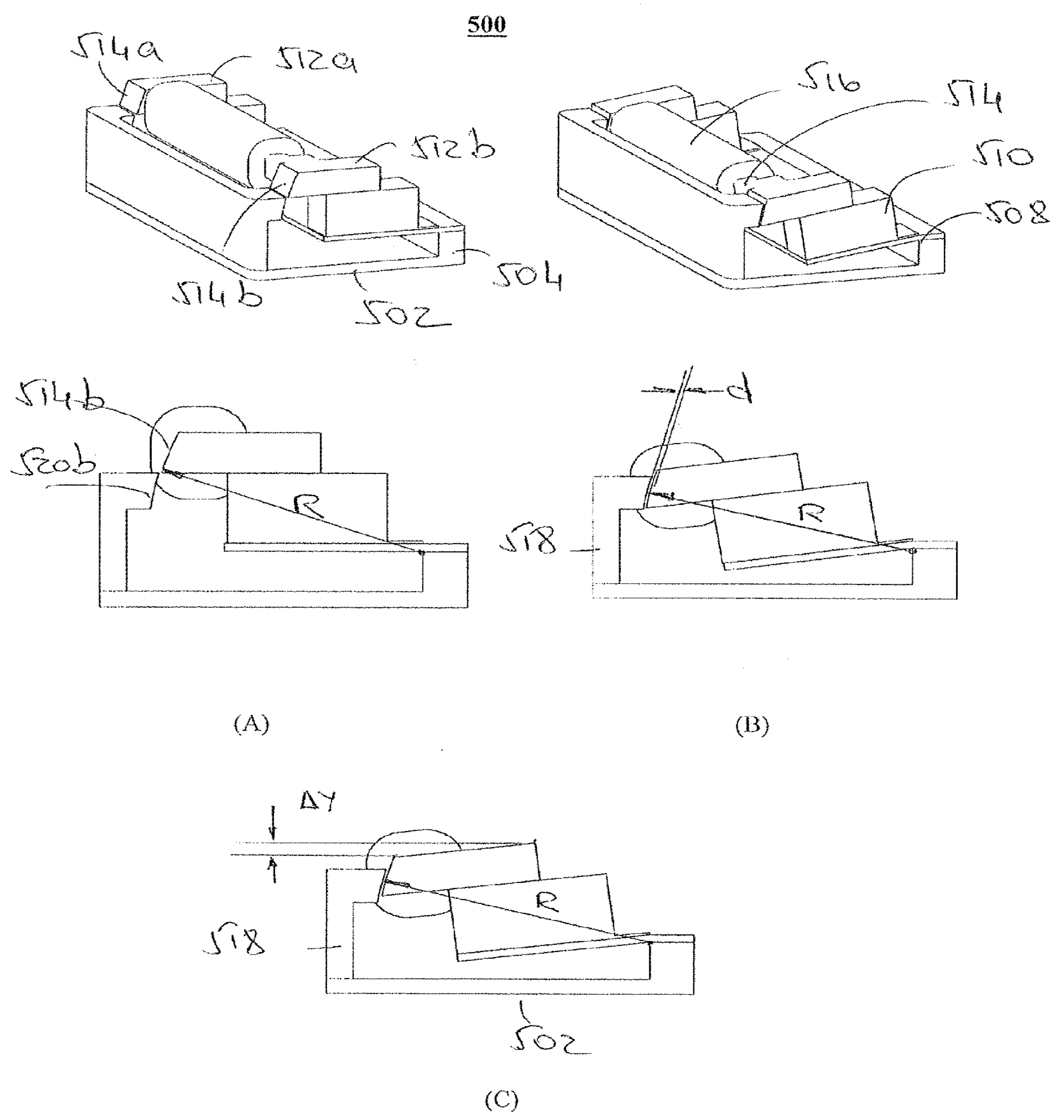
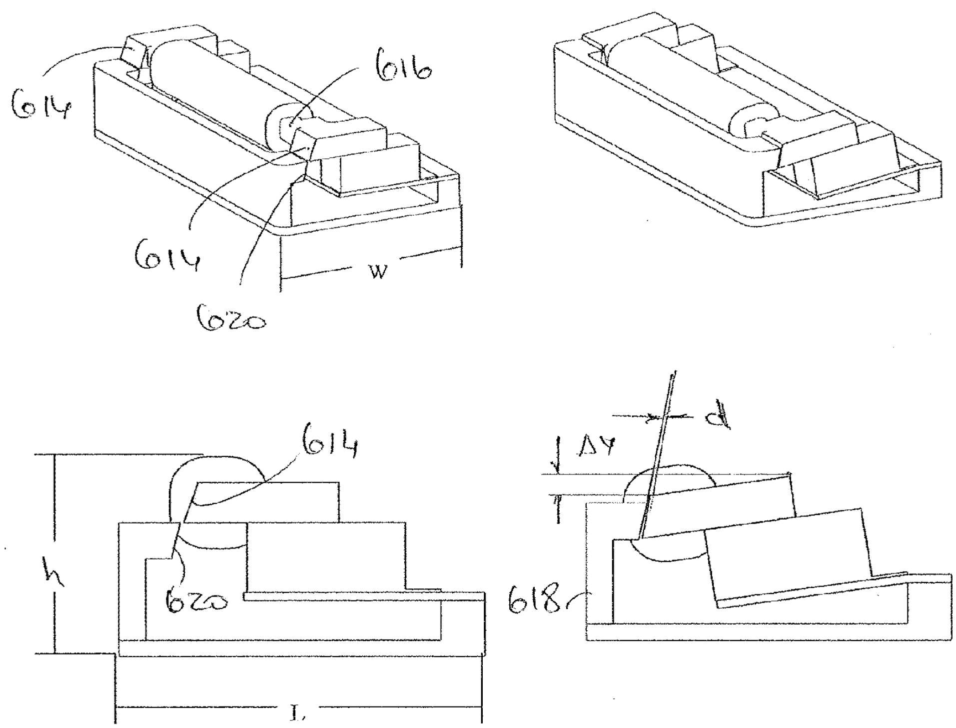

500
514a
512a
512b
514b
502
504
516
514
510
508
514b
520b
R
d
518
R
(A)
(B)
ΔY
518
R
502
(C)

FIG. 5

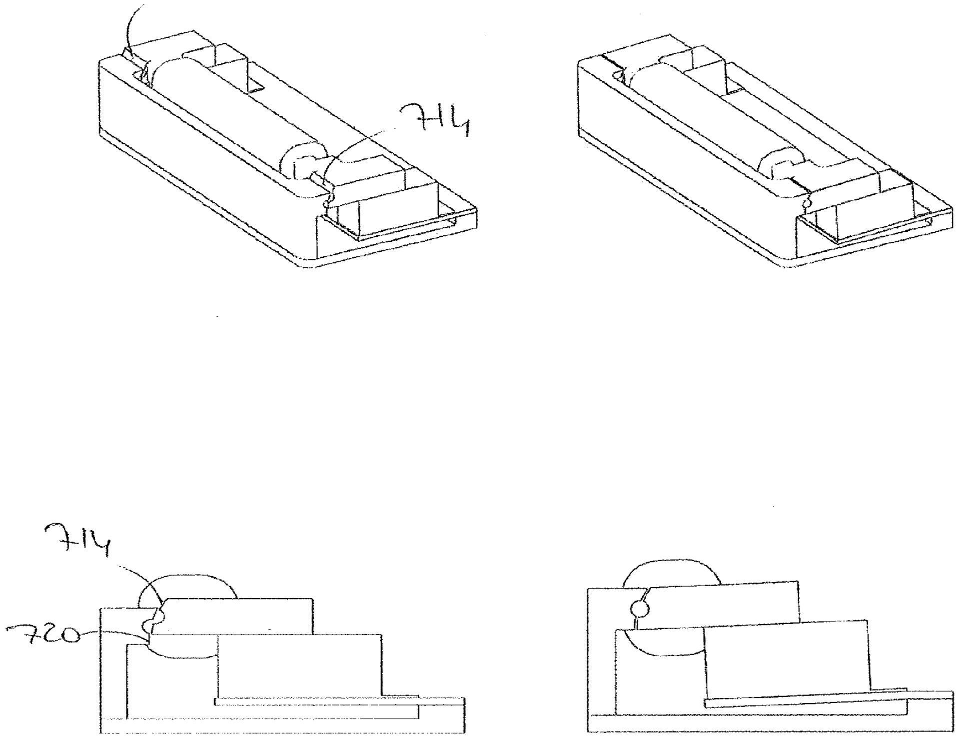
600



(A) (B)

FIG. 6

700



(A) (B)

FIG. 7

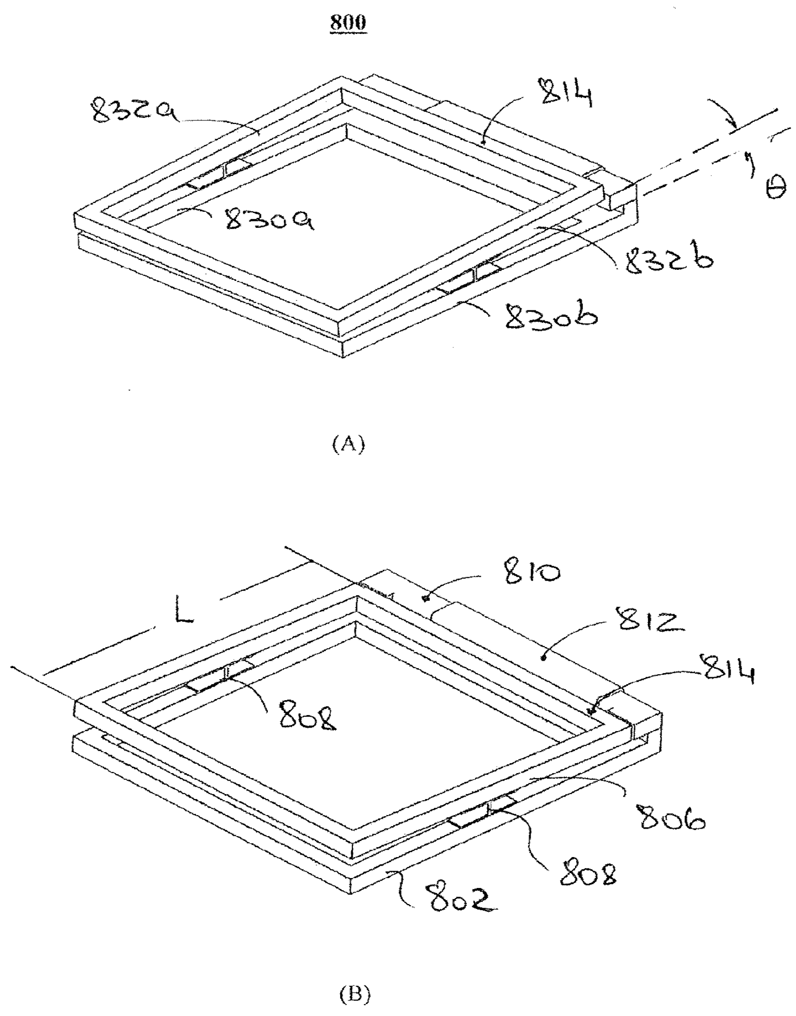


FIG. 8

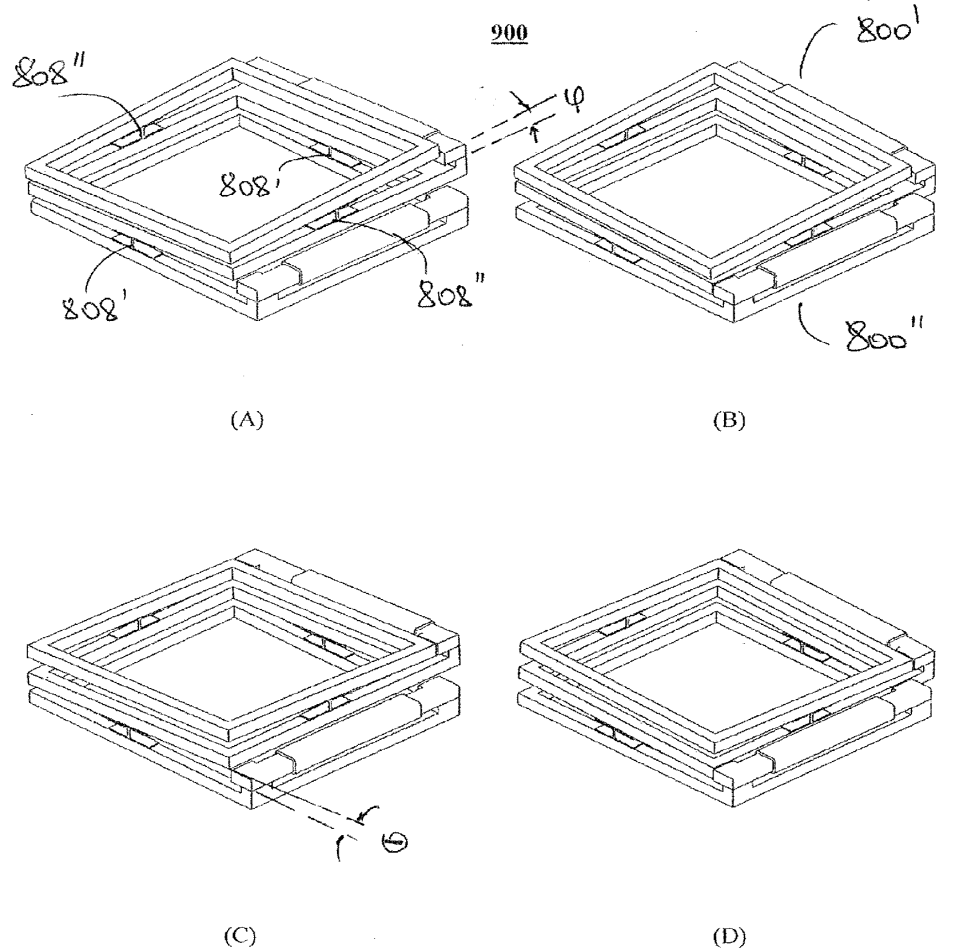


FIG. 9

1000

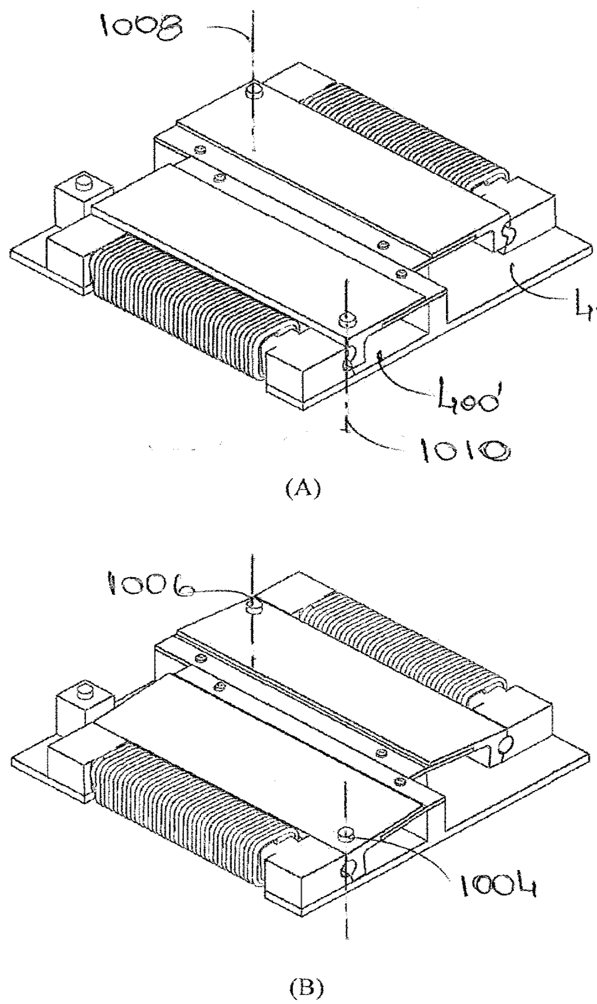


FIG. 10

<u>1100</u>

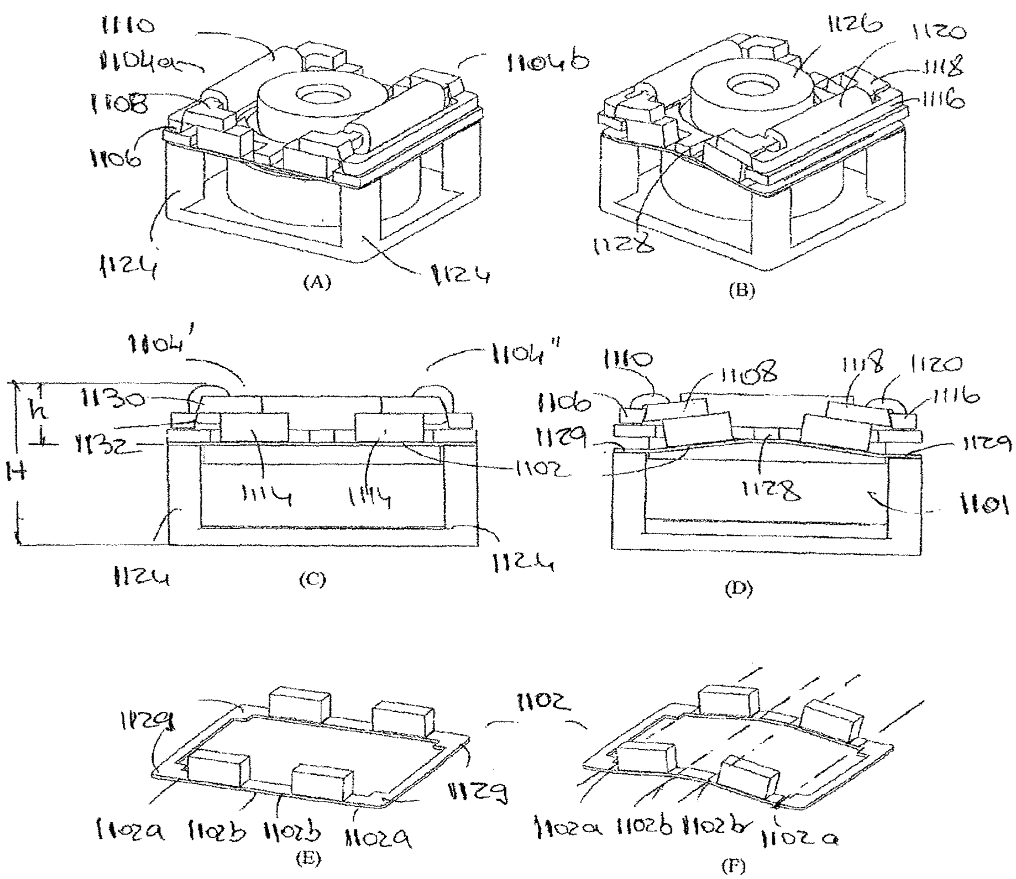


FIG. 11

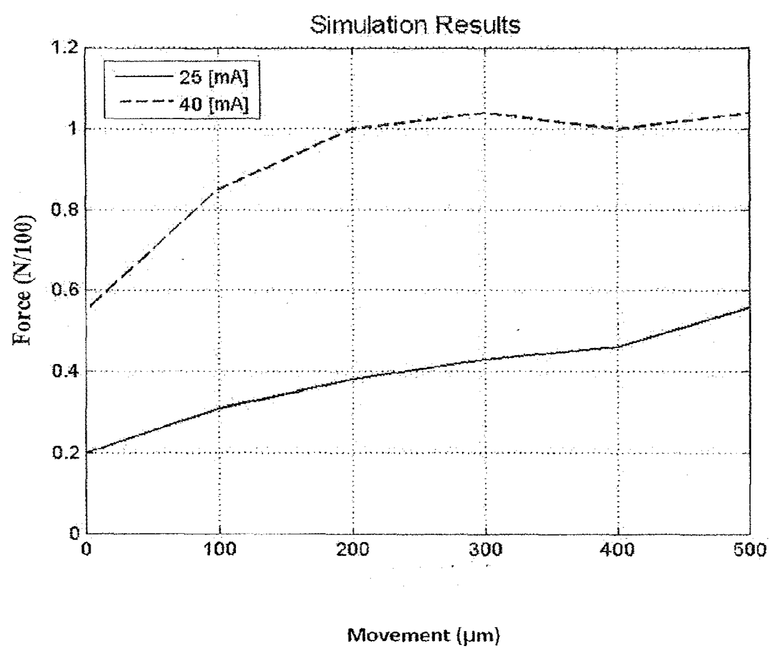

Simulation Results
25 [mA]
40 [mA]
Force (N/100)
Movement (μm)
0
0.2
0.4
0.6
0.8
1
1.2
0
100
200
300
400
500

FIG. 12

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Published:

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(54) Title: DUAL APERTURE ZOOM DIGITAL CAMERA

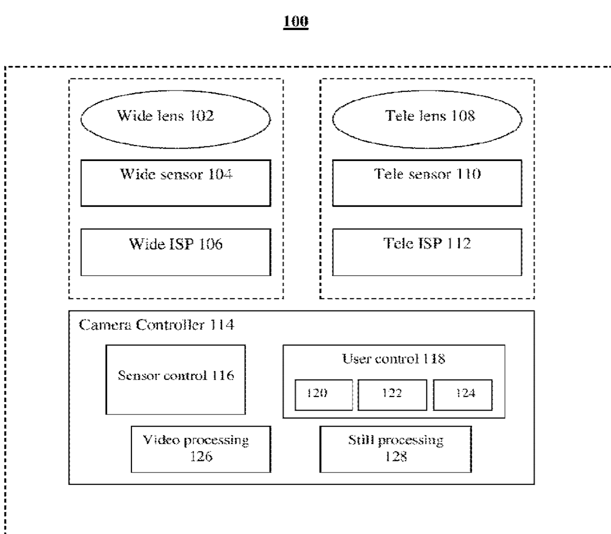

FIG. 1A

(57) Abstract: A dual-aperture zoom digital camera operable in both still and video modes. The camera includes Wide and Tele imaging sections with respective lens/sensor combinations and image signal processors and a camera controller operatively coupled to the Wide and Tele imaging sections. The Wide and Tele imaging sections provide respective image data. The controller is configured to combine in still mode at least some of the Wide and Tele image data to provide a fused output image from a particular point of view, and to provide without fusion continuous zoom video mode output images, each output image having a given output resolution, wherein the video mode output images are provided with a smooth transition when switching between a lower zoom factor (ZF) value and a higher ZF value or vice versa, and wherein at the lower ZF the output resolution is determined by the Wide sensor while at the higher ZF value the output resolution is determined by the Tele sensor.

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DUAL APERTURE ZOOM DIGITAL CAMERA

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to and claims priority from US Provisional Patent Application No. 61/834,486 having the same title and filed June 13, 2013, which is incorporated herein by reference in its entirety.

FIELD

Embodiments disclosed herein relate in general to digital cameras and in particular to thin zoom digital cameras with both still image and video capabilities

BACKGROUND

Digital camera modules are currently being incorporated into a variety of host devices. Such host devices include cellular telephones, personal data assistants (PDAs), computers, and so forth. Consumer demand for digital camera modules in host devices continues to grow.

Host device manufacturers prefer digital camera modules to be small, so that they can be incorporated into the host device without increasing its overall size. Further, there is an increasing demand for such cameras to have higher-performance characteristics. One such characteristic possessed by many higher-performance cameras (e.g., standalone digital still cameras) is the ability to vary the focal length of the camera to increase and decrease the magnification of the image. This ability, typically accomplished with a zoom lens, is known as optical zooming. "Zoom" is commonly understood as a capability to provide different magnifications of the same scene and/or object by changing the focal length of an optical system, with a higher level of zoom associated with greater magnification and a lower level of zoom associated with lower magnification. Optical zooming is typically accomplished by mechanically moving lens elements relative to each other. Such zoom lenses are typically more expensive, larger and less reliable than fixed focal length lenses. An alternative approach for approximating the zoom effect is achieved with what is known as digital zooming. With digital zooming, instead of varying the focal length of the lens, a processor in the camera crops the image and interpolates between the pixels of the captured image to create a magnified but lower-resolution image.

Attempts to use multi-aperture imaging systems to approximate the effect of a zoom lens are known. A multi-aperture imaging system (implemented for example in a digital camera) includes a plurality of optical sub-systems (also referred to as "sub-cameras"). Each sub-camera includes one or more lenses and/or other optical elements which define an aperture such that received electro-magnetic radiation is imaged by the optical sub-system and a resulting image is directed towards a two-dimensional (2D) pixelated image sensor region. The image sensor (or simply "sensor") region is configured to receive the image and to generate a set of image data based on the image. The digital camera may be aligned to receive electromagnetic radiation associated with scenery having a given set of one or more objects. The set of image data may be represented as digital image data, as well known in the art. Hereinafter in this description, "image" "image data" and "digital image data" may be used interchangeably. Also, "object" and "scene" may be used interchangeably.

Multi-aperture imaging systems and associated methods are described for example in US Patent Publications No. 2008/0030592, 2010/0277619 and 2011/0064327. In US 2008/0030592, two sensors are operated simultaneously to capture an image imaged through an associated lens. A sensor and its associated lens form a lens/sensor combination. The two lenses have different focal lengths. Thus, even though each lens/sensor combination is aligned to look in the same direction, each captures an image of the same subject but with two different fields of view (FOVs). One sensor is commonly called "Wide" and the other "Tele". Each sensor provides a separate image, referred to respectively as "Wide" (or "W") and "Tele" (or "T") images. A W-image reflects a wider FOV and has lower resolution than the T-image. The images are then stitched (fused) together to form a composite ("fused") image. In the composite image, the central portion is formed by the relatively higher-resolution image taken by the lens/sensor combination with the longer focal length, and the peripheral portion is formed by a peripheral portion of the relatively lower-resolution image taken by the lens/sensor combination with the shorter focal length. The user selects a desired amount of zoom and the composite image is used to interpolate values from the chosen amount of zoom to provide a respective zoom image. The solution offered by US 2008/0030592 requires, in video mode, very large processing resources in addition to high frame rate requirements and high power consumption (since both cameras are fully operational).

US 2010/0277619 teaches a camera with two lens/sensor combinations, the two lenses having different focal lengths, so that the image from one of the combinations has a FOV approximately 2-3 times greater than the image from the other combination. As a user of the camera requests a given amount of zoom, the zoomed image is provided from the lens/sensor combination having a FOV that is next larger than the requested FOV. Thus, if the requested FOV is less than the smaller FOV combination, the zoomed image is created from the image captured by that combination, using cropping and interpolation if necessary. Similarly, if the requested FOV is greater than the smaller FOV combination, the zoomed image is created from the image captured by the other combination, using cropping and interpolation if necessary. The solution offered by US 2010/0277619 leads to parallax artifacts when moving to the Tele camera in video mode.

In both US 2008/0030592 and US 2010/0277619, different focal length systems cause Tele and Wide matching FOVs to be exposed at different times using CMOS sensors. This degrades the overall image quality. Different optical F numbers ("F#") cause image intensity differences. Working with such a dual sensor system requires double bandwidth support, i.e. additional wires from the sensors to the following HW component. Neither US 2008/0030592 nor US 2010/0277619 deal with registration errors. Neither US 2008/000592 nor US 2010/0277619 refer to partial fusion, i.e. fusion of less than all the pixels of both Wide and Tele images in still mode.

US 2011/0064327 discloses multi-aperture imaging systems and methods for image data fusion that include providing first and second sets of image data corresponding to an imaged first and second scene respectively. The scenes overlap at least partially in an overlap region, defining a first collection of overlap image data as part of the first set of image data, and a second collection of overlap image data as part of the second set of image data. The second collection of overlap image data is represented as a plurality of image data sub-cameras such that each of the sub-cameras is based on at least one characteristic of the second collection, and each sub-camera spans the overlap region. A fused set of image data is produced by an image processor, by modifying the first collection of overlap image data based on at least a selected one of, but less than all of, the image data sub-cameras. The systems and methods disclosed in this application deal solely with fused still images.

None of the known art references provide a thin (e.g. fitting in a cell-phone) dual-aperture zoom digital camera with fixed focal length lenses, the camera configured to operate in both still mode and video mode to provide still and video images, wherein the camera configuration uses partial or full fusion to provide a fused image in still mode and does not use any fusion to provide a continuous, smooth zoom in video mode.

Therefore there is a need for, and it would be advantageous to have thin digital cameras with optical zoom operating in both video and still mode that do not suffer from commonly encountered problems and disadvantages, some of which are listed above.

SUMMARY

Embodiments disclosed herein teach the use of dual-aperture (also referred to as dual-lens or two-sensor) optical zoom digital cameras. The cameras include two sub-cameras, a Wide sub-camera and a Tele sub-camera, each sub-camera including a fixed focal length lens, an image sensor and an image signal processor (ISP). The Tele sub-camera is the higher zoom sub-camera and the Wide sub-camera is the lower zoom sub-camera. In some embodiments, the lenses are thin lenses with short optical paths of less than about 9mm. In some embodiments, the thickness/effective focal length (EFL) ratio of the Tele lens is smaller than about 1. The image sensor may include two separate 2D pixelated sensors or a single pixelated sensor divided into at least two areas. The digital camera can be operated in both still and video modes. In still mode, zoom is achieved "with fusion" (full or partial), by fusing W and T images, with the resulting fused image including always information from both W and T images. Partial fusion may be achieved by not using fusion in image areas where the Tele image is not focused. This advantageously reduces computational requirements (e.g. time).

In video mode, optical zoom is achieved "without fusion", by switching between the W and T images to shorten computational time requirements, thus enabling high video rate. To avoid discontinuities in video mode, the switching includes applying additional processing blocks, which include image scaling and shifting.

In order to reach optical zoom capabilities, a different magnification image of the same scene is captured (grabbed) by each camera sub-camera, resulting in FOV overlap between the two sub-cameras. Processing is applied on the two images to fuse and output one fused image in still mode. The fused image is processed according to a user zoom factor request. As part of the fusion procedure, up-sampling may be applied on one or both of the grabbed images to scale it to the image grabbed by the Tele sub-camera or to a scale defined by the user. The fusion or up-sampling may be applied to only some of the pixels of a sensor. Down-sampling can be performed as well if the output resolution is smaller than the sensor resolution. .

The cameras and associated methods disclosed herein address and correct many of the problems and disadvantages of known dual-aperture optical zoom digital cameras. They provide an overall zoom solution that refers to all aspects: optics, algorithmic processing and system hardware (HW). The proposed solution distinguishes between video and still mode in

the processing flow and specifies the optical requirements and HW requirements. In addition, it provides an innovative optical design that enables a low TTL/EFL ratio using a specific lens curvature order.

Due to the large focal length, objects that are in front or behind the plane of focus appear very blurry, and a nice foreground-to-background contrast is achieved. However, it is difficult to create such a blur using a compact camera with a relatively short focal length and small aperture size, such as a cell-phone camera. In some embodiments, a dual-aperture zoom system disclosed herein can be used to capture a shallow DOF photo (shallow compared with a DOF of a Wide camera alone), by taking advantage of the longer focal length of the Tele lens. The reduced DOF effect provided by the longer Tele focal length can be further enhanced in the final image by fusing data from an image captured simultaneously with the Wide lens. Depending on the distance to the object, with the Tele lens focused on a subject of the photo, the Wide lens can be focused to a closer distance than the subject so that objects behind the subject appear very blurry. Once the two images are captured, information from the out-of-focus blurred background in the Wide image is fused with the original Tele image background information, providing a blurrier background and even shallower DOF.

In an embodiment there is provided a zoom digital camera comprising a Wide imaging section that includes a fixed focal length Wide lens with a Wide FOV, a Wide sensor and a Wide image signal processor (ISP), the Wide imaging section operative to provide Wide image data of an object or scene; a Tele imaging section that includes a fixed focal length Tele lens with a Tele FOV that is narrower than the Wide FOV, a Tele sensor and a Tele ISP, the Tele imaging section operative to provide Tele image data of the object or scene; and a camera controller operatively coupled to the Wide and Tele imaging sections, the camera controller configured to combine in still mode at least some of the Wide and Tele image data to provide a fused output image of the object or scene from a particular point of view (POV), and to provide without fusion continuous zoom video mode output images of the object or scene, a camera controller operatively coupled to the Wide and Tele imaging sections, the camera controller configured to combine in still mode at least some of the Wide and Tele image data to provide a fused output image of the object or scene from a particular point of view and to provide without fusion continuous zoom video mode output images of the object or scene, each output image having a respective output resolution, wherein the video output images are provided with a smooth transition when switching between a lower zoom factor (ZF) value and a higher ZF value or vice versa, wherein at the lower ZF value the output resolution is determined by the Wide sensor, and wherein at the higher ZF value the output resolution is determined by the Tele sensor.

In an embodiment, the camera controller configuration to provide video output images with a smooth transition when switching between a lower ZF value and a higher ZF value or vice versa includes a configuration that uses at high ZF secondary information from the Wide camera and uses at low ZF secondary information from the Tele camera. As used herein, "secondary information" refers to white balance gain, exposure time, analog gain and color correction matrix.

In a dual-aperture camera image plane, as seen by each sub-camera (and respective image sensor), a given object will be shifted and have different perspective (shape). This is referred to as point-of-view (POV). The system output image can have the shape and position of either sub-camera image or the shape or position of a combination thereof. If the output image retains the Wide image shape then it has the Wide perspective POV. If it retains the Wide camera position then it has the Wide position POV. The same applies for Tele images position and perspective. As used in this description, the perspective POV may be of the Wide or Tele sub-cameras, while the position POV may shift continuously between the Wide and Tele sub-cameras. In fused images, it is possible to register Tele image pixels to a matching pixel set within the Wide image pixels, in which case the output image will retain the Wide POV ("Wide fusion"). Alternatively, it is possible to register Wide image pixels to a matching pixel set within the Tele image pixels, in which case the output image will retain the Tele POV ("Tele fusion"). It is also possible to perform the registration after either sub-camera image is shifted, in which case the output image will retain the respective Wide or Tele perspective POV.

In an embodiment there is provided a method for obtaining zoom images of an object or scene in both still and video modes using a digital camera, the method comprising the steps of providing in the digital camera a Wide imaging section having a Wide lens with a Wide FOV, a Wide sensor and a Wide image signal processor (ISP), a Tele imaging section having a Tele lens with a Tele FOV that is narrower than the Wide FOV, a Tele sensor and a Tele ISP, and a camera controller operatively coupled to the Wide and Tele imaging sections; and configuring the camera controller to combine in still mode at least some of the Wide and Tele image data to provide a fused output image of the object or scene from a particular point of view, and to provide without fusion continuous zoom video mode output images of the object or scene, each output image having a respective output resolution, wherein the video mode output images are provided with a smooth transition when switching between a lower ZF value and a higher ZF value or vice versa, and wherein at the lower ZF value the output resolution is determined by the Wide sensor while at the higher ZF value the output resolution is determined by the Tele sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting examples of embodiments disclosed herein are described below with reference to figures attached hereto that are listed following this paragraph. The drawings and descriptions are meant to illuminate and clarify embodiments disclosed herein, and should not be considered limiting in any way.

FIG. 1A shows schematically a block diagram illustrating a dual-aperture zoom imaging system disclosed herein;

FIG. 1B is a schematic mechanical diagram of the dual-aperture zoom imaging system of FIG. 1A:

FIG. 2 shows an example of Wide sensor, Tele sensor and their respective FOVs;

FIG. 3 shows a schematically embodiment of CMOS sensor image grabbing vs. time;

FIG. 4 shows schematically a sensor time configuration which enables sharing one sensor interface using dual sensor zoom system;

FIG. 5 shows an embodiment of a method disclosed herein for acquiring a zoom image in capture mode;

FIG. 6 shows an embodiment of a method disclosed herein for acquiring a zoom image in video/preview mode;

FIG. 7 shows a graph illustrating an effective resolution zoom factor;

FIG. 8 shows one embodiment of a lens block in a thin camera disclosed herein;

FIG. 9 shows another embodiment of a lens block in a thin camera disclosed herein.

DETAILED DESCRIPTION

FIG. 1A shows schematically a block diagram illustrating an embodiment of a dual-aperture zoom imaging system (also referred to simply as "digital camera" or "camera") disclosed herein and numbered **100**. Camera **100** comprises a Wide imaging section ("sub-camera") that includes a Wide lens block **102**, a Wide image sensor **104** and a Wide image processor **106.** Camera **100** further comprises a Tele imaging section ("sub-camera") that includes a Tele lens block **108**, a Tele image sensor **110** and a Tele image processor **112**. The image sensors may be physically separate or may be part of a single larger image sensor. The

Wide sensor pixel size can be equal to or different from the Tele sensor pixel size. Camera **100** further comprises a camera fusion processing core (also referred to as "controller") **114** that includes a sensor control module **116**, a user control module **118,** a video processing module **126** and a capture processing module **128,** all operationally coupled to sensor control block **110**. User control module **118** comprises an operational mode function **120**, a region of interest (ROI) function **122** and a zoom factor (ZF) function **124**.

Sensor control module **116** is connected to the two sub-cameras and to the user control module **118** and used to choose, according to the zoom factor, which of the sensors is operational and to control the exposure mechanism and the sensor readout. Mode choice function **120** is used for choosing capture/video modes. ROI function **122** is used to choose a region of interest. As used herein, "ROI" is a user defined as a sub-region of the image that may be exemplarily 4% or less of the image area. The ROI is the region on which both sub-cameras are focused on. . Zoom factor function **124** is used to choose a zoom factor. Video processing module **126** is connected to mode choice function **120** and used for video processing. Still processing module **128** is connected to the mode choice function **120** and used for high image quality still mode images. The video processing module is applied when the user desires to shoot in video mode. The capture processing module is applied when the user wishes to shoot still pictures.

FIG. 1B is a schematic mechanical diagram of the dual-aperture zoom imaging system of FIG. 1A. Exemplary dimensions: Wide lens TTL = 4.2mm and EFL = 3.5mm; Tele lens TTL = 6mm and EFL = 7 mm; both Wide and Tele sensors 1/3 inch. External dimensions of Wide and Tele cameras: width (w) and length (l) = 8.5 mm and height (h) = 6.8 mm. Distance "d" between camera centers = 10mm.

Following is a detailed description and examples of different methods of use of camera **100.**

Design for continuous and smooth zoom in video mode

In an embodiment, in order to reach high quality continuous and smooth optical zooming in video camera mode while reaching real optical zoom using fixed focal length sub-cameras, the system is designed according to the following rules (Equations 1-3):

$$\text{Tan}\,(FOV_{Wide})/\text{Tan}\,(FOV_{Tele}) = PL_{Wide}/\,PL_{video} \qquad (1)$$

where Tan refers to "tangent", while FOV_{Wide} and FOV_{Tele} refer respectively to the Wide and

Tele lens fields of view (in degrees). As used herein, the FOV is measured from the center axis to the corner of the sensor (i.e. half the angle of the normal definition). PL_{Wide} and PL_{video} refer respectively to the "in-line" (i.e. in a line) number of Wide sensor pixels and in-line number of output video format pixels. The ratio PL_{Wide}/PL_{video} is called an "oversampling ratio". For example, in order to get full and continuous optical zoom experience with a 12Mp sensor (sensor dimensions 4000x3000) and a required 1080p (dimension 1920x1080) video format, the FOV ratio should be 4000/1920=2.083. Moreover, if the Wide lens FOV is given as $FOV_{Wide} = 37.5^0$, the required Tele lens FOV is 20.2^0 The zoom switching point is set according to the ratio between sensor pixels in-line and the number of pixels in-line in the video format and defined as:

$$Z_{switch}=PL_{Wide}/ PL_{video} \quad (2)$$

Maximum optical zoom is reached according to the following formula:

$$Z_{max}= \text{Tan}(FOV_{Wide})/\text{Tan}(FOV_{Tele}) * PL_{Tele}/ PL_{video} \quad (3)$$

For example: for the configuration defined above and assuming PL_{Tele}=4000 and PL_{video}= 1920, Z_{max}=4.35.

In an embodiment, the sensor control module has a setting that depends on the Wide and Tele FOVs and on a sensor oversampling ratio, the setting used in the configuration of each sensor. For example, when using a 4000x3000 sensor and when outputting a 1920x1080 image, the oversampling ratio is 4000/1920=2.0833.

In an embodiment, the Wide and Tele FOVs and the oversampling ratio satisfy the condition

$$0.8*PL_{Wide}/ PL_{video} < \text{Tan}(FOV_{Wide})/\text{Tan}(FOV_{Tele}) <1.2*PL_{Wide}/ PL_{video}. \quad (4)$$

Still mode operation/function

In still camera mode, the obtained image is fused from information obtained by both sub-cameras at all zoom levels, see FIG. 2, which shows a Wide sensor **202** and a Tele sensor **204** and their respective FOVs. Exemplarily, as shown, the Tele sensor FOV is half the Wide sensor FOV. The still camera mode processing includes two stages: (1) setting HW settings and configuration, where a first objective is to control the sensors in such a way that matching FOVs in both images (Tele and Wide) are scanned at the same time. A second objective is to control the relative exposures according to the lens properties. A third objective is to minimize the required bandwidth from both sensors for the ISPs; and (2) image processing that fuses the Wide and the Tele images to achieve optical zoom, improves SNR and provides wide dynamic range.

FIG. 3 shows image line numbers vs. time for an image section captured by CMOS sensors. A fused image is obtained by line (row) scans of each image. To prevent matching FOVs in both sensors to be scanned at different times, a particular configuration is applied by the camera controller on both image sensors while keeping the same frame rate. The difference in FOV between the sensors determines the relationship between the rolling shutter time and the vertical blanking time for each sensor. In the particular configuration, the scanning is synchronized such that the same points of the object in each view are obtained simultaneously.

Specifically with reference to FIG. 3 and according to an embodiment of a method disclosed herein, the configuration to synchronize the scanning includes: setting the Tele sensor vertical blanking time VB_{Tele} to equal the Wide sensor vertical blanking time VB_{Wide} plus half the Wide sensor rolling shutter time RST_{Wide}; setting the Tele and Wide sensor exposure times ET_{Tele} and ET_{Wide} to be equal or different; setting the Tele sensor rolling shutter time RST_{Tele} to be $0.5*RST_{Wide}$; and setting the frame rates of the two sensors to be equal. This procedure results in identical image pixels in the Tele and Wide sensor images being exposed at the same time

In another embodiment, the camera controller synchronizes the Wide and Tele sensors so that for both sensors the rolling shutter starts at the same time.

The exposure times applied to the two sensors could be different, for example in order to reach same image intensity using different F# and different pixel size for the Tele and Wide systems. In this case, the relative exposure time may be configured according to the formula below:

$$ET_{Tele} = ET_{Wide} \cdot (F\#_{Tele}/F\#_{Wide})^2 \cdot (\text{Pixel size}_{Wide}/\text{Pixel size}_{Tele})^2 \qquad (5)$$

Other exposure time ratios may be applied to achieve wide dynamic range and improved SNR. Fusing two images with different intensities will result in wide dynamic range image.

In more detail with reference to FIG. 3, in the first stage, after the user chooses a required zoom factor ZF, the sensor control module configures each sensor as follows:

1) Cropping index Wide sensor:

$Y_{Wide\ start} = 1/2 \cdot PC_{Wide}(1-1/ZF)$

$Y_{Wide\ end} = 1/2 \cdot PC_{Wide}(1+1/ZF)$

where PC is the number of pixels in a column, and Y is the row number

2) Cropping index Tele sensor:

If $ZF > Tan\ (FOV_{Wide})/Tan\ (FOV_{Tele})$, then

$Y_{Tele\ start} = 1/2 \cdot PC_{Tele}(1-(1/ZF) \cdot Tan\ (FOV_{Tele})/Tan\ (FOV_{Wide}))$

$Y_{Tele\ end} = 1/2 \cdot PC_{Tele}(1+(1/ZF) \cdot Tan\ (FOV_{Tele})/Tan\ (FOV_{Wide}))$

If $ZF < Tan\ (FOV_{Wide})/Tan\ (FOV_{Tele})$, then

$Y_{Tele\ start} = 0$

$Y_{Tele\ end} = PC_{Tele}$

This will result in an exposure start time of the Tele sensor with a delay of (in numbers of lines, relative to the Wide sensor start time):

$$(1-ZF/((Tan\ (FOV_{Wide})/Tan\ (FOV_{Tele}))) \cdot 1/(2 \cdot FPS) \qquad (6)$$

where FPS is the sensor's frame per second configuration. In cases where $ZF > Tan\ (FOV_{Wide})/Tan\ (FOV_{Tele})$, no delay will be introduced between Tele and Wide exposure starting point. For example, for a case where $Tan\ (FOV_{Wide})/Tan\ (FOV_{Tele})=2$ and ZF=1, the Tele image first pixel is exposed $1/4 \cdot (1/FPS)$ second after the Wide image first pixel was exposed.

After applying the cropping according to the required zoom factor, the sensor rolling shutter time and the vertical blank should be configured in order to satisfy the equation to keep the same frame rate:

$$VB_{Wide}+RST_{Wide} = VB_{Tele}+RST_{Tele} \qquad (7)$$

FIG. 3 exemplifies Eq. (7). One way to satisfy Eq. (7) is to increase the RST_{Wide}. Controlling the RST_{Wide} may be done by changing the horizontal blanking (HB) of the Wide sensor. This will cause a delay between the data coming out from each row of the Wide sensor.

Generally, working with a dual-sensor system requires multiplying the bandwidth to the following block, for example the ISP. For example, using 12Mp working at 30fps, 10bit per pixel requires working at 3.6Gbit/sec. In this example, supporting this bandwidth requires 4 lanes from each sensor to the respective following ISP in the processing chain. Therefore, working with two sensors requires double bandwidth (7.2Gbit/sec) and 8 lanes connected to the respective following blocks. The bandwidth can be reduced by configuring and synchronizing the two sensors. Consequently, the number of lanes can be half that of a conventional configuration (3.6Gbit/sec).

FIG. 4 shows schematically a sensor time configuration that enables sharing one sensor interface using a dual-sensor zoom system, while fulfilling the conditions in the description of FIG. 3 above. For simplicity, assuming the Tele sensor image is magnified by a factor of 2 compared with the Wide sensor image, the Wide sensor horizontal blanking time HB_{Wide} is set to twice the Wide sensor line readout time. This causes a delay between output Wide lines. This delay time matches exactly the time needed to output two lines from the Tele sensor. After outputting two lines from the Tele sensor, the Tele sensor horizontal blanking time HB_{Tele} is set to be one Wide line readout time, so, while the Wide sensor outputs a row from the sensor, no data is being output from the Tele sensor. For this example, every 3rd line in the Tele sensor is delayed by an additional HB_{Tele}. In this delay time, one line from the Wide sensor is output from the dual-sensor system. After the sensor configuration stage, the data is sent in parallel or by using multiplexing into the processing section.

FIG. 5 shows an embodiment of a method disclosed herein for acquiring a zoom image in still mode. In ISP step **502**, the data of each sensor is transferred to the respective ISP component, which performs on the data various processes such as denoising, demosaicing, sharpening, scaling, etc, as known in the art. After the processing in step **502,** all following actions are performed in capture processing core **128**: in rectification step **504,** both Wide and Tele images are aligned to be on the epipolar line; in registration step **506**, mapping between the Wide and the Tele aligned images is performed to produce a registration map; in resampling step **508,** the Tele image is resampled according to the registration map, resulting in a re-sampled Tele image; in decision step **510**, the re-sampled Tele image and the Wide image are processed to detect errors in the registration and to provide a decision output. In more detail, in step **510,** the re-sampled Tele image data is compared with the Wide image data and if the comparison detects significant dissimilarities, an error is indicated. In this case, the Wide pixel values are chosen to be used in the output image. Then, in fusion step **512,** the decision output, re-sampled Tele image and the Wide image are fused into a single zoom image.

To reduce processing time and power, steps **506, 508, 510, 512** could be bypassed by not fusing the images in non-focused areas. In this case, all steps specified above should be applied on focused areas only. Since the Tele optical system will introduce shallower depth of field than the Wide optical system, defocused areas will suffer from lower contrast in the Tele system.

Zoom-in and Zoom-out in still camera mode

We define the following: TFOV = tan (camera FOV/2). "Low ZF" refers to all ZF that comply with ZF < Wide TFOV/Tele TFOV. "High ZF" refers to all ZF that comply with ZF > Wide TFOV/Tele TFOV. "ZFT" refers to a ZF that complies with ZF = Wide TFOV/Tele TFOV. In one embodiment, zoom-in and zoom-out in still mode is performed as follows:

Zoom-in: at low ZF up to slightly above ZFT, the output image is a digitally zoomed, Wide fusion output. For the up-transfer ZF, the Tele image is shifted and corrected by global registration (GR) to achieve smooth transition. Then, the output is transformed to a Tele fusion output. For higher (than the up-transfer) ZF, the output is the Tele fusion output digitally zoomed.

Zoom-out: at high ZF down to slightly below ZFT, the output image is a digitally zoomed, Tele fusion output. For the down-transfer ZF, the Wide image is shifted and corrected by GR to achieve smooth transition. Then, the output is transformed to a Wide fusion output. For lower (than the down-transfer) ZF, the output is basically the down-transfer ZF output digitally zoomed but with gradually smaller Wide shift correction, until for ZF=1 the output is the unchanged Wide camera output.

In another embodiment, zoom-in and zoom-out in still mode is performed as follows:

Zoom-in: at low ZF up to slightly above ZFT, the output image is a digitally zoomed, Wide fusion output. For the up-transfer ZF and above, the output image is the Tele fusion output.

Zoom-out: at high ZF down to slightly below ZFT, the output image is a digitally zoomed, Tele fusion output. For the down-transfer ZF and below, the output image is the Wide fusion output.

Video mode operation/function

Smooth transition

When a dual-aperture camera switches the camera output between sub-cameras or points of view, a user will normally see a "jump" (discontinuous) image change. However, a change in the zoom factor for the same camera and POV is viewed as a continuous change. A "smooth transition" is a transition between cameras or POVs that minimizes the jump effect. This may include matching the position, scale, brightness and color of the output image before and after the transition. However, an entire image position matching between the sub-camera outputs is in many cases impossible, because parallax causes the position shift to be dependent on the object distance. Therefore, in a smooth transition as disclosed herein, the position matching is achieved only in the ROI region while scale brightness and color are matched for the entire output image area.

Zoom-in and Zoom-out in video mode

In video mode, sensor oversampling is used to enable continuous and smooth zoom experience. Processing is applied to eliminate the changes in the image during crossover from one sub-camera to the other. Zoom from 1 to Z_{switch} is performed using the Wide sensor only. From Z_{switch} and on, it is performed mainly by the Tele sensor. To prevent "jumps" (roughness in the image), switching to the Tele image is done using a zoom factor which is a bit higher (Z_{switch} +ΔZoom) than Z_{switch}. ΔZoom is determined according to the system's properties and is different for cases where zoom-in is applied and cases where zoom-out is applied ($\Delta Zoom_{in} \neq \Delta Zoom_{out}$). This is done to prevent residual jumps artifacts to be visible at a certain zoom factor. The switching between sensors, for an increasing zoom and for decreasing zoom, is done on a different zoom factor.

The zoom video mode operation includes two stages: (1) sensor control and configuration, and (2) image processing. In the range from 1 to Z_{switch}, only the Wide sensor is operational, hence, power can be supplied only to this sensor. Similar conditions hold for a Wide AF mechanism. From Z_{switch}+ΔZoom to Z_{max} only the Tele sensor is operational, hence, power is supplied only to this sensor. Similarly, only the Tele sensor is operational and power is supplied only to it for a Tele AF mechanism. Another option is that the Tele sensor is operational and the Wide sensor is working in low frame rate. From Z_{switch} to Z_{switch}+ΔZoom, both sensors are operational.

Zoom-in: at low ZF up to slightly above ZFT, the output image is the digitally zoomed, unchanged Wide camera output. For the up-transfer ZF, the output is a transformed Tele sub-camera output, where the transformation is performed by a global registration (GR) algorithm to achieve smooth transition. For higher (than the up-transfer), the output is the transfer ZF output digitally zoomed.

Zoom-out: at high ZF down to slightly below ZFT, the output image is the digitally zoomed transformed Tele camera output. For the down-transfer ZF, the output is a shifted Wide camera output, where the Wide shift correction is performed by the GR algorithm to achieve smooth transition, i.e. with no jump in the ROI region. For lower (than the down-transfer) ZF, the output is basically the down-transfer ZF output digitally zoomed but with gradually smaller Wide shift correction, until for ZF=1 the output is the unchanged Wide camera output.

FIG. 6 shows an embodiment of a method disclosed herein for acquiring a zoom image in video/preview mode for 3 different zoom factor (ZF) ranges: (a) ZF range = 1 : Z_{switch}; (b) ZF range = Z_{switch} : Z_{switch} + $\Delta Zoom_{in}$; and (c) Zoom factor range = Z_{switch} + $\Delta Zoom_{in}$: Z_{max}. The description is with reference to a graph of effective resolution vs. zoom value (FIG. 7). In step **602**, sensor control module **116** chooses (directs) the sensor (Wide, Tele or both) to be operational. Specifically, if the ZF range = 1:Z_{switch}, module **116** directs the Wide sensor to be operational and the Tele sensor to be non-operational. If the ZF range is Z_{switch} : Z_{switch} + $\Delta Zoom_{in}$, module **116** directs both sensors to be operational and the zoom image is generated from the Wide sensor. If the ZF range is Z_{switch} + $\Delta Zoom_{in}$: Z_{max}, module **116** directs the Wide sensor to be non-operational and the Tele sensor to be operational. After the sensor choice in step **602,** all following actions are performed in video processing core **126**. Optionally, in step **604**, color balance is calculated if two images are provided by the two sensors. Optionally yet, in step **606**, the calculated color balance is applied in one of the images (depending on the zoom factor). Further optionally, in step **608**, registration is performed between the Wide and Tele images to output a transformation coefficient. The transformation coefficient can be used to set an AF position in step **610**. In step **612**, an output of any of steps **602-608** is applied on one of the images (depending on the zoom factor) for image signal processing that may include denoising, demosaicing, sharpening, scaling, etc. In step **614**, the processed image is resampled according to the transformation coefficient, the requested ZF (obtained from zoom function **124**) and the output video resolution (for example 1080p). To avoid a transition point to be executed at the same ZF, $\Delta Zoom$ can change while zooming in and while zooming out. This will result in hysteresis in the sensor switching point.

In more detail, for ZF range 1 : Z_{switch}, for ZF < Z_{switch}, the Wide image data is transferred to the ISP in step **612** and resampled in step **614**. For ZF range = Z_{switch} : Z_{switch} + $\Delta Zoom_{in}$, both sensors are operational and the zoom image is generated from the Wide sensor. The color balance is calculated for both images according to a given ROI. In addition, for a given ROI, registration is performed between the Wide and Tele images to output a transformation coefficient. The transformation coefficient is used to set an AF position. The transformation coefficient includes the translation between matching points in the two images. This translation can be measured in a number of pixels. Different translations will result in a different number of pixel movements between matching points in the images. This movement can be translated into depth and the depth can be translated into an AF position. This enables to set the AF position by only analyzing two images (Wide & Tele). The result is fast focusing.

Both color balance ratios and transformation coefficient are used in the ISP step. In parallel, the Wide image is processed to provide a processed image, followed by resampling. For ZF range = $Z_{switch} + \Delta Zoom_{in} : Z_{max}$ and for Zoom factor > $Z_{switch,} + \Delta Zoom_{in}$, the color balance calculated previously is now applied on the Tele image. The Tele image data is transferred to the ISP in step **612** and resampled in step **614**. To eliminate crossover artifacts and to enable smooth transition to the Tele image, the processed Tele image is resampled according to the transformation coefficient, the requested ZF (obtained from zoom function **124**) and the output video resolution (for example 1080p).

FIG. 7 shows the effective resolution as a function of the zoom factor for a zoom-in case and for a a zoom-out case $\Delta Zoom_{up}$ is set when we zoom in, and $\Delta Zoom_{down}$ is set when we zoom out. Setting $\Delta Zoom_{up}$ to be different from $\Delta Zoom_{down}$ will result in transition between the sensors to be performed at different zoom factor ("hysteresis") when zoom-in is used and when zoom-out is used. This hysteresis phenomenon in the video mode results in smooth continuous zoom experience.

Optical Design

Additional optical design considerations were taken into account to enable reaching optical zoom resolution using small total track length (TTL). These considerations refer to the Tele lens. In an embodiment, the camera is "thin" (see also FIG. 1B) in the sense that is has an optical path of less than 9mm and a thickness/focal length (FP) ratio smaller than about 0.85. Exemplarily, as shown in FIG. 8, such a thin camera has a lens block that includes (along an optical axis starting from an object) five lenses: a first lens element **802** with positive power and two lenses **804** and **806** and with negative power, a fourth lens **808** with positive power and a fifth lens **810** with negative power. In the embodiment of FIG. 8, the EFL is 7 mm, the TTL is 4.7 mm, f = 6.12 and FOV = 20^0. Thus the Tele lens TTL/EFL ratio is smaller than 0.9. In other embodiments, the Tele lens TTL/EFL ratio may be smaller than 1.

In another embodiment of a lens block in a thin camera, shown in FIG. 9, the camera has a lens block that includes (along an optical axis starting from an object) a first lens element **902** with positive power a second lens element **904** with negative power, a third lens element with positive power **906** and a fourth lens element with negative power **908**, and a fifth filed lens element **910** with positive or negative power. In this embodiment, f =7.14, F# = 3.5, TTL = 5.8mm and FOV = 22.7^0.

In conclusion, dual aperture optical zoom digital cameras and associate methods disclosed herein reduce the amount of processing resources, lower frame rate requirements, reduce power consumption, remove parallax artifacts and provide continuous focus (or provide loss of focus) when changing from Wide to Tele in video mode. They provide a dramatic reduction of the disparity range and avoid false registration in capture mode. They reduce image intensity differences and enable work with a single sensor bandwidth instead of two, as in known cameras.

All 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 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 disclosure.

While this disclosure has been described in terms of certain embodiments and generally associated methods, alterations and permutations of the embodiments and methods will be apparent to those skilled in the art. The disclosure is to be understood as not limited by the specific embodiments described herein, but only by the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A zoom digital camera comprising:

a) a Wide imaging section that includes a fixed focal length Wide lens with a Wide field of view (FOV), a Wide sensor and a Wide image signal processor (ISP), the Wide imaging section operative to provide Wide image data of an object or scene;

b) a Tele imaging section that includes a fixed focal length Tele lens with a Tele FOV that is narrower than the Wide FOV, a Tele sensor and a Tele ISP, the Tele imaging section operative to provide Tele image data of the object or scene; and

c) a camera controller operatively coupled to the Wide and Tele imaging sections, the camera controller configured to combine in still mode at least some of the Wide and Tele image data to provide a fused output image of the object or scene from a particular point of view and to provide without fusion continuous zoom video mode output images of the object or scene, each output image having a respective output resolution;

wherein the video output images are provided with a smooth transition when switching between a lower zoom factor (ZF) value and a higher ZF value or vice versa, wherein at the lower ZF value the output resolution is determined by the Wide sensor, and wherein at the higher ZF value the output resolution is determined by the Tele sensor.

2. The camera of claim 1, wherein the controller includes a user control module for receiving user inputs and a sensor control module for configuring each sensor to acquire the Wide and Tele image data based on the user inputs.

3. The camera of claim 2, wherein the user inputs include a zoom factor, a camera mode and a region of interest (ROI).

4. The camera of claim 2, wherein the sensor control module has a setting that depends on the Wide and Tele fields of view and on a sensor oversampling ratio, the setting used in the configuration of each sensor.

5. The camera of claim 4, wherein the Wide and Tele FOVs and the sensor oversampling ratio satisfy the condition $0.8*PL_{Wide}/ PL_{video} < Tan (FOV_{Wide})/Tan (FOV_{Tele}) <1.2*PL_{Wide}/ PL_{video}$, wherein PL_{Wide} is an in-line number of Wide sensor pixels and wherein PL_{video} is an in-line number of output video format pixels.

6. The camera of claim 1, wherein the Tele lens includes a ratio of total length (TTL)/effective focal length (EFL) smaller than 1.

7. The camera of claim 5 wherein each lens includes five lens elements.

8. The camera of claim 6, wherein the five elements have, in order from the object side, positive-negative-negative-positive-negative powers.

9. The camera of claim 6, wherein the five elements have, in order from the object side, positive-negative-positive-negative and positive or negative powers.

10. The camera of claim 1, wherein the camera controller configuration to provide video output images with a smooth transition when switching between a lower ZF value and a higher ZF value or vice versa includes a configuration that uses information either from the Wide sensor or from the Tele sensor.

11. The camera of claim 1,wherein the camera controller configuration to provide video output images with a smooth transition when switching between a lower ZF value and a higher ZF value or vice versa includes a configuration that uses at high ZF secondary information from the Wide camera and uses at low ZF secondary information from the Tele camera.

12. A method for obtaining zoom images of an object or scene in both still and video modes using a digital camera, the method comprising the steps of:

a) providing in the digital camera a Wide imaging section having a Wide lens with a Wide field of view (FOV), a Wide sensor and a Wide image signal processor (ISP), a Tele imaging section having a Tele lens with a Tele FOV that is narrower than the Wide FOV, a Tele sensor and a Tele ISP, and a camera controller operatively coupled to the Wide and Tele imaging sections; and

b) configuring the camera controller to combine in still mode at least some of the Wide and Tele image data to provide a fused output image of the object or scene from a particular point of view, and to provide without fusion continuous zoom video mode output images of the object or scene, each output image having a respective output resolution, wherein the video mode output images are provided with a smooth transition when switching between a lower zoom factor (ZF) value and a higher ZF value or vice versa, and wherein at the lower ZF value the output resolution is determined by the Wide sensor while at the higher ZF value the output resolution is determined by the Tele sensor.

13. The method of claim 12, wherein the step of configuring the camera controller to provide without fusion continuous zoom video mode output images of the object or scene includes configuring each sensor with a setting that depends on the Wide and Tele FOVs and on a sensor oversampling ratio.

14. The method of claim 13, wherein the Wide and Tele FOVs and the oversampling ratio satisfy the condition $0.8*PL_{WIDE}/PL_{video} < Tan(FOV_{Wide})/Tan(FOV_{Tele}) < 1.2*PL_{Wide}/PL_{video}$, wherein PL_{Wide} is an inline number of Wide sensor pixels and PL_{video} is an in-line number of output video format pixels.

15. The method of claim 12, wherein the step of configuring the camera controller to provide without fusion continuous zoom video mode output images of the object or scene includes performing a registration between the Wide and Tele images to output a transformation coefficient and using the transformation coefficient to set an autofocus position.

16. The method of claim 12, wherein the smooth transition is obtained when zooming-in by switching between a lower ZF factor and a higher ZF factor at a first ZF value, and is obtained when zooming-out by switching between a higher ZF factor and a lower ZF factor at a second ZF value different from the first ZF value.

17. The method of claim 12, wherein the step of configuring the camera controller to combine in still mode at least some of the Wide and Tele image data to provide a fused output image includes configuring the camera controller to combine Wide and Tele image data only in focused areas.

18. The method of claim 12, wherein each lens has a different F number and wherein the step of configuring the camera controller to combine in still mode at least some of the Wide

and Tele image data to provide a fused output image includes configuring the camera controller to set an exposure time based on a ratio of the different F numbers.

19. The method of claim 12, wherein the step of wherein the step of configuring the camera controller to combine in still mode at least some of the Wide and Tele image data to provide a fused output image includes configuring the camera controller to set two images with different intensities to provide a wide dynamic range image.

20. The method of claim 12, wherein the step of configuring the camera controller to combine in still mode at least some of the Wide and Tele image data to provide a fused output image includes configuring the two sensors to obtain the fused image using a single sensor bandwidth.

21. The method of claim 12, wherein the step of configuring the camera controller to combine in still mode at least some of the Wide and Tele image data to provide a fused output image includes configuring the camera controller to synchronize the Wide and Tele sensors to force an overlap area in the object image to be exposed at the same time, wherein the synchronizing includes:

i. setting a Tele sensor vertical blanking time VB_{Tele} to equal a Wide sensor vertical blanking time VB_{Wide} plus half a Wide sensor rolling shutter time RST_{Wide},

ii. setting respective Tele and Wide sensor exposure times ET_{Tele} and ET_{Wide} to be equal,

iii. setting a Tele sensor rolling shutter time RST_{tele} to be $RST_{Wide}/2$, and

iv. setting frame rates of the two sensors to be equal.

22. The method of claim 12, wherein the step of configuring the camera controller to combine in still mode at least some of the Wide and Tele image data to provide a fused output image includes configuring the camera controller to synchronize the Wide and Tele sensors to force the two sensors to start exposure at the same time.

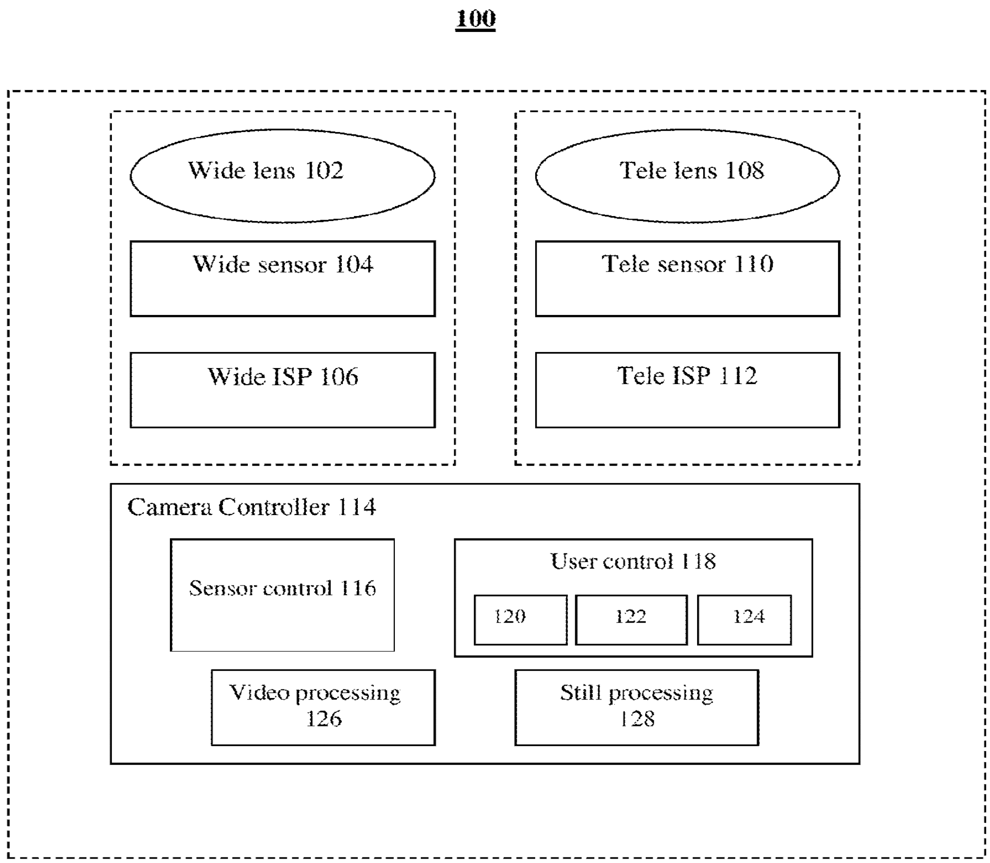
100
Wide lens 102
Tele lens 108
Wide sensor 104
Tele sensor 110
Wide ISP 106
Tele ISP 112
Camera Controller 114
Sensor control 116
User control 118
120
122
124
Video processing 126
Still processing 128

FIG. 1A

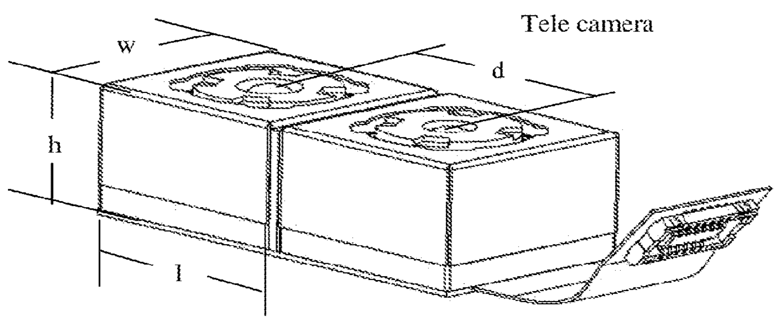
Tele camera
w
d
h
l

FIG. 1B

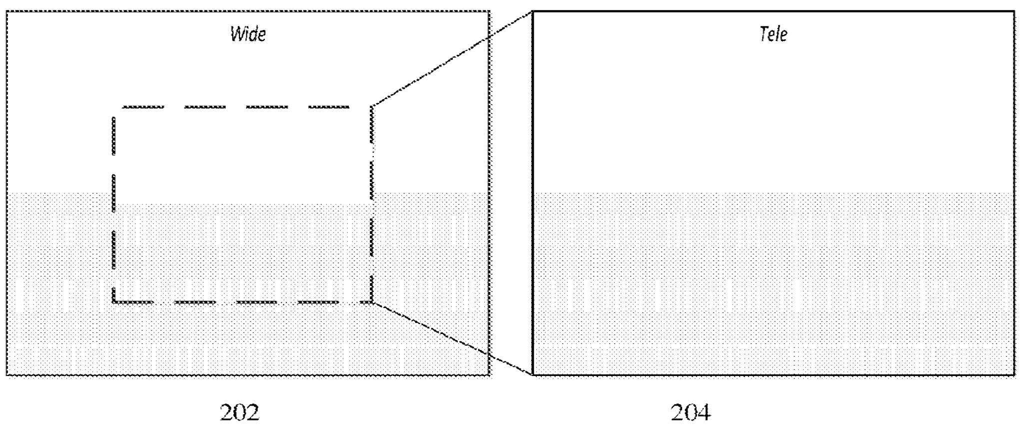

FIG. 2

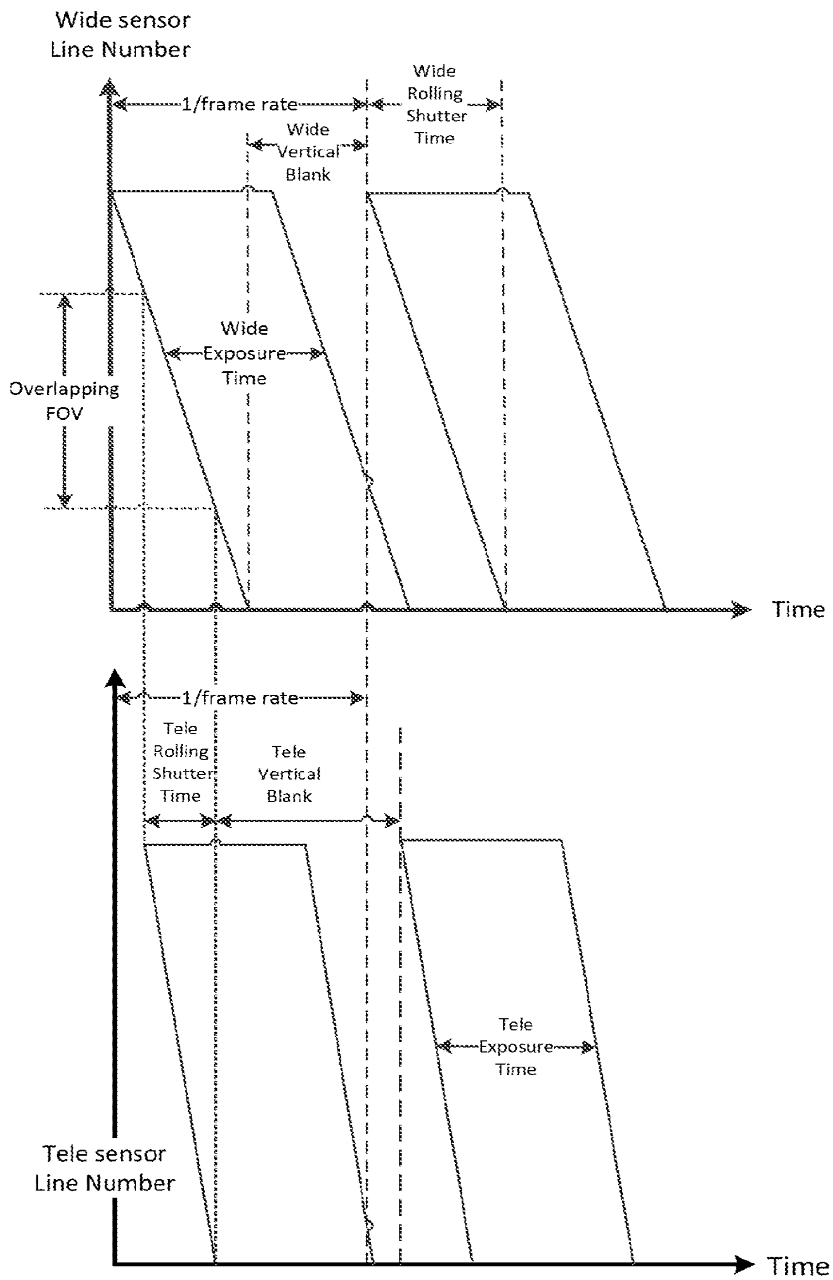
Wide sensor
Line Number
1/frame rate
Wide
Rolling
Shutter
Time
Wide
Vertical
Blank
Wide
Exposure
Time
Overlapping
FOV
Time
1/frame rate
Tele
Rolling
Shutter
Time
Tele
Vertical
Blank
Tele
Exposure
Time
Tele sensor
Line Number
Time

FIG. 3

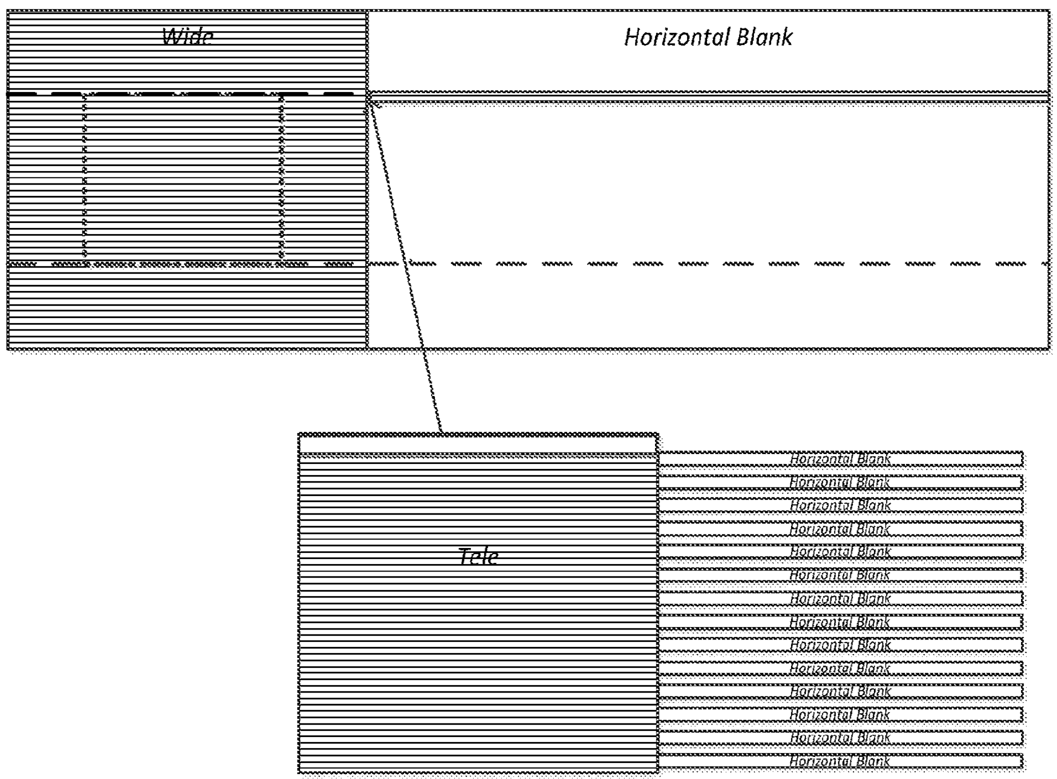
Wide
Horizontal Blank
Tele
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank
Horizontal Blank

FIG. 4

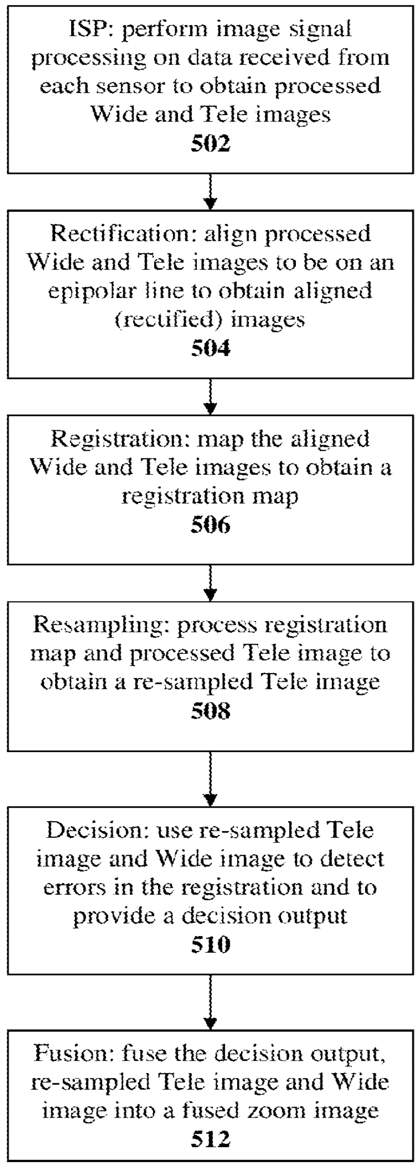
ISP: perform image signal processing on data received from each sensor to obtain processed Wide and Tele images
502
Rectification: align processed Wide and Tele images to be on an epipolar line to obtain aligned (rectified) images
504
Registration: map the aligned Wide and Tele images to obtain a registration map
506
Resampling: process registration map and processed Tele image to obtain a re-sampled Tele image
508
Decision: use re-sampled Tele image and Wide image to detect errors in the registration and to provide a decision output
510
Fusion: fuse the decision output, re-sampled Tele image and Wide image into a fused zoom image
512

FIG. 5

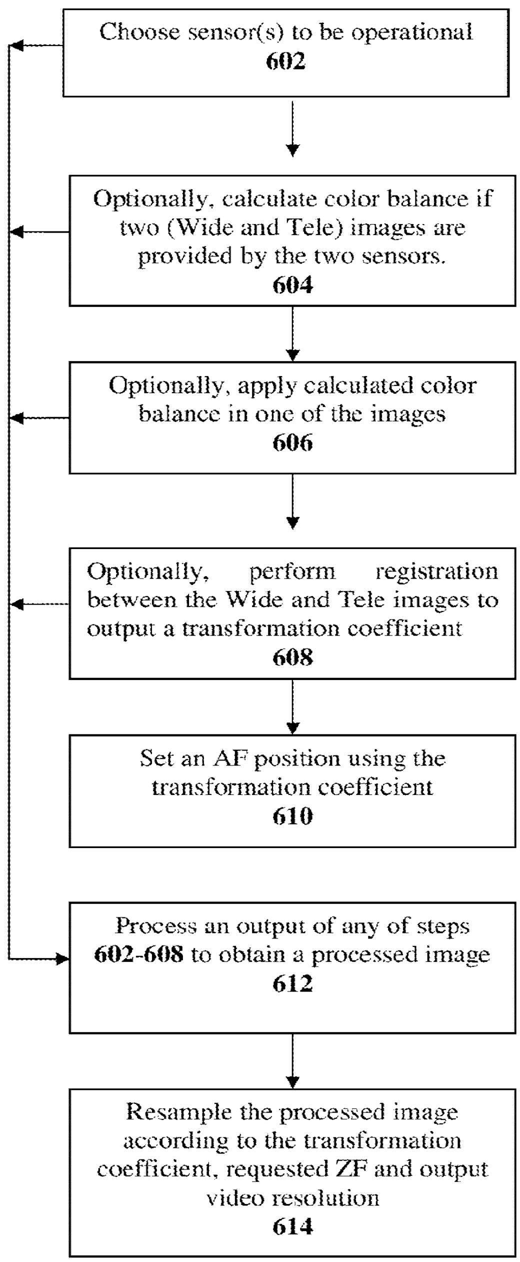
Choose sensor(s) to be operational
602
Optionally, calculate color balance if two (Wide and Tele) images are provided by the two sensors.
604
Optionally, apply calculated color balance in one of the images
606
Optionally, perform registration between the Wide and Tele images to output a transformation coefficient
608
Set an AF position using the transformation coefficient
610
Process an output of any of steps 602-608 to obtain a processed image
612
Resample the processed image according to the transformation coefficient, requested ZF and output video resolution
614

FIG. 6

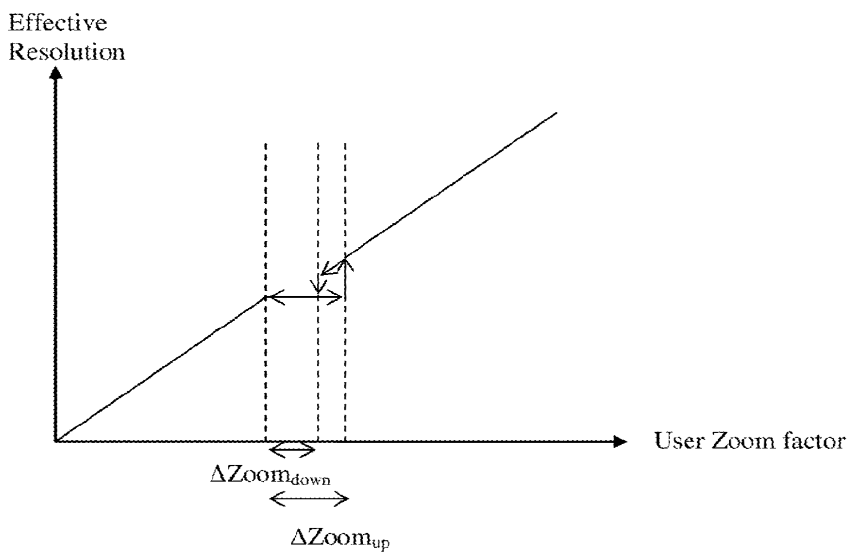

FIG. 7

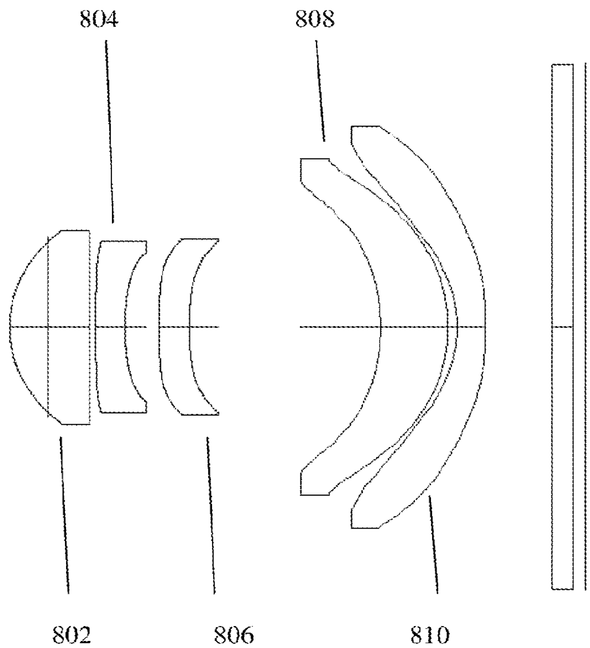

FIG. 8

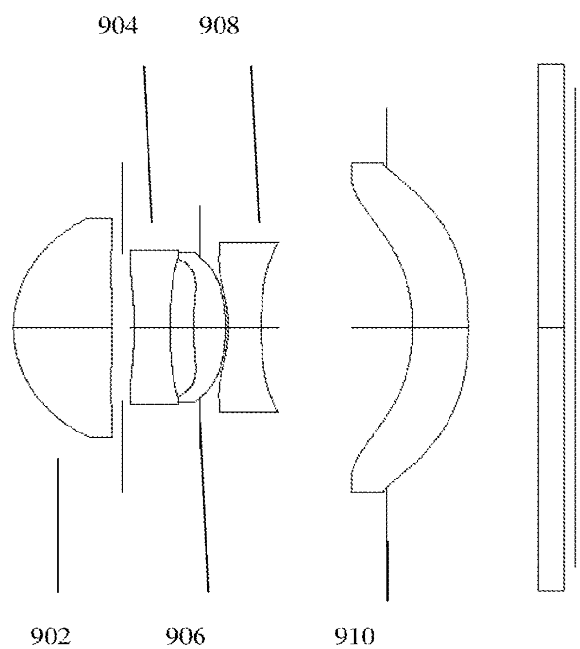

FIG. 9

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(54) Title: THIN MULTI-APERTURE IMAGING SYSTEM WITH AUTO-FOCUS AND METHODS FOR USING SAME

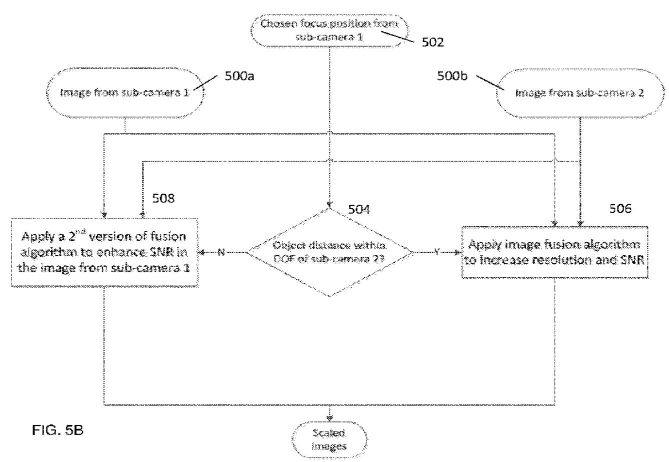

FIG. 5B

(57) Abstract: Dual-aperture digital cameras with auto-focus (AF) and related methods for obtaining a focused and, optionally optically stabilized color image of an object or scene. A dual- aperture camera includes a first sub-camera having a first optics bloc and a color image sensor for providing a color image, a second sub-camera having a second optics bloc and a clear image sensor for providing a luminance image, the first and second sub-cameras having substantially the same field of view, an AF mechanism coupled mechanically at least to the first optics bloc, and a camera controller coupled to the AF mechanism and to the two image sensors and configured to control the AF mechanism, to calculate a scaling difference and a sharpness difference between the color and luminance images, the scaling and sharpness differences being due to the AF mechanism, and to process the color and luminance images into a fused color image using the calculated differences.

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THIN MULTI-APERTURE IMAGING SYSTEM WITH AUTO-FOCUS AND METHODS FOR USING SAME

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to and claims priority from US Provisional Patent Application No. 61/861,185 filed August 1, 2013 and having the same title, which is incorporated herein by reference in its entirety.

FIELD

Embodiments disclosed herein relate in general to digital cameras and in particular to thin multi-aperture digital cameras with auto-focus.

BACKGROUND

In recent years, mobile devices such as cell-phones, tablets and laptops have become ubiquitous. Most of these devices include one or two compact cameras – a main rear-facing camera (i.e. a camera on the back side of the device, facing away from the user and often used for casual photography) and a secondary front-facing camera (i.e. a camera located on the front side of the device and often used for video conferencing).

Although relatively compact in nature, the design of most of these cameras is very similar to the traditional structure of a digital still camera, i.e. they comprise an optical component (or a train of several optical elements and a main aperture) placed on top of an image sensor. The optical component (also referred to as "optics") refracts the incoming light rays and bends them to create an image of a scene on the sensor. The dimensions of these cameras are largely determined by the size of the sensor and by the height of the optics. These are usually tied together through the focal length ("f") of the lens and its field of view (FOV) – a lens that has to image a certain FOV on a sensor of a certain size has a specific focal length. Keeping the FOV constant, the larger the sensor dimensions (e.g. in an X-Y plane), the larger the focal length and the optics height.

As the dimensions of mobile devices shrink, the compact camera dimensions become more and more a key factor that limits the device thickness. Several approaches have been proposed to reduce the compact camera thickness in order to alleviate this constraint.

Recently, multi-aperture systems have been proposed for this purpose. In such systems, instead of having one aperture with one train of optical elements, the camera is divided into several apertures, each with dedicated optical elements, all apertures sharing a similar field of view. Hereinafter, each such aperture, together with the optics and the sensor area on which the image is formed, is defined as a “sub-camera”. Typically, in multi-aperture camera designs, each sub-camera creates a smaller image on the image sensor compared with the image created by a reference single-aperture camera. Therefore, the height of each sub-camera can be smaller than the height of a single-aperture camera, reducing the total height of the camera could be reduced and allowing for slimmer designs of mobile devices.

FIG. 1A and FIG. 1B show a schematic design of a traditional camera and of a dual-aperture camera with two sub-cameras, respectively. A traditional camera **100'** in FIG. 1A includes an image sensor **102** placed on a substrate **104** and a lens **106.** A "camera height" is defined as the height of the camera module, from substrate **104** to the top of lens **106**. A dual-aperture camera **100"** in FIG. 1B includes two sub-cameras, a sub-camera 1 with an image sensor **112a** and a lens **116a** with an optical axis **118a**, and a sub-camera 2 with, an image sensor **112b** and a lens **116b** with an optical axis **118b**. The two sensors are placed on, respectively, substrates **114a** and **114b**. For comparison's sake, it is assumed that the reference single-aperture camera and the dual-aperture camera have the same field of view (FOV) and the sensors have the same pixel size. However, image sensor **102** has a higher resolution (number of pixels) compared with image sensor **112a** or image sensor **112b**, and is therefore larger in size. The potential advantage in camera height of the dual-aperture camera (i.e. the thickness from substrate **114a** to the top of lens **116a** and from substrate **114b** to the top of lens **116b**) may be appreciated.

There are several significant challenges involved in multi-aperture camera designs. First and foremost, the sensor area of each sub-camera is smaller compared with that of a single-aperture camera. If the pixel size in each sub-camera sensor is kept the same as that in the single-aperture camera sensor, the resolution of an image captured by each sub-camera is smaller than that captured by the single-aperture camera. If the resolution of the output image is to be kept the same, the images from the different sub-cameras need to be combined into a higher-resolution image. This is usually done in the digital domain, by a dedicated algorithm. Several methods have been proposed for combining lower-resolution images to produce a higher-resolution image. Some algorithms in such methods require a registration step between the set of low-resolution images, to account for parallax (which is present in a multi-aperture camera system due to the shift in point-of-view between sub-cameras). One such algorithm is described in co-assigned PCT patent application PCT/IB2014/062180 titled "Dual aperture zoom digital camera", which is incorporated herein by reference in its entirety.

Another challenge relates to the requirement that the camera provides an in-focus image for a wide range of object distances (usually from several centimeters to infinity in compact camera modules). To fulfill this requirement, a single-aperture camera may include an Auto-Focus (AF) mechanism that controls the focus position of the optics, by moving the optical element along the optical axis, thus changing its height above the sensor. In multi-aperture cameras, in order to support an in-focus image for a wide range of object distances, a straightforward approach would be to provide a dedicated AF mechanism in each sub-camera. This approach has several drawbacks including increased size and cost of the camera, higher operating power and more complicated control, as the AF mechanisms of each sub-camera needs to be synchronized, to ensure all of the sub-cameras are focused to the same position.

Another complication that may arise when using an AF mechanism in a multi-aperture camera is connected with the algorithm that combines the lower resolution sub-camera images to produce a higher resolution image. Since an AF mechanism moves the optical element along the optical axis above the sensor, it scales the image that is formed on the sensor to some extent. Slight differences between the focusing positions of different AF mechanisms in each sub-camera may result in different scales applied to the lower resolution sub-camera images. Such differences in scale may degrade the performance of the image registration step in the algorithm. Correcting for the different scale is not trivial, due to the dynamic nature of the scale - the scale applied on the image depends on the focus position of the optics, which in turn changes with object distance. This means that the scale cannot be trivially corrected by calibrating the multi-aperture camera and applying a fixed correction, but rather, the correct scale has to be estimated at each image. Estimating the correct scale to apply from the image is not trivial, in the presence of parallax (where different objects appear at different locations as a function from their distance from the camera) and in the presence of possible occlusions of objects in one aperture but not in the other. There is therefore a need for a method that can accurately estimate and correct differences in scaling on a per-image basis.

As an alternative to using AF, multi-aperture camera designs have been proposed with no AF mechanism at all. Such designs rely on the smaller focal length of each sub-camera to provide increased depth-of-focus (DOF) compared with a corresponding single-aperture camera that supports a larger sensor. Since a larger DOF means that a wider range of object distances is imaged in-focus onto the sensor, the AF mechanism could be removed. While this approach is advantageous in terms of cost, size and system complexity, the larger DOF that results from the shorter focal length of a multi-aperture camera is often insufficient to support an in-focus image for object distances ranging from a few centimeters to infinity. In these cases, settling for a multi-aperture camera with fixed-focus optics results in poor imaging performance at close object distances.

Between using multiple AF mechanisms and using only fixed-focus optics, there is a need for a multi-aperture camera system that combines the benefits of an AF mechanism without adding additional complexity and cost to the camera system.

SUMMARY

Embodiments disclosed herein provide designs of a multi-aperture camera with an AF mechanism, describe an algorithm that dynamically corrects for scale differences between sub-camera images, and propose a color filter array (CFA) design that may result in higher resolution and sensitivity when combining sub-camera images, compared with standard CFAs.

In various embodiments, there are provided dual-aperture digital cameras with auto-focus (AF) for imaging an object or scene, each such dual-aperture digital camera comprising a first sub-camera that includes a first optics bloc and a color image sensor with a first number of pixels, the first camera operative to provide a color image of the object or scene, a second sub-camera that includes a second optics bloc and a clear image sensor having a second number of pixels, the second sub-camera operative to provide a luminance image of the object or scene, the first and second sub-cameras having substantially the same field of view, an AF mechanism coupled mechanically at least to the first optics bloc, and a camera controller coupled to the AF mechanism and to the two image sensors and configured to control the AF mechanism, to calculate a scaling difference and a sharpness difference between the color and luminance images, the scaling and sharpness differences being due to the AF mechanism, and to process the color and luminance images into a fused color image using the calculated differences.

The first number of pixels and second number of pixels may be equal or different. The first and second images sensors are formed on a single substrate. The first sub-camera may include an infra-red (IR) filter that blocks IR wavelengths from entering the color image sensor and the second sub-camera may be configured to allow at least some IR wavelengths to enter the clear image sensor. In some embodiments, the color image sensor may include a non-standard color filter array (CFA).

In an embodiment, the AF mechanism may be coupled mechanically to the first optics bloc, and the second optics bloc may have a fixed focus position. In an embodiment, the fixed focus position may be such that a DOF range of the second sub-camera is between infinity and less than about 100 cm. In an embodiment, the AF mechanism may be coupled mechanically to the first and second optics blocs and operative to move them together in a direction common to respective optics bloc optical axes.

In an embodiment, the camera may further comprise an optical image stabilization mechanism coupled mechanically to the first and second optics blocs and in a direction perpendicular to respective optics bloc optical axes to optically stabilize the AF fused color image.

In an embodiment there is provided method for obtaining a focused color image of an object or scene using a dual-aperture camera, comprising the steps of obtaining simultaneously an auto-focused color image and an auto-focused or fixed focus luminance image of the object or scene, wherein the color image has a first resolution, a first effective resolution and a first signal-to-noise ratio (SNR), and wherein the luminance image has a second resolution, a second effective resolution and a second SNR, preprocessing the two images to obtain respective rectified, normalized and scale- adjusted color and luminance images considering scaling and sharpness differences caused by the AF action, performing local registration between the rectified, normalized and scale-adjusted color and luminance images to obtain registered images, and fusing the registered images into a focused fused color image.

In an embodiment, the step of preprocessing to obtain scale-adjusted color and luminance images includes calculating a set of corresponding points in the color and luminance images, extracting a single coordinate from each corresponding point and using the single coordinate to estimate a scaling factor S between the color and luminance images. The extracted coordinate is Y and the scaling factor S may be given by $S = (Y2'*W*Y2)\backslash Y2'*W*Y1$, where Y1 is a vector of Y coordinates of points taken from one image, Y2 is a vector of Y coordinates of points taken from the other image, and W is a diagonal matrix that holds the absolute values of Y2.

In an embodiment, a method may further comprise using scaling factor S to scale one of the images to match the other image, thereby obtaining the registered images.

In an embodiment, a method may further comprise optically stabilizing the obtained color and luminance images.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting examples of embodiments disclosed herein are described below with reference to figures attached hereto that are listed following this paragraph. The drawings and descriptions are meant to illuminate and clarify embodiments disclosed herein, and should not be considered limiting in any way.

FIG. 1A shows schematically the design of a traditional digital camera;

FIG. 1B shows schematically the design of a dual-aperture camera;

FIG. 2 shows schematically an embodiment of a dual-aperture imaging system with auto-focus disclosed herein, in (a) a general isomeric view, and (b) a sectioned isomeric view;

FIG. 3 shows an embodiment of an image sensor for the imaging system in FIG. 2, in which one sub-camera has a CFA sensor, while another sub-camera has a clear sensor;

FIG. 4A shows schematically in a flow chart an embodiment of a method disclosed herein;

FIG. 4B shows in a flow chart details of the scale adjustment step in the method shown in FIG. 4A;

FIG. 4C shows two images with corresponding points;

FIG. 5A shows schematically another embodiment of a dual-aperture imaging system with a single auto-focus mechanism disclosed herein in a sectioned isomeric view;

Fig. 5B shows schematically in a flow chart an embodiment of a method for auto-focus imaging with the imaging system in FIG. 5A;

FIG. 6 shows schematically yet another embodiment of a dual-aperture imaging system numbered with a single auto-focus mechanism in a sectioned isomeric view.

DETAILED DESCRIPTION

FIG. 2 shows schematically an embodiment of a dual-aperture imaging system with auto-focus disclosed herein and numbered **200**, in (a) a general isomeric view, and (b) a sectioned isomeric view. In the following description, "imaging system" and "camera" may be used interchangeably. System **200** comprises two sub-cameras, labeled **202** and **204**, each sub-camera having its own optics. Thus, sub-camera **202** includes an optics bloc **206** with an aperture **208** and an optical lens module **210**, as well as a sensor **212**. Similarly, sub-camera **204** includes an optics bloc **214** with an aperture **216** and an optical lens module **218**, as well as a sensor **220**. The sensors are also referred to henceforth as "sensor 1" (**212**) and "sensor 2" (**220**). Note that the two sensors may be implemented as two distinct areas on the same substrate, and not necessarily as two stand-alone sensors. Each optical lens module may include several lens elements as well as an Infra-Red (IR) filter **222a, b**. In some embodiments, some or all of the lens elements belonging to different apertures may be formed on the same substrate. The two sub-cameras are positioned next to each other, with a small baseline **224** between the two apertures **208** and **216**. Each sub-camera further includes an auto-focus mechanism**,** respectively **226** and **228.**

The sensors used in each sub-camera may have different color filter arrays (CFAs). In some embodiments, sensor 1 may have one type of CFA, while sensor 2 may have another type of CFA. In some embodiments, sensor 1 may have a CFA and sensor 2 may have a "white" or "clear" filter array (marked by "W") – in which all the pixels absorb the same wide range of wavelengths, e.g. between 400nm and 700nm (instead of each pixel absorbing a smaller portion of the spectrum). A sensor having a color filter array may be referred to henceforth as a "color image sensor", while a sensor with a clear or W filter array is referred to as a "clear image sensor".

FIG. 3 shows a sensor embodiment **300**, where numeral "1" represents sensor 1 (with a CFA) and numeral "2" represents sensor 2 (with a clear "white" filter array). Circles **302a, 302b** mark image circles formed by the optics on the sensors, while a white area **304** marks the substrate on which the sensors are located. Circles **302a, 302b** may be larger than the respective size of the sensor the image is formed on. In some cases, overlap between the two image circles may occur and mechanical light blocking elements (e.g., walls) may be needed to prevent optical cross-talk between the sub-cameras. By using a CFA on sensor 1, sub-camera 1 captures the color information about the scene, while sub-camera 2 captures luminance information about the scene.

The CFA of sensor 1 may be standard or non-standard. As used herein, a "standard CFA" may include a known CFA such as Bayer, RGBE, CYYM, CYGM and different RGBW filters such as RGBW#1, RGBW#2 and RGBW#3. "Non-standard" CFA patterns may exemplarily include repetitions of a 2x2 micro-cell in which the color filter order is RRBB, RBBR or YCCY where Y=Yellow = Green + Red, C = Cyan = Green + Blue; repetition of a 3x3 micro-cell in which the color filter order is GBRRGBBRG (e.g. as in sensor 1 in FIG. 3A); and repetitions of a 6x6 micro-cell in which the color filter order is one of the following options:

1. Line 1: RBBRRB. Line 2: RWRBWB. Line3: BBRBRR. Line 4: RRBRBB. Line 5: BWBRWR. Line 6: BRRBBR.
2. Line 1: BBGRRG. Line 2: RGRBGB. Line 3: GBRGRB. Line 4: RRGBBG. Line 5: BGBRGR. Line 6: GRBGBR.
3. Line 1: RBBRRB. Line 2: RGRBGB. Line 3: BBRBRR. Line 4: RRBRBB. Line 5: BGBRGR. Line 6: BRRBBR.
4. Line 1: RBRBRB. Line 2: BGBRGR. Line 3: RBRBRB. Line 4: BRBRBR. Line 5: RGRBGB. Line 6: BRBRBR.

The CFA pattern of sensor 1, utilizing some of the non-standard CFAs listed above has an advantage over the standard Bayer pattern in that it divides the red, green and blue colors evenly across the sensor pixels. This results in a finer sampling of red and blue colors, while the green color experiences coarser sampling compared with the standard Bayer pattern. However, as the image captured by sensor 2 is used to extract luminance information about the scene (instead of relying on the green channel for that, as is the case when using a Bayer CFA), the green pixels are used only for color information.

In traditional compact camera design, a filter that lets in light in the visible range and blocks light in the IR range is typically placed in the optical path, sometimes as part of a cover glass that protects the sensor. Although the blocking of IR light wastes photons, it allows for a more accurate estimation of the color in the scene, as it reduces color crosstalk from the spectral response of the R, G and B color filters (which may be sensitive to IR light). In an embodiment, clear sensor 2 is made sensitive to IR light by removing the IR filter or by redesigning its spectral response to let in some light in the IR range. The motivation for capturing IR light, in addition to light in the visible range, is to increase the Signal-to-Noise Ratio (SNR) in the image, as many natural and artificial light sources also emit photons in the IR spectrum. Unlike a sensor with a color CFA (i.e. sensor 1), absorption of IR light does not introduce color cross-talk in clear sensor 2 (since the sensor records a panchromatic image of the scene).

Removing the IR filter may have some negative implications on image quality. For example, extending the range of wavelengths that are captured by the camera may lead to longitudinal chromatic aberrations that may degrade the Point Spread Function (PSF), resulting in a blurrier image. To address this issue, in an embodiment, the optics of sub-camera 2 are optimized across both the visible and the IR range, to mitigate the effect of chromatic aberrations and to result in a more compact PSF compared with standard compact camera optics that use an IR filter. This is unlike the standard optimization process, which considers only wavelengths inside the visible range.

In use, the two sub-cameras share a similar FOV and have substantially equal (limited only by manufacturing tolerances) focal lengths. An image capture process is synchronized, so that the two sub-cameras capture an image of the scene at a particular moment. Due to the small baseline between the two apertures (which could be only a few millimeters, for example 6.5mm or 8.5mm) of the sub-cameras, the output images may show parallax, depending on the object distances in the scene. A digital image processing algorithm combines the two images into one image, in a process called "image fusion". Henceforth, the algorithm performing this process is called "image fusion algorithm". The resulting image may have a higher resolution (in terms of image pixels) and/or a higher "effective resolution" (in terms of the ability to resolve spatial frequencies in the scene, higher "effective resolution" meaning the ability to resolve higher spatial frequencies) and/ or a higher SNR than that of one sub-camera image.

In terms of resolution and exemplarily, if each sub-camera produces a 5 megapixel (2592x1944 pixels) image, the image fusion algorithm may combine the two images to produce one image with 8 megapixel (3264x2448 pixels) resolution. In terms of effective resolution, assuming that an imaged object or scene includes spatial frequencies, the use of a dual-aperture camera having a clear sensor and a color sensor as disclosed herein leads to an overall increase in effective resolution because of the ability of the clear sensor to resolve higher spatial frequencies of the luminance component of the scene, compared with a color sensor. The fusion of the color and clear images as performed in a method disclosed herein (see below) adds information in spatial frequencies which are higher than what could be captured by a color (e.g. Bayer) sub-camera.

In order to generate a higher-resolution or higher effective resolution image, the image fusion algorithm combines the color information from sub-camera 1 with the luminance information from sub-camera 2. Since clear sensor 2 samples the scene at a higher effective spatial sampling rate compared with any color channel or luminance thereof in the color sensor 1, the algorithm synthesizes an image that includes information at higher spatial frequencies compared with the output image from sub-camera 1 alone. The target of the algorithm is to achieve a spatial resolution similar to that obtained from a single-aperture camera with a sensor that has a higher number of pixels. Continuing the example above, the algorithm may combine two 5 megapixel images, one color and one luminance, to produce one 8 megapixel image with information content similar to that of a single-aperture 8 megapixel color camera.

In addition to improved spatial resolution, the image fusion algorithm uses the luminance information from clear sensor 2 to generate an image with increased SNR, vs. an image from a corresponding single-aperture camera. The fact that the pixels of sensor 2 are not covered by color filters allow each pixel to absorb light in a wider wavelength spectrum, resulting in a significant increase in the light efficiency compared with a color CFA camera. In an embodiment, the fusion of clear image information and color image information then provides a +3dB SNR increase over that of a single aperture digital camera.

As clear sensor 2 is more sensitive than color sensor 1, there may be a need to adjust exposure times or analog gains to match the digital signal levels between the two cameras. This could be achieved by fixing the same exposure times to both sensors and configuring a different analog gain to each sensor, or by fixing the analog gain in both sensors and configuring a different exposure time to each sensor.

FIG. 4A shows schematically, in a flow chart, an embodiment of a method disclosed herein. FIG. 4B shows in a flow chart details of the scale adjustment step in the method shown in FIG. 4A. Two images **400a** and **400b** from respectively sub-cameras 1 and 2 serve as inputs. The two images undergo pre-processing, in respectively step **402a** for the color image of sensor 1 and **402b** for the luminance image of sensor 2. Step **402a** includes digital image signal processing (ISP) in an ISP pipeline. The ISP generates a full color image, with R, G, B values at each image pixel. If the CFA pattern on sensor 1 is non-standard, the ISP includes non-standard demosaicing to interpolate the missing colors at each pixel location. In addition to demosaicing, other standard ISP pipeline algorithms may be applied on the image, e.g., black level correction, defect pixel correction, noise removal, etc, as known in the art. The luminance image from sub-camera 2 is also pre-processed to correct for defects, noise, shading profile, blur and other optical, analog and digital aberrations. Normalization, rectification and scale adjustment are then applied on the two images in step **404**. First, the two images are normalized to have the same mean signal intensity and standard deviation (which is a measure for the image dynamic range). This is done by subtracting the mean from each pixel and dividing each pixel by the standard deviation in each image. Then, the images are rectified by applying two projection matrices, in order to correct for different rotations around the x, y and z axes, to correct for x-y translations of the optical center of the two cameras and to fix lens distortions. The projection matrices parameters are pre-calculated from calibration data, which may be acquired through a calibration step that is applied for each camera module during camera module assembly. The data may be saved in one-time programmable memory or EEPROM in the camera module. After the rectification step, epipolar lines in both images are more-or-less parallel to the horizontal axis of the image, in case the two sub-cameras are positioned one beside the other along the X-axis, or parallel to the vertical axis of the image, in case the two sub-cameras are positioned one beside the other along the Y axis.

The scale adjustment, done after the rectification step, is described now in more detail with reference to FIGS. 4B. Preprocessed and rectified images **418a** and **418b** (also shown exemplarily in FIG. 4C) from respectively sub-cameras 1 and 2 serve as inputs. In step **420**, corresponding points between the two images are found. In an embodiment, the set of corresponding points is calculated over the entire image. In another embodiment, the set of corresponding points is found for a specific region of interest (ROI) in each image. FIG. 4C, which shows schematically two images A and B of the same scene captured by adjacent cameras (i.e. A captured by sub-camera 1 and A' captured by sub-camera 2) with some parallax – due to the different viewpoint, objects are imaged with some displacement in one image compared with the other, depending on their distance from the cameras. Pairs of features a - a', b- b' and c - c' represent the same "corresponding points" in the two images A and A'. An algorithm is used to find corresponding points between the two images. A set of prominent points are found (e.g. corners) in the two images and then the algorithm finds matches between the points in the two images. Such algorithms are known to the skilled in the art. In step **422**, the Y coordinate only is extracted in order to estimate the scale between the two images. Since the position of the optics, which is controlled by the AF mechanism, may introduce different scales between the two sub-camera images, the proper scale needs to be determined for each captured image (i.e. for each focus position). Assuming the two sub-cameras are positioned adjacent to one another along the X-axis, once corresponding pairs of points are found, a single coordinate is extracted from each point in step **422.** That is, the algorithm considers only their Y coordinate and disregards their X coordinate. The inventors have advantageously realized that while the X coordinate may be affected by parallax, the Y coordinate is largely unaffected by parallax after the rectification step, and therefore the Y coordinates can be used to estimate the scale more robustly. If the two sub-cameras are positioned adjacent along the Y-axis, then once corresponding pairs of point are found, the algorithm considers only their X coordinate and disregards their Y coordinate. Continuing with the assumption of the two sub-cameras being adjacent along the X-axis, the Y coordinates of the corresponding points are used to estimate a scaling factor S between the images in step **424**. In an exemplary embodiment, the scaling factor estimation is performed using least-squares, in which case S is given by

$$S = (Y2'*W*Y2)\backslash Y2'*W*Y1$$

where Y1 is a vector of Y coordinates of points taken from one image, Y2 is a vector of Y coordinates of points taken from the other image, and W is a diagonal matrix that holds the absolute values of Y2. Scaling factor S is then used in step **426** to scale one image in order to match the scale between the two images. In step **426**, point coordinates in each image are multiplied by the same scaling factor S. Finally, in step **428**, the corresponding pairs of scaled points are used to calculate a shift in x and y axes between the two images for each axis. In an embodiment, only a subset of the corresponding points that lie in a certain ROI is used to calculate the shift in x and y. For example, the ROI may be the region used to determine the focus, and may be chosen by the user or the camera software (SW). The estimated shift is applied on one of the images or on both images. The result of the scale adjustment process in FIG. 4B (and in step **404**, FIG. 4A) are scaled images **430.**

Returning now to FIG. 4A, local registration and parallax correction to estimate a disparity map are applied to the scaled images in step **406**. The local registration uses scale and shift parameters found in step **404**. Fusion to enhance the resolution and improve SNR in the final image is then performed in step **408**, by combining information from both images, according to the disparity map. The fusion process uses the image from sub-camera 1 as a baseline. The output is a fused image **410**. Post-processing such as tone mapping, gamma correction, contrast enhancement and color correction/enhancement may then be applied to the fused image.

Auto-Focus

As mentioned with respect to FIG. 2, a camera system disclosed herein includes an AF mechanism that controls the focus position of the optics. The system shown in FIG. 2 includes two such AF mechanisms. FIG. 5A shows schematically another embodiment of a dual-aperture imaging system numbered **500** with a single auto-focus mechanism in a sectioned isomeric view. System **500** includes in addition to the regular image sensors and optics only one AF mechanism **502**, positioned in a color sub-camera 1. A luminance sub-camera 2 does not have an AF mechanism, being instead a fixed-focus camera, with the focus fixed to a certain object distance. The focus position is such that the DOF range of sub-camera 2 is between infinity and several tens of centimeters, depending on the focal length and optical design. For example, the DOF may be between infinity and 50cm, such that sub-camera 2 would produce sharp images for object distances that lie within this range from the camera. In system **500**, sub-camera 1 can produce an image in which the main object is in focus for a wide range of object distances, so that it appears sharp in a sub-camera 1 image, by changing the focus position of the optics.

Fig. 5B shows schematically in a flow chart an embodiment of a method for image fusion using an imaging system **500** that has AF. Two images **500a** and **500b** from respectively sub-cameras 1 and 2 serve as inputs. A focus position is chosen for sub-camera 1 in step **502**. A check is performed in step **504** to determine whether the distance of an imaged object lies within the DOF of sub-camera 2, by calculating a sharpness metric on the images of sub-cameras 1 and 2, as known in the art. The calculation of the sharpness metric may result in a sharpness difference. If the answer in the check of step **504** is "Yes", the object will appear sharp in the sub-camera 2 image. In such a case, image fusion as described above is applied to the object image obtained by both sub-cameras in step **506** to achieve higher output resolution and better SNR. If the answer to check **504** is "No" (i.e. the object lies closer to the camera, outside the DOF range of sub-camera 2), the object will appear blurry (not sharp) in the sub-camera 2 image. In this case, the image from sub-camera 2 is not used to enhance the resolution, but only to improve the SNR of the image from sub-camera 1. To this end, another algorithm (procedure) similar to the fusion algorithm (procedure) above is applied in step **508**. The image from sub-camera 1 is scaled to the proper output size and a de-noising algorithm that uses information from the sub-camera 2 image is applied. Since in this case high frequencies are lost in the sub-camera 2 image (due to defocus), the algorithm only considers information at low spatial frequencies from the image of sub-camera 2. In order to determine the object distance, the chosen focus position of the AF mechanism of sub-camera 1 is used (after the focusing process has converged).

FIG. 6 shows schematically yet another embodiment of a dual-aperture imaging system numbered **600** with a single AF mechanism in a sectioned isomeric view. Similar to system **500,** system **600** includes in addition to the regular image sensors and optics only one AF mechanism **602**. However, in contrast with AF mechanism **502**, AF mechanism **602** moves the optics of sub-camera 1 and the optics of sub-camera 2 together. The optical elements are mounted on a lens holder **604** with dedicated threads to hold the two lenses, which is moved by the AF mechanism. Since the optics of sub-camera 1 and sub-camera 2 have very similar focal lengths, the mechanical movement brings the image from sub-camera

1 and from sub-camera 2 to focus at the same time. The advantage of this construction over having only one AF mechanism is that both sub-cameras support the same range of object distances, so that the image fusion algorithm can be applied for the entire range. When the AF mechanism chooses the best focus position for the lens, information from both sub-camera images can be taken into account (e.g. to assist in focusing in low-light situations). In low-light, AF sharpness measurements are noisier, due to the lower SNR in the images. Using two images instead of one can help reduce the noise and improve the robustness and accuracy of the AF process (algorithm).

In an embodiment, some or all the optical elements of sub-camera 1 and sub-camera 2, are made on the same die, using wafer-level optics manufacturing techniques or injection molding of glass or plastic materials. In this case, the single AF mechanism moves the optical dies on which the optical elements of the two sub-cameras are fabricated, so that the two optical stacks move together.

In another embodiment, a camera is similar to camera **500** and includes a single AF mechanism placed on sub-camera 1 (with the color CFA). Sub-camera 2 does not have an AF mechanism, but uses instead fixed focus optics with unique characteristics that provide extended depth of focus, which is achieved by means of optical design (e.g., by employing optics with narrower aperture and higher F-number). The optical performance of the optics of sub-camera 2 is designed to support sharp images for object distances between infinity and several cm from the camera – in this case, the fusion algorithm can be applied to enhance output resolution for a wider range of object distances compared with the single AF embodiment described above. There is usually a tradeoff between the DOF of the camera and the minimal achievable PSF size across the DOF range. An algorithm may be used to enhance the sharpness of the image captured by sub-camera 2 before the fusion algorithm is applied to combine the photos. Such an algorithm is known in the art.

To conclude, dual-aperture cameras and methods of use of such cameras disclosed herein have a number of advantages over single aperture cameras, in terms of camera height resolution, effective resolution and SNR. In terms of camera height, in one example, a standard 8Mpix 1/3" camera with a 70 degree diagonal FOV may have a module height of 5.7mm. In comparison, a dual-aperture camera disclosed herein, with two 5Mpix 1/4" image sensors (one color and one clear), each with 70 degrees diagonal field of view may have a module height of 4.5mm. In another example, a standard 8Mpix 1/3" camera with a 76 degree diagonal FOV may have a module height of 5.2mm. In comparison, a dual-aperture camera disclosed herein, with two 5Mpix 1/4" image sensors (one color and one clear), each with a

76 degree diagonal FOV, may have a module height of 4.1 mm.

While this disclosure has been described in terms of certain embodiments and generally associated methods, alterations and permutations of the embodiments and methods will be apparent to those skilled in the art. The disclosure is to be understood as not limited by the specific embodiments described herein, but only by the scope of the appended claims. 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 application.

WHAT IS CLAIMED IS:

1. A dual-aperture digital camera with auto-focus (AF) for imaging an object or scene, comprising:

a) a first sub-camera that includes a first optics bloc and a color image sensor with a first number of pixels, the first camera operative to provide a color image of the object or scene;

b) a second sub-camera that includes a second optics bloc and a clear image sensor having a second number of pixels, the second sub-camera operative to provide a luminance image of the object or scene, wherein the first and second sub-cameras have substantially the same field of view;

c) an AF mechanism coupled mechanically at least to the first optics bloc; and

d) a camera controller coupled to the AF mechanism and to the two image sensors and configured to control the AF mechanism, to calculate a scaling difference and a sharpness difference between the color and luminance images, the scaling and sharpness differences being due to the AF mechanism, and to process the color and luminance images into a fused color image using the calculated differences.

2. The camera of claim 1, wherein the AF mechanism is coupled mechanically to the first optics bloc and wherein the second optics bloc has a fixed focus position.

3. The camera of claim 2, wherein the fixed focus position is such that a depth of field range of the second sub-camera is between infinity and less than about 100 cm.

4. The camera of claim 1, wherein the AF mechanism is coupled mechanically to the first and second optics blocs and operative to move them together in a direction common to respective optics bloc optical axes.

5. The camera of claim 4, further comprising an optical image stabilization mechanism coupled mechanically to the first and second optics blocs and operative to move them together in a direction perpendicular to respective optics bloc optical axes to optically stabilize the AF fused color image.

6. The camera of claim 1, wherein the first number of pixels and second number of pixels are equal.

7. The camera of claim 1, wherein the first number of pixels and the second numbers of pixels are different.

8. The camera of claim 1, wherein the first and second images sensors are formed on a single substrate.

9. The camera of claim 1, wherein the first sub-camera includes an infra-red (IR) filter that blocks IR wavelengths from entering the color image sensor and wherein the second sub-camera is configured to allow at least some IR wavelengths to enter the clear image sensor.

10. The camera of claim 1, wherein the color image sensor include a non-standard color filter array (CFA).

11. The camera of claim 10, wherein the non-standard CFA includes a repetition of a 3x3 micro-cell in which the color filter order is GBRRGBBRG.

12. A method for obtaining a focused color image of an object or scene using a dual-aperture camera, comprising the steps of:

a) obtaining simultaneously an auto-focused (AF) color image and an auto-focused or fixed focus (FF) luminance image of the object or scene, wherein the color image has a first resolution, a first effective resolution and a first signal-to-noise ratio (SNR), and wherein the luminance image has a second resolution, a second effective resolution and a second SNR;

b) non-standardpreprocessing the two images to obtain respective rectified, normalized and scale- adjusted color and luminance images considering scaling and sharpness differences caused by the AF action;

c) performing local registration between the rectified, normalized and scale-adjusted color and luminance images to obtain registered images; and

d) fusing the registered images into a focused fused color image.

13. The method of claim 12, wherein the step of preprocessing to obtain scale-adjusted color and luminance images includes calculating a set of corresponding points in the color and luminance images, extracting a single coordinate from each corresponding point and using the single coordinate to estimate a scaling factor S between the color and luminance images.

14. The method of claim 13, wherein the extracted coordinate is Y and wherein the scaling factor S is given by S = (Y2'*W*Y2)\Y2'*W*Y1, wherein Y1 is a vector of Y coordinates of points taken from one image, Y2 is a vector of Y coordinates of points taken from the other image, and W is a diagonal matrix which holds the absolute values of Y2.

15. The method of claim 14, further comprising the step of using scaling factor S to scale one of the images to match the other image, thereby obtaining the registered images.

16. The method of claim 12, further comprising the step of optically stabilizing the obtained color and luminance images.

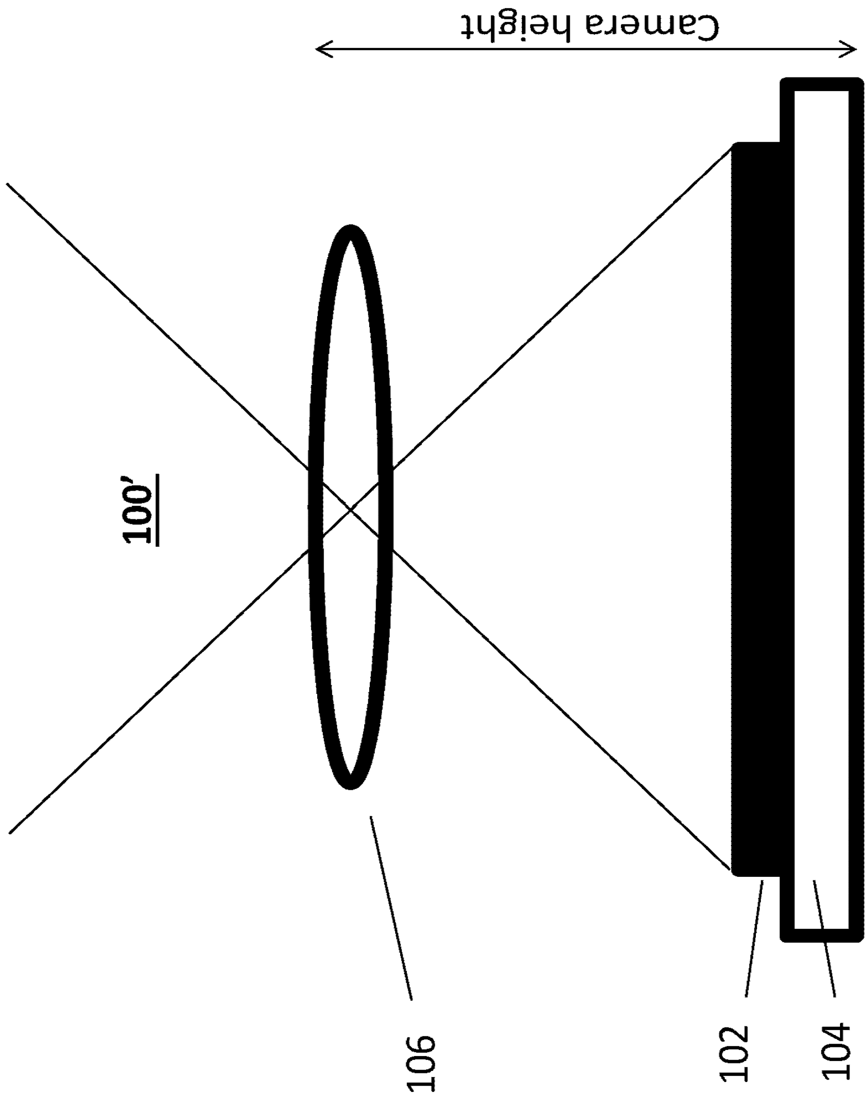

FIG. 1A

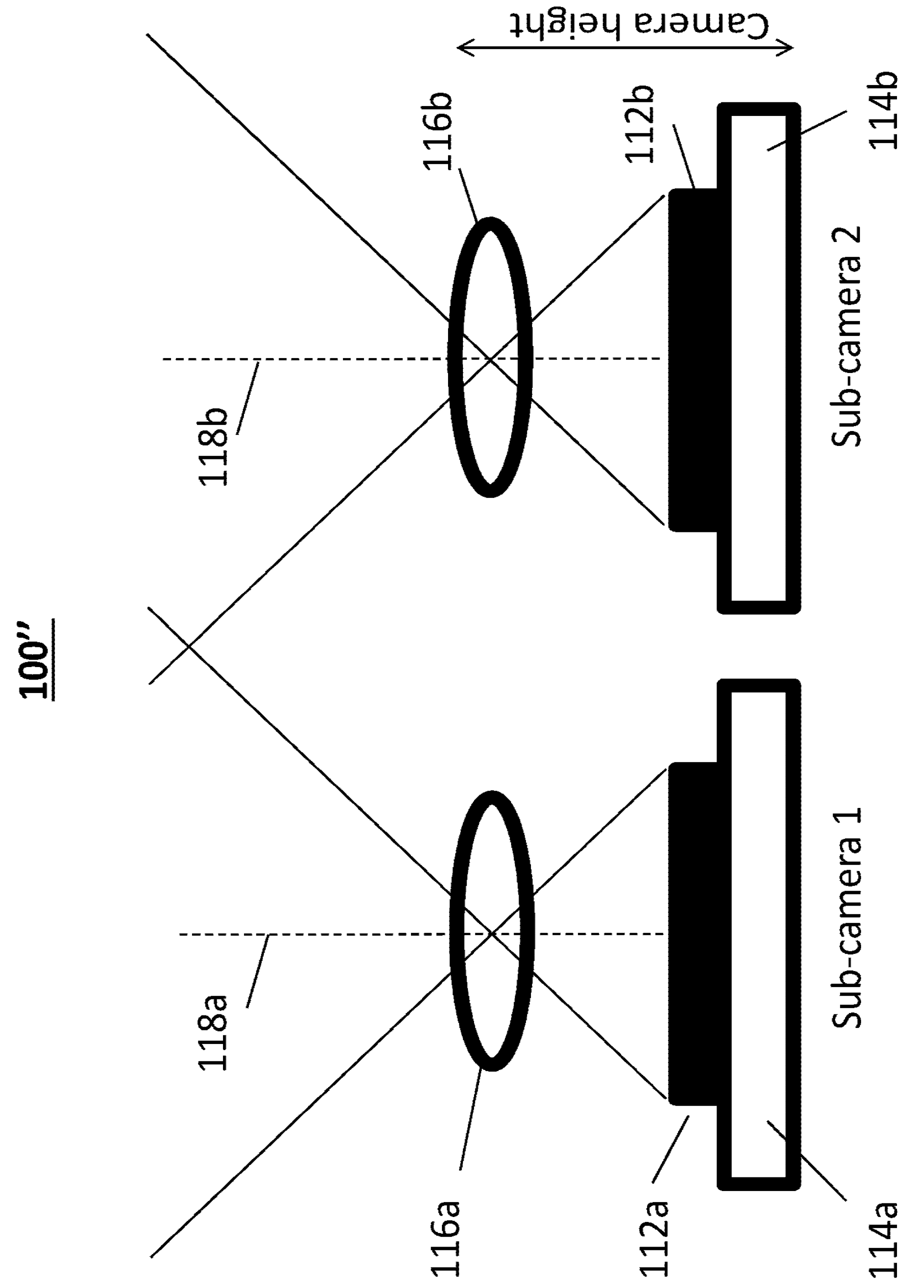
100''
Camera height
116b
112b
114b
118b
Sub-camera 2
118a
116a
112a
114a
Sub-camera 1

FIG. 1B

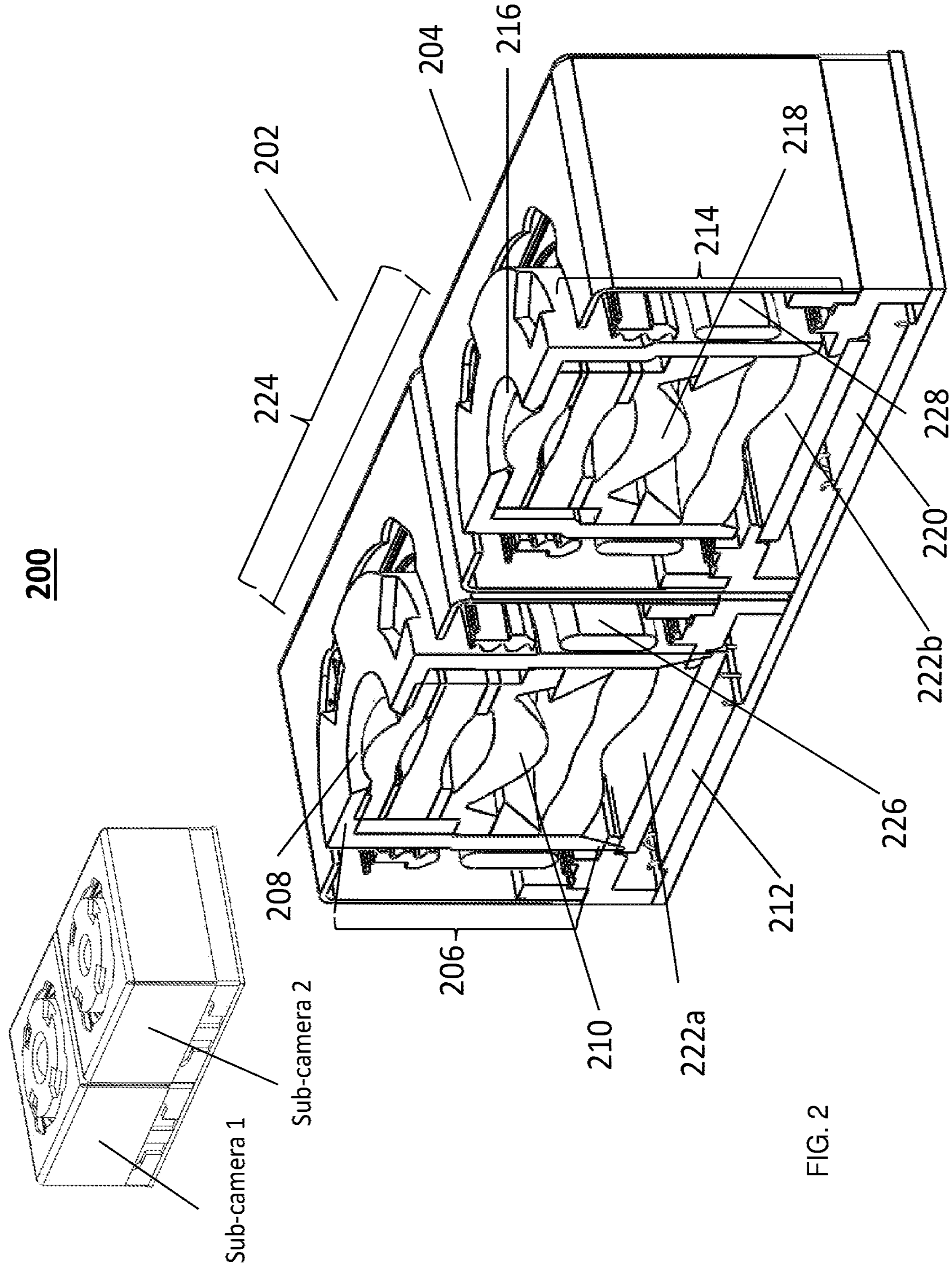
200
202
204
216
224
218
214
228
220
222b
226
212
222a
210
206
208
Sub-camera 1
Sub-camera 2

FIG. 2

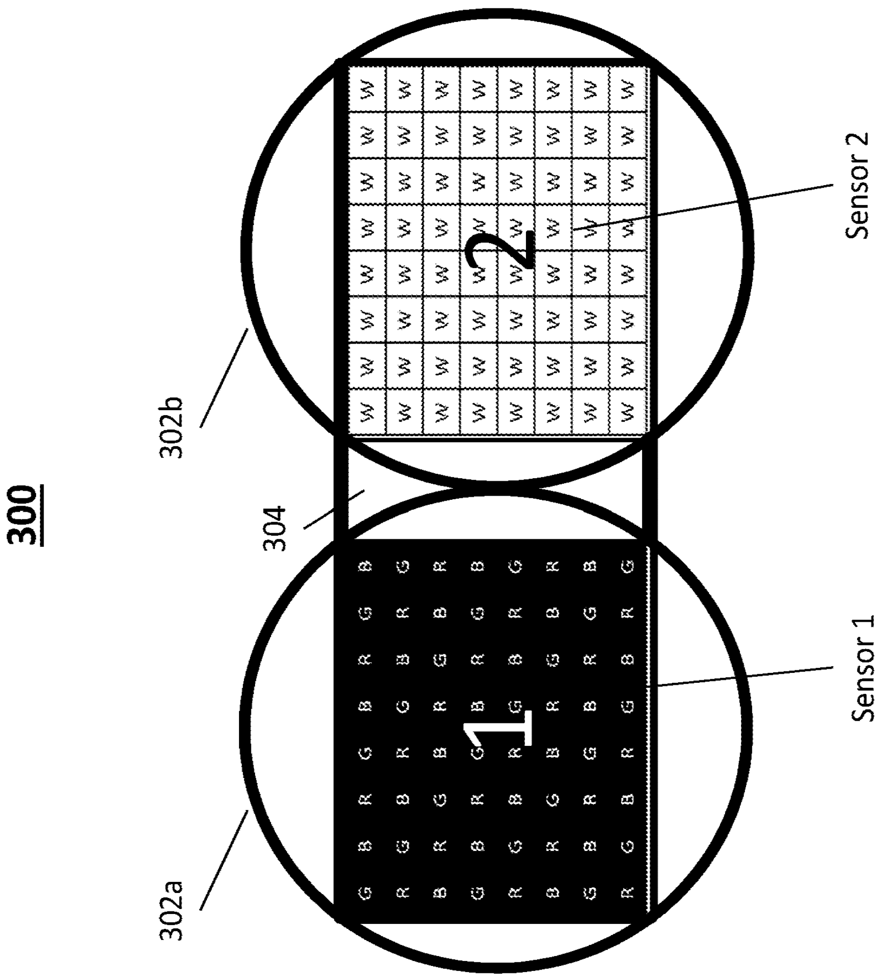

FIG. 3

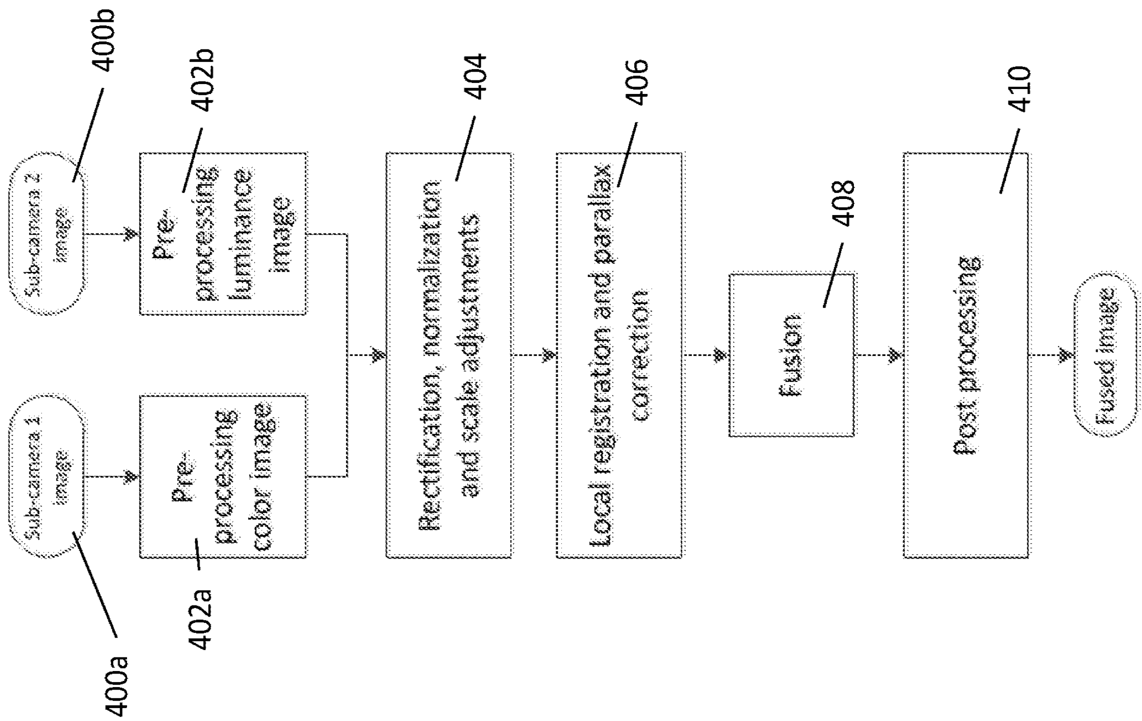
Sub-camera 1 image
Sub-camera 2 image
Pre-processing color image
Pre-processing luminance image
Rectification, normalization and scale adjustments
Local registration and parallax correction
Fusion
Post processing
Fused image
400a
400b
402a
402b
404
406
408
410

FIG. 4A

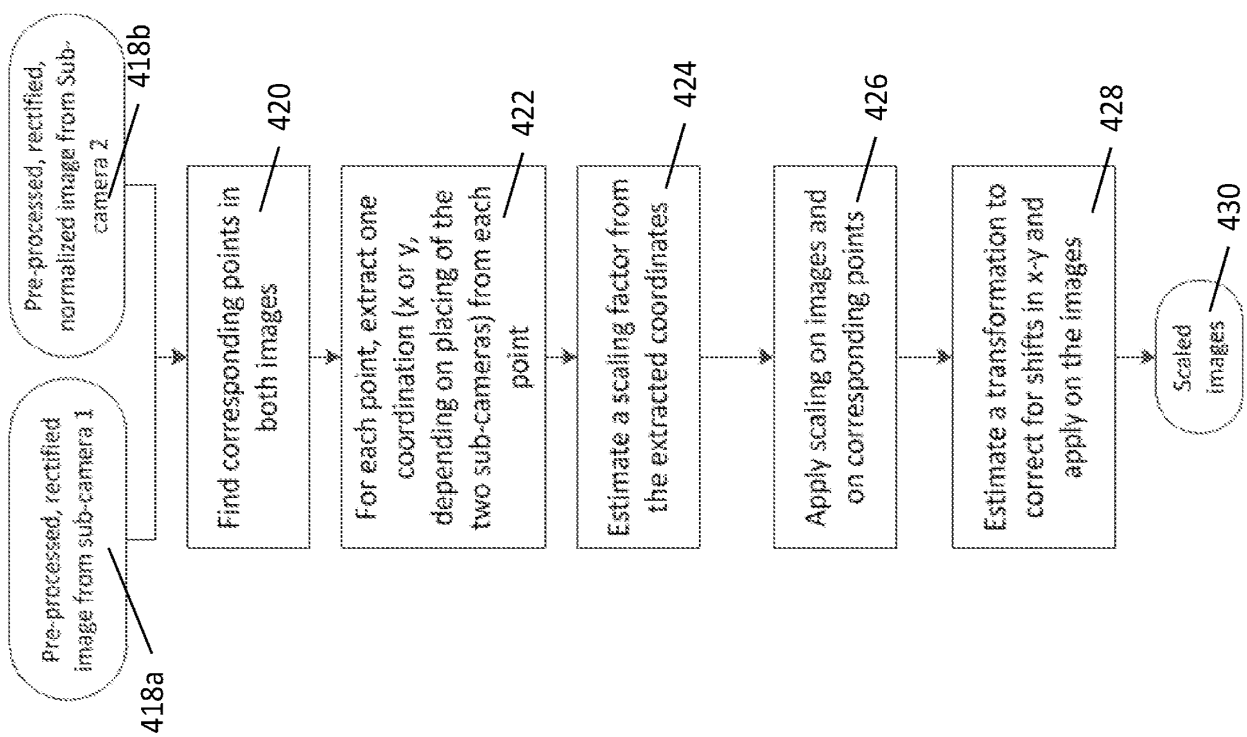
Pre-processed, rectified image from sub-camera 1
418a
Pre-processed, rectified, normalized image from Sub-camera 2
418b
Find corresponding points in both images
420
For each point, extract one coordination (x or y, depending on placing of the two sub-cameras) from each point
422
Estimate a scaling factor from the extracted coordinates
424
Apply scaling on images and on corresponding points
426
Estimate a transformation to correct for shifts in x-y and apply on the images
428
Scaled images
430

FIG. 4B

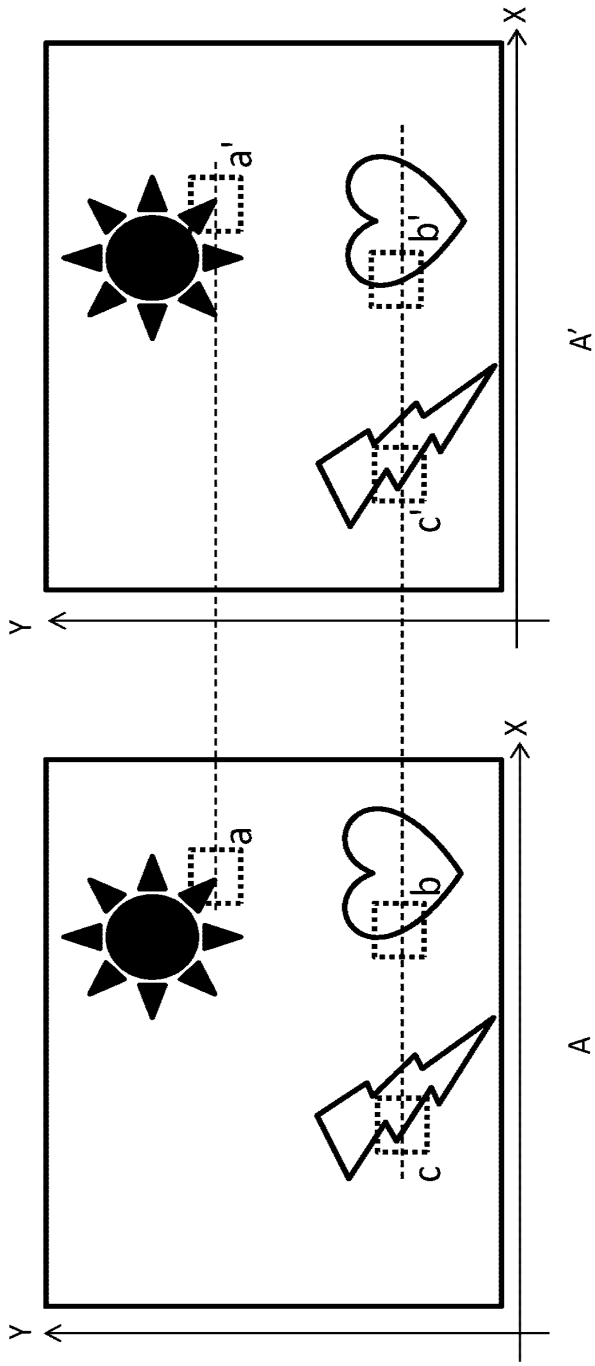

FIG. 4C

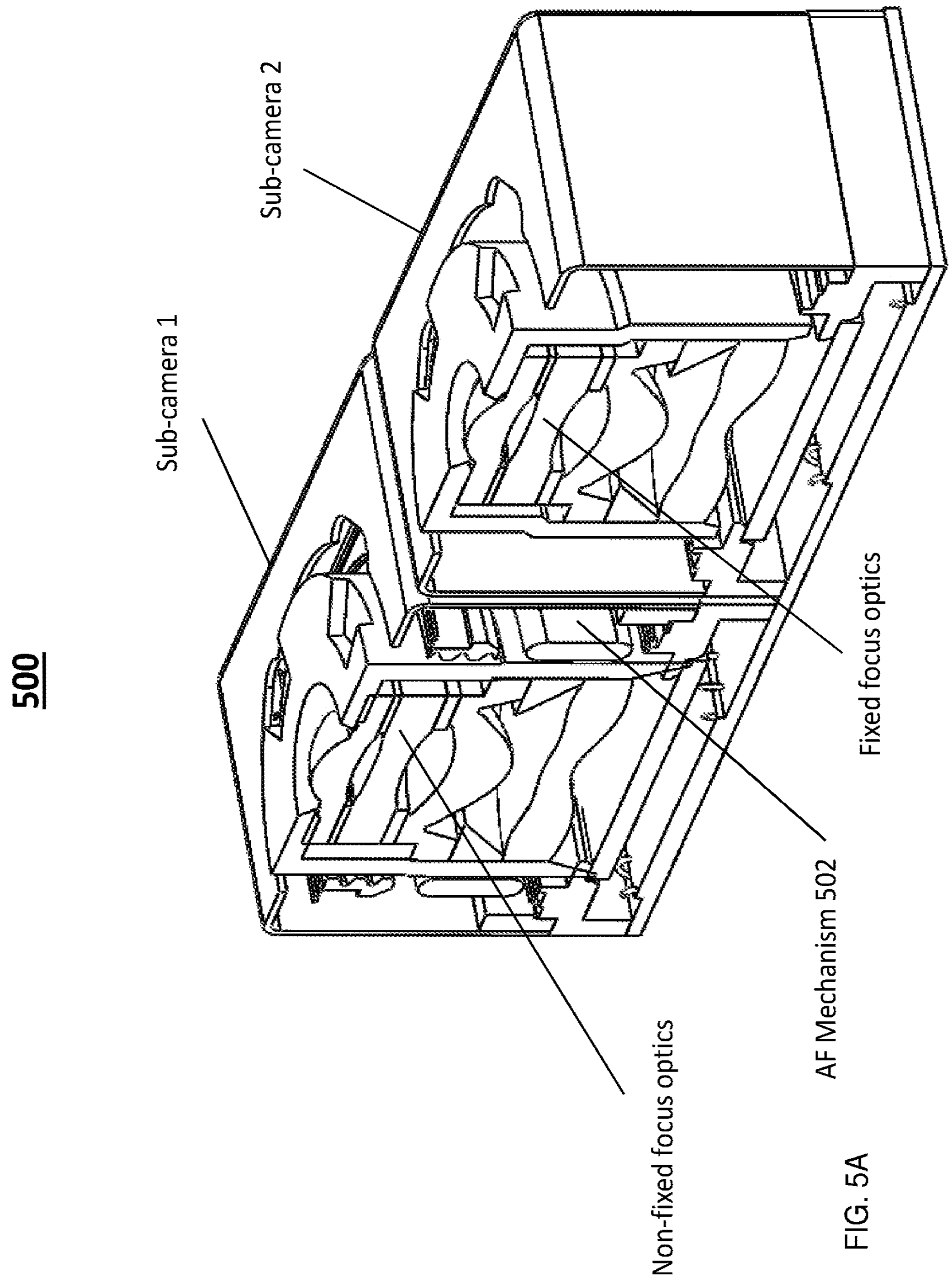
500
Sub-camera 1
Sub-camera 2
Fixed focus optics
AF Mechanism 502
Non-fixed focus optics

FIG. 5A

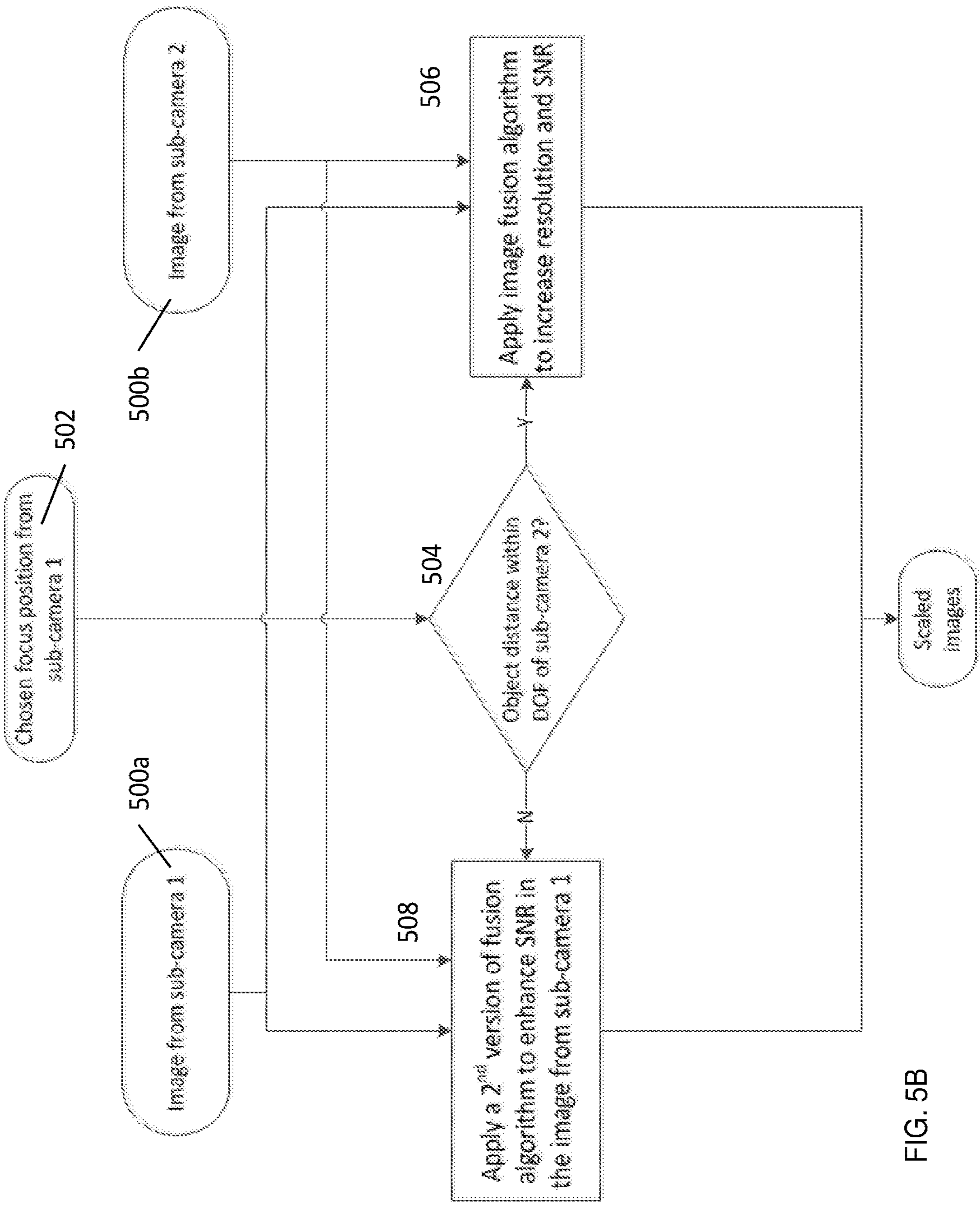
Image from sub-camera 2
500b
Chosen focus position from sub-camera 1
502
Image from sub-camera 1
500a
506
Apply image fusion algorithm to increase resolution and SNR
504
Object distance within DOF of sub-camera 2?
Y
N
508
Apply a 2nd version of fusion algorithm to enhance SNR in the image from sub-camera 1
Scaled images

FIG. 5B

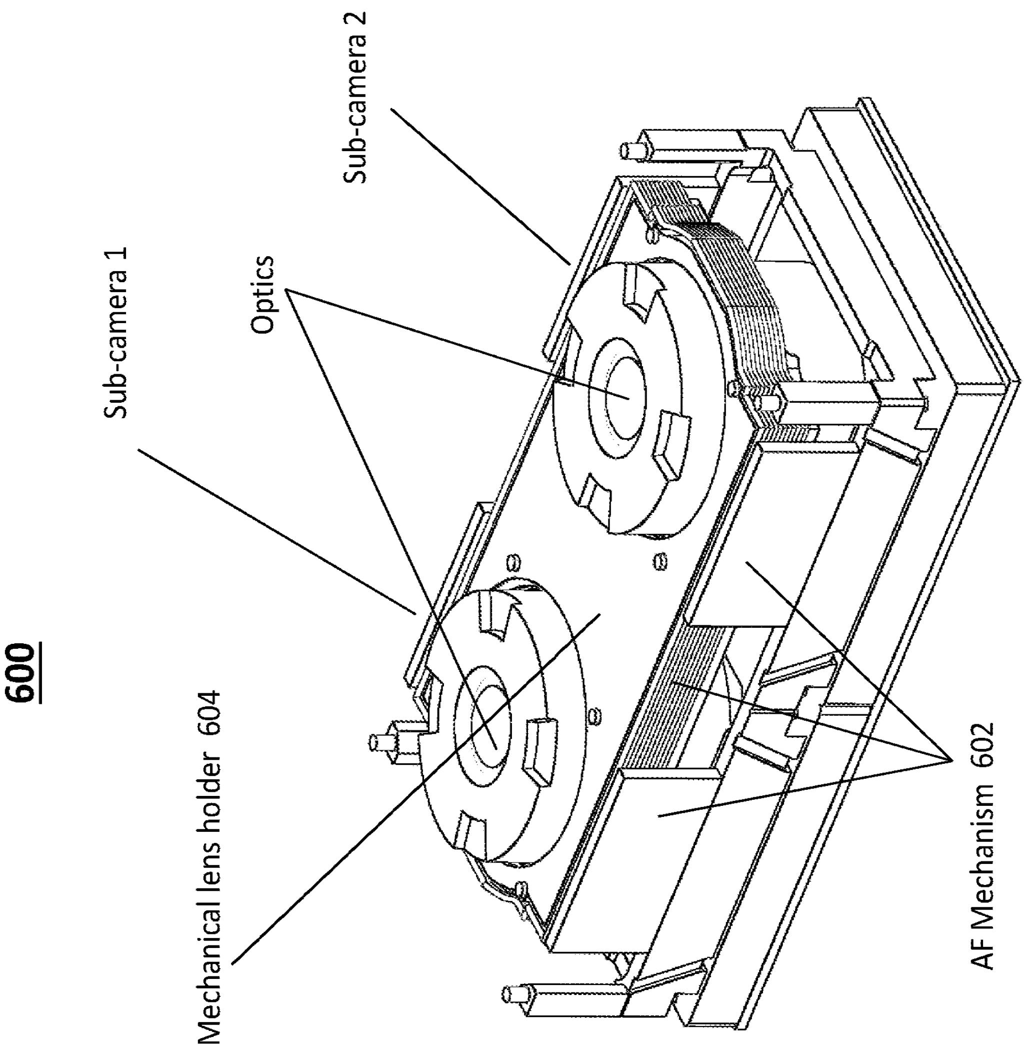
600
Sub-camera 1
Sub-camera 2
Optics
Mechanical lens holder 604
AF Mechanism 602

FIG. 6

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

92342 7590 11/08/2017
Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

EXAMINER	
LESTER, EVELYN A	
ART UNIT	PAPER NUMBER
2872	

DATE MAILED: 11/08/2017

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/418,925	01/30/2017	Michael Dror	COREPH-0080 US CIP	5957

TITLE OF INVENTION: MINIATURE TELEPHOTO LENS ASSEMBLY

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$480	$0	$0	$480	02/08/2018

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.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
or Fax (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)

92342 7590 11/08/2017

Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

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 facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)

(Signature)

(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/418,925	01/30/2017	Michael Dror	COREPH-0080 US CIP	5957

TITLE OF INVENTION: MINIATURE TELEPHOTO LENS ASSEMBLY

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$480	$0	$0	$480	02/08/2018

EXAMINER	ART UNIT	CLASS-SUBCLASS
LESTER, EVELYN A	2872	359-714000

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 03-02 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 has been filed for recordation as set forth in 37 CFR 3.11. 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. The following fee(s) are submitted:
- ❑ Issue Fee
- ❑ Publication Fee (No small entity discount permitted)
- ❑ Advance Order - # of Copies ______________

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
- ❑ A check is enclosed.
- ❑ Payment by credit card. Form PTO-2038 is attached.
- ❑ The director is hereby authorized to charge the required fee(s), any deficiency, or credits any overpayment, to Deposit Account Number ____________ (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)
- ❑ Applicant certifying micro entity status. See 37 CFR 1.29 — 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.
- ❑ Applicant asserting small entity status. See 37 CFR 1.27 — 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.
- ❑ Applicant changing to regular undiscounted fee 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. ______________________

PTOL-85 Part B (10-13) Approved for use through 10/31/2013. OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/418,925	01/30/2017	Michael Dror	COREPH-0080 US CIP	5957

92342 7590 11/08/2017

Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

EXAMINER	
LESTER, EVELYN A	
ART UNIT	**PAPER NUMBER**
2872	

DATE MAILED: 11/08/2017

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.

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 12 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. 15/418,925	Applicant(s) DROR ET AL.	
	Examiner EVELYN A. LESTER	Art Unit 2872	AIA (First Inventor to File) 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 *application filed on 1-30-17*.

   ☐ 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 *1-5*. 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 _____.

/EVELYN A. LESTER/
Primary Examiner, Art Unit 2872

The present application, filed on or after March 16, 2013, is being examined under the first inventor to file provisions of the AIA.

REASONS FOR ALLOWANCE

1. The following is an examiner's statement of reasons for allowance:

The prior art does not show or fairly suggest the claimed invention of a lens assembly having the claimed structure and claimed limitations, wherein a rejection under 35 USC 102 or 103 would be improper. Please particularly note the combination of claimed elements and claimed limitations, including as recited in independent claim 1 (with claims 2-5 dependent thereon), a lens assembly, comprising: a plurality of refractive lens elements arranged along an optical axis with a first lens element on an object side, wherein at least one surface of at least one of the plurality of lens elements is aspheric, wherein the lens assembly has an effective focal length (EFL), a total track length (TTL) of 6.5 millimeters or less, a ratio TTL/EFL of less than 1.0, a F number smaller than 3.2 and a ratio between a largest optical axis thickness Lll and a circumferential edge thickness Lie of the first lens element of Lll/Lle < 4. The claimed invention thereby provides an optical lens assembly of a miniature telephoto lens that has a small TTL/EFL of less than one and improved image quality.

Therefore, the claimed invention is considered to be in condition for allowance as being novel and nonobvious over the prior art.

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

Drawings

2. The drawings were received on 1-30-17. These drawings are approved.

Conclusion

3. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure.

The following are various configurations of lens assemblies, but fail to meet the recited details and conditional statements of the claimed invention:

Do	U.S. Patent Pub. 2009/0185289 A1
Engelhardt et al	U.S. Patent Pub. 2011/0115965 A1
Tang et al	U.S. Patent Pub. 2011/0249346 A1
Chen et al	U.S. Patent Pub. 2011/0261470 A1
Tang et al	U.S. Patent Pub. 2011/0279910 A1
Tsai et al	U.S. Patent Pub. 2012/0086848 A1
Shinohara	U.S. Patent Pub. 2014/0098428 A1
Ohtsu	U.S. Patent Pub. 2015/0146076 A1

The following are related an application and U.S. Patents to the claimed invention (i.e. were copending applications):

Dror et al	U.S. Patent Pub. 2015/0029601 A1
Dror et al	U.S. Patent 9,402,032 B2
Dror et al	U.S. Patent 9,568,712 B2.

4. Any inquiry concerning this communication or earlier communications from the examiner should be directed to EVELYN A. LESTER whose telephone number is

(571)272-2332. The examiner can normally be reached on M-F, subject to an increased flex schedule.

Examiner interviews are available via telephone, in-person, and video conferencing using a USPTO supplied web-based collaboration tool. To schedule an interview, applicant is encouraged to use the USPTO Automated Interview Request (AIR) at http://www.uspto.gov/interviewpractice.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Ricky L. Mack can be reached on (571) 272-2333. 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.

/EVELYN A. LESTER/
Primary Examiner
Art Unit 2872

Notice of References Cited	Application/Control No. 15/418,925	Applicant(s)/Patent Under Reexamination DROR ET AL.	
	Examiner EVELYN A. LESTER	Art Unit 2872	Page 1 of 1

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*	B	US-2011/0115965 A1	05-2011	Engelhardt; Kai	G02B13/004	359/715
*	C	US-2011/0249346 A1	10-2011	Tang; Hsiang Chi	G02B13/0045	359/764
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*	J	US-9,402,032 B2	07-2016	Dror; Michael	G02B9/60	1/1
*	K	US-9,568,712 B2	02-2017	Dror; Michael	G02B9/60	1/1
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	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
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	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.

U.S. Patent and Trademark Office
PTO-892 (Rev. 01-2001) **Notice of References Cited** Part of Paper No. 20171030

EAST Search History

EAST Search History (Prior Art)

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EAST Search History

EAST Search History (Prior Art)

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CONFIRMATION NO. 5957

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
15/418,925	01/30/2017 **RULE**	359	2872	COREPH-0080 US CIP

APPLICANTS
Corephotonics Ltd., Tel-Aviv, ISRAEL;

INVENTORS
Michael Dror, Nes Ziona, ISRAEL;
Ephraim Goldenberg, Ashdod, ISRAEL;
Gal Shabtay, Tel Aviv, ISRAEL;

** **CONTINUING DATA** *************************
This application is a CIP of 15/170,472 06/01/2016 PAT 9568712
which is a CON of 14/932,319 11/04/2015 PAT 9402032
which is a CON of 14/367,924 09/19/2014 ABN *
which is a 371 of PCT/IB2014/062465 06/20/2014
which claims benefit of 61/842,987 07/04/2013
(*)Data provided by applicant is not consistent with PTO records.

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

** **IF REQUIRED, FOREIGN FILING LICENSE GRANTED** ** ** SMALL ENTITY **
02/06/2017

Foreign Priority claimed ☐ Yes ☑ No 35 USC 119(a-d) conditions met ☐ Yes ☑ No Verified and Acknowledged /EVELYN A LESTER/ Examiner's Signature	☐ Met after Allowance Initials	STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
		ISRAEL	6	5	1

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TITLE

MINIATURE TELEPHOTO LENS ASSEMBLY

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

BIB (Rev. 05/07).

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15418925	DROR ET AL.
	Examiner	**Art Unit**
	EVELYN A LESTER	2872

CPC					
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G02B	9	/	60	I	2013-01-01
G02B	27	/	0025	I	2013-01-01
G02B	1	/	041	I	2013-01-01
G02B	27	/	646	I	2013-01-01
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Y10T	29	/	4913	A	2015-01-15
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CPC Combination Sets							
Symbol				**Type**	**Set**	**Ranking**	**Version**
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NONE (Assistant Examiner) (Date)	**Total Claims Allowed:** 5	
/EVELYN A LESTER/ Primary Examiner.Art Unit 2872 10-30-17 (Primary Examiner) (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1A

U.S. Patent and Trademark Office Part of Paper No. 20171030

Issue Classification

Application/Control No.	Applicant(s)/Patent Under Reexamination
15418925	DROR ET AL.
Examiner	**Art Unit**
EVELYN A LESTER	2872

US ORIGINAL CLASSIFICATION

CLASS	SUBCLASS
359	714

CROSS REFERENCE(S)

CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				
359	739	740	763	764	

INTERNATIONAL CLASSIFICATION

CLAIMED					NON-CLAIMED
G	0	2	B	9 / 60 (2006.01.01)	
G	0	2	B	13 / 18 (2006.01.01)	

NONE (Assistant Examiner)	(Date)	Total Claims Allowed: 5
/EVELYN A LESTER/ Primary Examiner.Art Unit 2872 (Primary Examiner)	10-30-17 (Date)	O.G. Print Claim(s): 1 O.G. Print Figure: 1A

U.S. Patent and Trademark Office

Part of Paper No. 20171030

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	15418925	DROR ET AL.
	Examiner	**Art Unit**
	EVELYN A LESTER	2872

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

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NONE (Assistant Examiner) (Date)	**Total Claims Allowed:** 5	
/EVELYN A LESTER/ Primary Examiner.Art Unit 2872 10-30-17 (Primary Examiner) (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1A

U.S. Patent and Trademark Office Part of Paper No. 20171030

Search Notes	**Application/Control No.** 15418925	**Applicant(s)/Patent Under Reexamination** DROR ET AL.
	Examiner EVELYN A LESTER	**Art Unit** 2872

CPC- SEARCHED		
Symbol	**Date**	**Examiner**
G02B 13/0045; G02B 9/60; G02B 27/0025; G02B 5/005; G02B 13/02; G02B 1/041; G02B 13/002; G02B 9/00; G02B 27/646; H04N 2101/00; Y10T 29/4913.	10-1-17	EAL
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US CLASSIFICATION SEARCHED			
Class	**Subclass**	**Date**	**Examiner**
359	714, 739, 740, 763, 764.	10-1-17	EAL
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* 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**
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Classification searches for CPC and USPC, crossed with the above text search; see search strategy for details.	10-1-17	EAL
Update search of all the above.	10-29-17	EAL
Inventor and Assignee searches in EAST.	10-29-17	EAL

INTERFERENCE SEARCH			
US Class/ CPC Symbol	**US Subclass / CPC Group**	**Date**	**Examiner**

	/EVELYN A LESTER/ Primary Examiner.Art Unit 2872

INTERFERENCE SEARCH			
US Class/ CPC Symbol	**US Subclass / CPC Group**	**Date**	**Examiner**
Same search as for the	CPC and USPC searches, crossed with a text search; see search strategy for details.	10-29-17	EAL

/EVELYN A LESTER/
Primary Examiner.Art Unit 2872

EAST Search History

EAST Search History (Interference)

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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)

92342 7590 11/08/2017
Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

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 facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/418,925	01/30/2017	Michael Dror	COREPH-0080 US CIP	5957

TITLE OF INVENTION: MINIATURE TELEPHOTO LENS ASSEMBLY

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$480	$0	$0	$480	02/08/2018

EXAMINER	ART UNIT	CLASS-SUBCLASS
LESTER, EVELYN A	2872	359-714000

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 03-02 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 Nathan & Associates Patent Agents Ltd.
   2 Menachem Nathan
   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 has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: Corephotonics Ltd.
(B) RESIDENCE: (CITY and STATE OR COUNTRY): Tel Aviv, Israel

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

4a. The following fee(s) are submitted:
- ☒ Issue Fee
- ☐ Publication Fee (No small entity discount permitted)
- ☐ Advance Order - # of Copies ______

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
- ☐ A check is enclosed.
- ☒ Payment by credit card. ~~Form PTO-2038 is attached.~~ Via EFS-Web
- ☐ The director is hereby authorized to charge the required fee(s), any deficiency, or credits any overpayment, to Deposit Account Number ______ (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)
- ☐ Applicant certifying micro entity status. See 37 CFR 1.29
  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.
- ☐ Applicant asserting small entity status. See 37 CFR 1.27
  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.
- ☐ Applicant changing to regular undiscounted fee 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 /Menachem Nathan/ Date 11/08/2017

Typed or printed name Menachem Nathan Registration No. 65392

PTOL-85 Part B (10-13) Approved for use through 10/31/2013. OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Electronic Patent Application Fee Transmittal

Application Number:	15418925
Filing Date:	30-Jan-2017
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Filer:	Menachem Nathan
Attorney Docket Number:	COREPH-0080 US CIP

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	480	480

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**480**

Electronic Acknowledgement Receipt

EFS ID:	30890002
Application Number:	15418925
International Application Number:	
Confirmation Number:	5957
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Customer Number:	92342
Filer:	Menachem Nathan
Filer Authorized By:	
Attorney Docket Number:	COREPH-0080 US CIP
Receipt Date:	08-NOV-2017
Filing Date:	30-JAN-2017
Time Stamp:	14:01:00
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$480
RAM confirmation Number	110917INTEFSW14025900
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)	Issue_fee.pdf	2454008 caa5b9c9265758bb1ee44247da27aeeb998a4125	no	1
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	30142 a6292a1797397159b9a7558fb6df0020690731a4	no	2
Warnings:					
Information:					
			Total Files Size (in bytes):	2484150	

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.

<u>New Applications Under 35 U.S.C. 111</u>
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.
<u>National Stage of an International Application under 35 U.S.C. 371</u>
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.
<u>New International Application Filed with the USPTO as a Receiving Office</u>
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.

UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
15/418,925	01/30/2017	Michael Dror	COREPH-0080 US CIP

CONFIRMATION NO. 5957

PUBLICATION NOTICE

OC000000091633050

92342
Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

Title:MINIATURE TELEPHOTO LENS ASSEMBLY

Publication No.US-2017-0146777-A1
Publication Date:05/25/2017

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently http://www.uspto.gov/patft/.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Office of Public Records. The Office of Public Records can be reached by telephone at (571) 272-3150 or (800) 972-6382, by facsimile at (571) 273-3250, by mail addressed to the United States Patent and Trademark Office, Office of Public Records, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently http://pair.uspto.gov/. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Office of Data Managment, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 15/418,925

APPLICATION AS FILED - PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	70		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	300		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	360		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	5 minus 20 =	*	x 40 =	0.00	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	1 minus 3 =	*	x 210 =	0.00			
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).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
			TOTAL	730		TOTAL	

* If the difference in column 1 is less than zero, enter "0" in column 2.

APPLICATION AS AMENDED - PART II

AMENDMENT A		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

AMENDMENT B		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** 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 found in the appropriate box in column 1.

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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
15/418,925	01/30/2017	2872	730	COREPH-0080 US CIP	5	1

CONFIRMATION NO. 5957

UPDATED FILING RECEIPT

OC000000089237074

92342
Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

Date Mailed: 02/16/2017

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. 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)

Michael Dror, Nes Ziona, ISRAEL;
Ephraim Goldenberg, Ashdod, ISRAEL;
Gal Shabtay, Tel Aviv, ISRAEL;

Applicant(s)

Corephotonics Ltd., Tel-Aviv, ISRAEL;

Power of Attorney: The patent practitioners associated with Customer Number 92342

Domestic Priority data as claimed by applicant

This application is a CIP of 15/170,472 06/01/2016 PAT 9568712
which is a CON of 14/932,319 11/04/2015 PAT 9402032
which is a CON of 14/367,924 09/19/2014 ABN *
which is a 371 of PCT/IB2014/062465 06/20/2014
which claims benefit of 61/842,987 07/04/2013
(*)Data provided by applicant is not consistent with PTO records.

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 02/06/2017

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 15/418,925**

Projected Publication Date: 05/25/2017

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

MINIATURE TELEPHOTO LENS ASSEMBLY

Preliminary Class

359

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).

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Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

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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).

SelectUSA

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 U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

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UNITED STATES DEPARTMENT OF COMMERCE
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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
15/418,925	01/30/2017	Michael Dror	COREPH-0080 US CIP

CONFIRMATION NO. 5957

FORMALITIES LETTER

OC000000089024712

92342
Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

Date Mailed: 02/08/2017

NOTICE TO FILE CORRECTED APPLICATION PAPERS

Filing Date Granted

An application number and filing date have been accorded to this application. The application is informal since it does not comply with the regulations for the reason(s) indicated below. Applicant is given TWO MONTHS from the date of this Notice within which to correct the informalities indicated below. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

The required item(s) identified below must be timely submitted to avoid abandonment:

- Replacement drawings in compliance with 37 CFR 1.84 and 37 CFR 1.121(d) are required. The drawings submitted are not acceptable because:
  - More than one figure is present and each figure is not labeled "Fig." with a consecutive Arabic numeral (1, 2, etc.) or an Arabic numeral and capital letter in the English alphabet (A, B, etc.)(see 37 CFR 1.84(u)(1)). See Figure(s) 2C. A brief description of the several views of the drawings (see 37 CFR 1.74) should be added or amended to correspond to the corrected numbering of the figures. See also 37 CFR 1.77(b)(9).

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

Replies must be received in the USPTO within the set time period or must include a proper Certificate of Mailing or Transmission under 37 CFR 1.8 with a mailing or transmission date within the set time period. For more information and a suggested format, see Form PTO/SB/92 and MPEP 512.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web, including a copy of this Notice and selecting the document description "Applicant response to Pre-Exam Formalities Notice". https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at 1-866-217-9197 or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

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

/amanalac/

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Applicant:	§	Confirmation No: 5957
	§	
Michael Dror	§	
	§	
Serial No.: 15/418,925		
Title: **MINIATURE TELEPHOTO LENS ASSEMBLY**		
	§	
Filed: 01/30/2017	§	
	§	Attorney Docket: Coreph-0080 US CIP

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

RESPONSE

This is in response to the Notice to File Corrected Application Papers Action having a Notification Date of 02/08/2016, which response is made timely. The Notice requested Replacement Drawings. Applicant hereby provides a full set of drawings including a REPLACEMENT SHEET with a corrected number of a figure to read "FIG. 2C".

It is respectfully submitted that claims 1-5 are in condition for allowance. Prompt notice of allowance is respectfully and earnestly solicited.

Respectfully submitted,

/ Menachem Nathan /
Menachem Nathan
Agent for Applicant
Registration No. 65392

Date: February 11, 2017

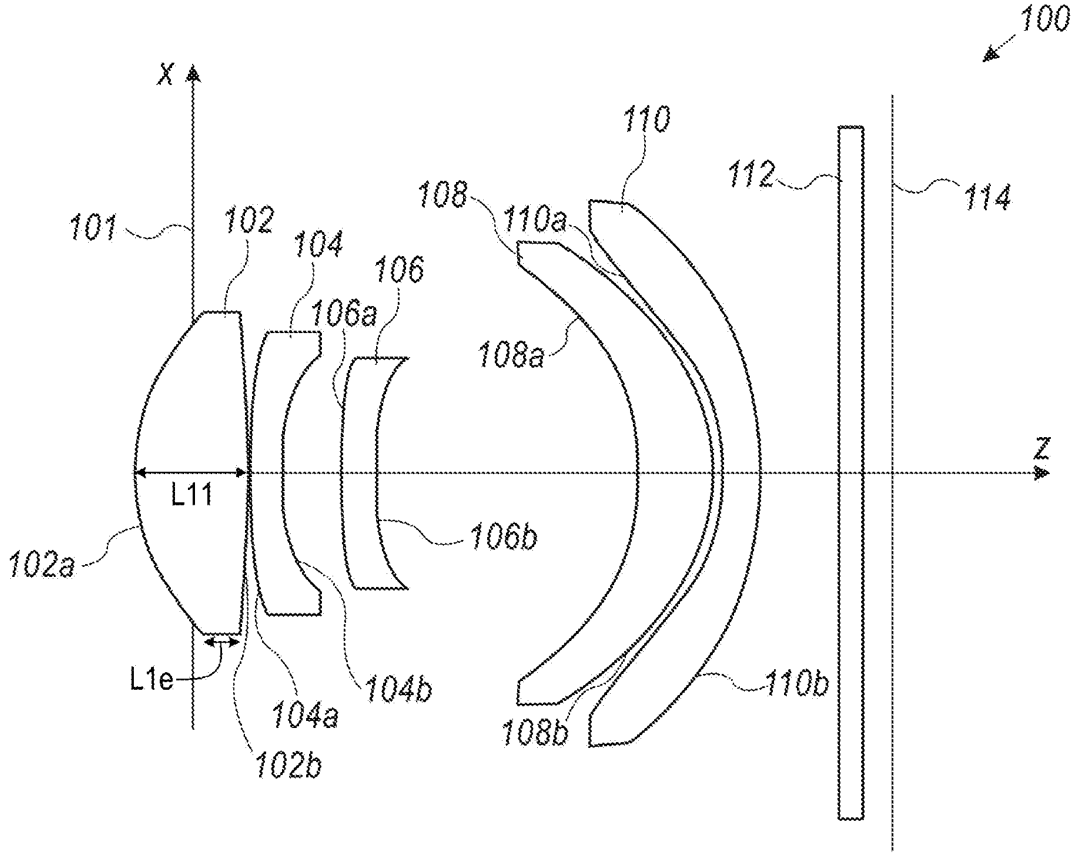
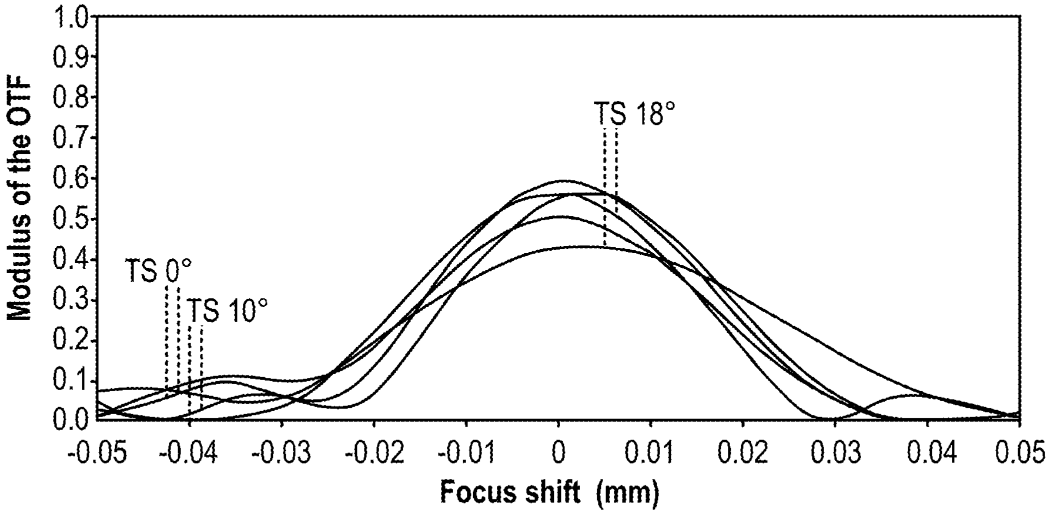
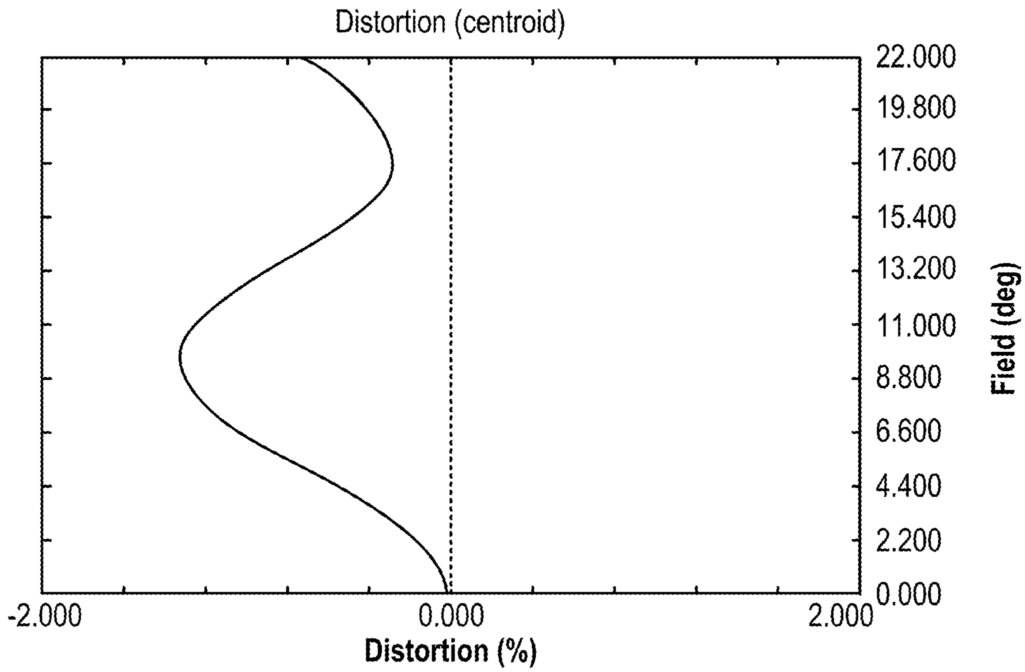

100
X
110
112
114
108
110a
101
102
104
106
106a
108a
Z
L11
106b
102a
L1e
104a
104b
110b
108b
102b

FIG. 1A



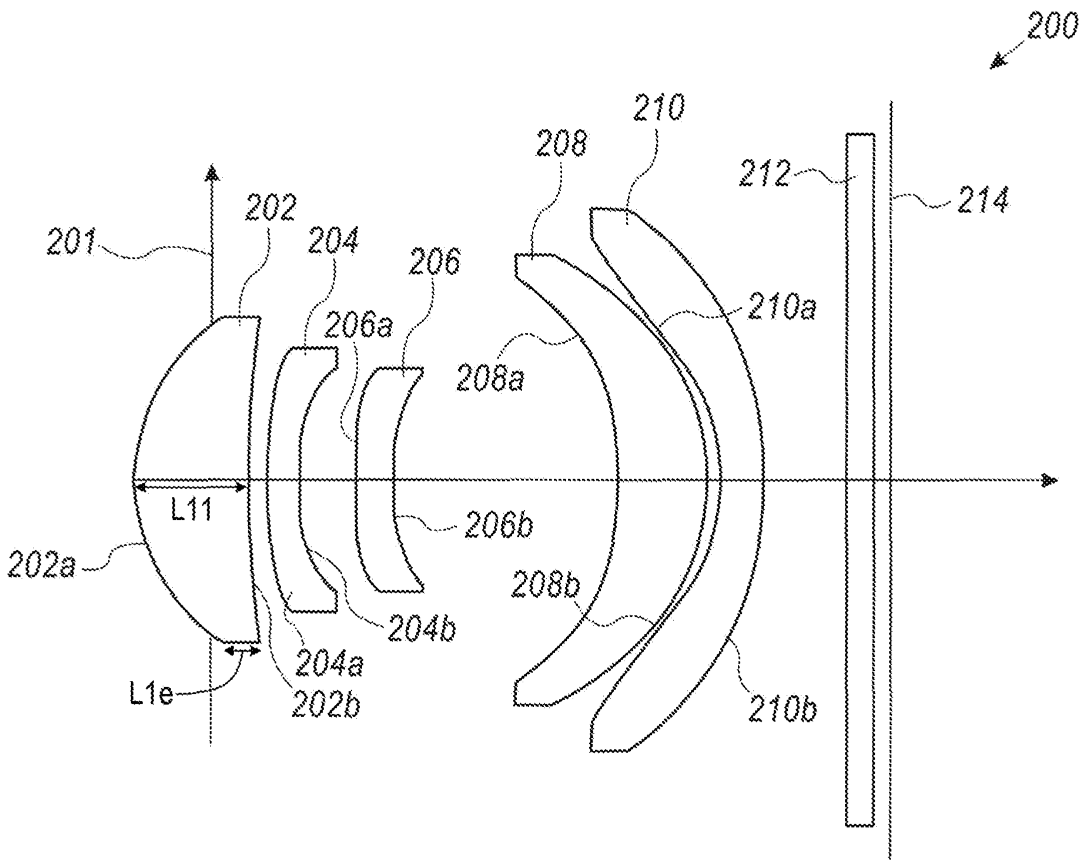
Polychromatic Diffraction Through Focus MTF
Angle 6/2/2013
Data for 0.4350 to 0.6560 µm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 1B



30/06/2013
Maximum distortion = 1.3%

FIG. 1C


200
210
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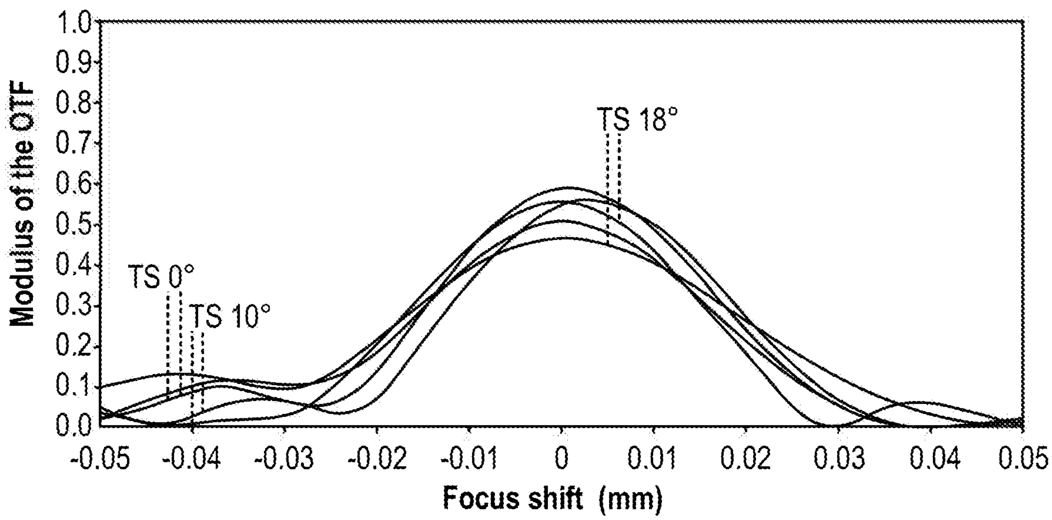
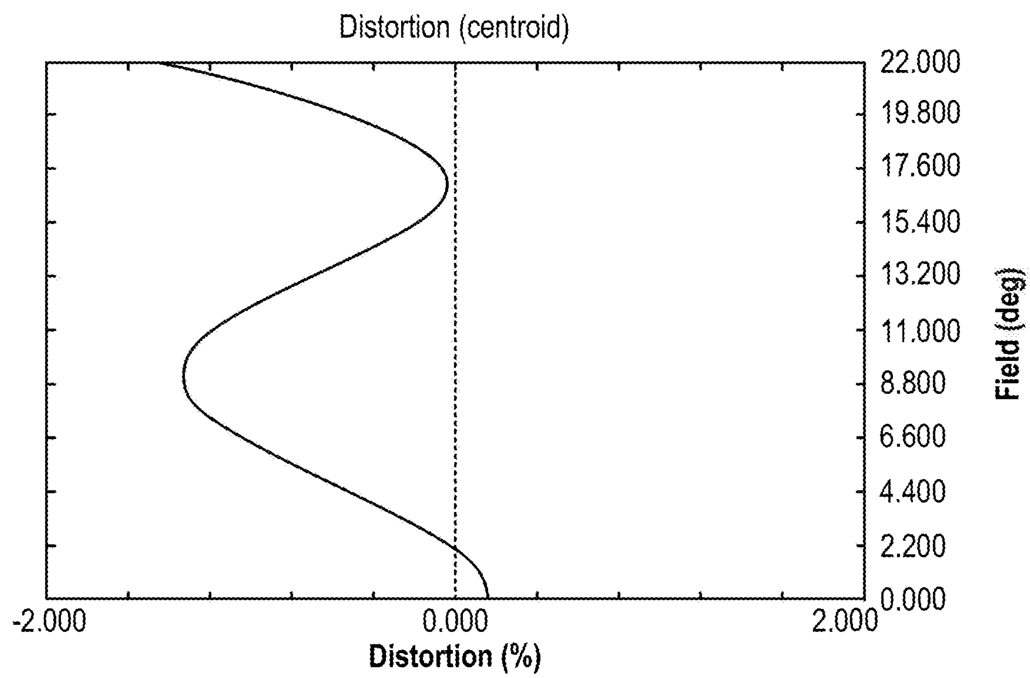
206
206a
210a
208a
L11
206b
202a
208b
204b
204a
L1e
202b
210b

FIG. 2A



Polychromatic Diffraction Through Focus MTF
Angle 6/2/2013
Data for 0.4350 to 0.6560 µm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 2B



30/06/2013
Maximum distortion = 1.5%

FIG. 2C

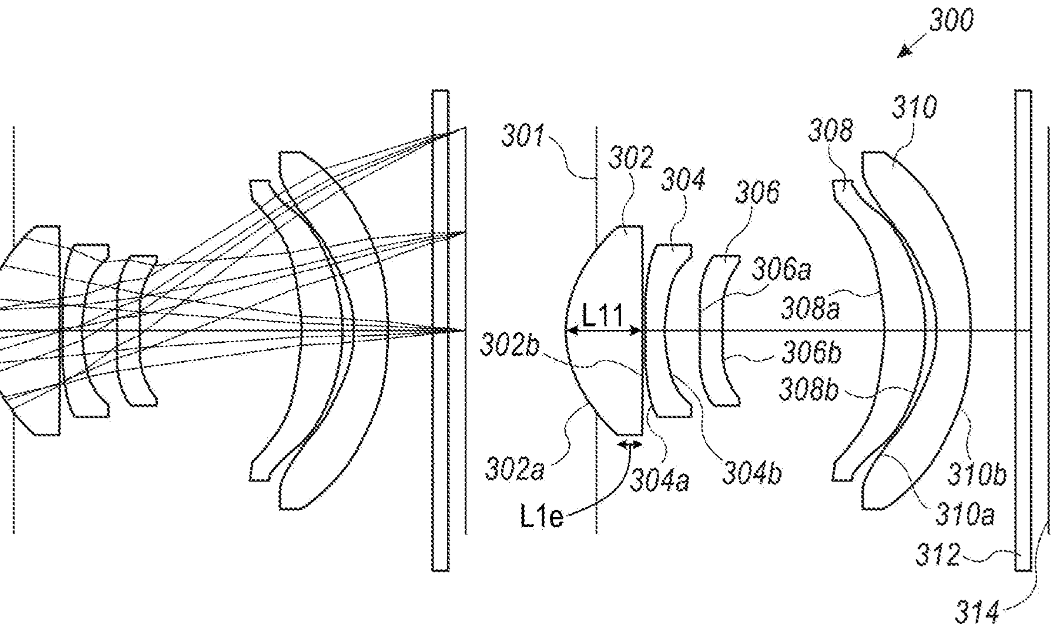
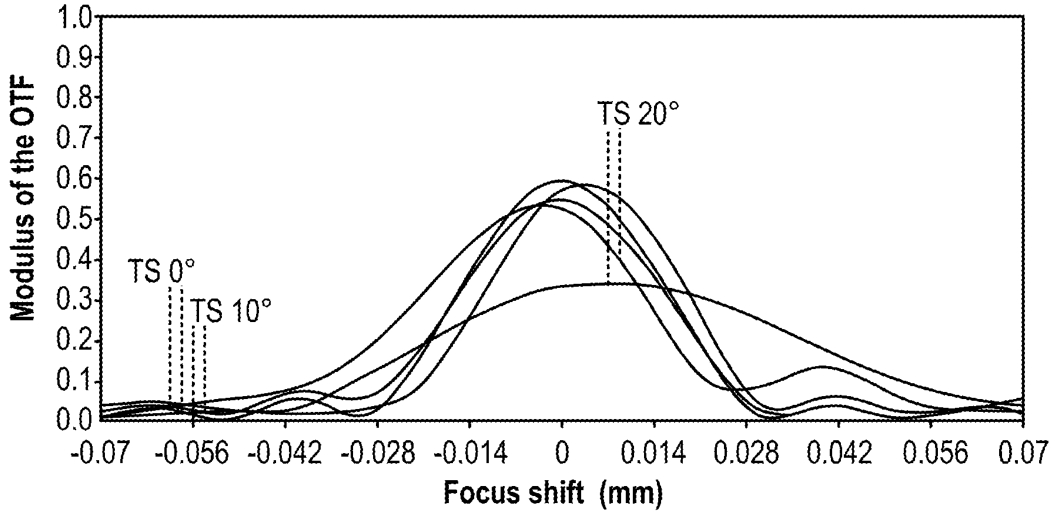
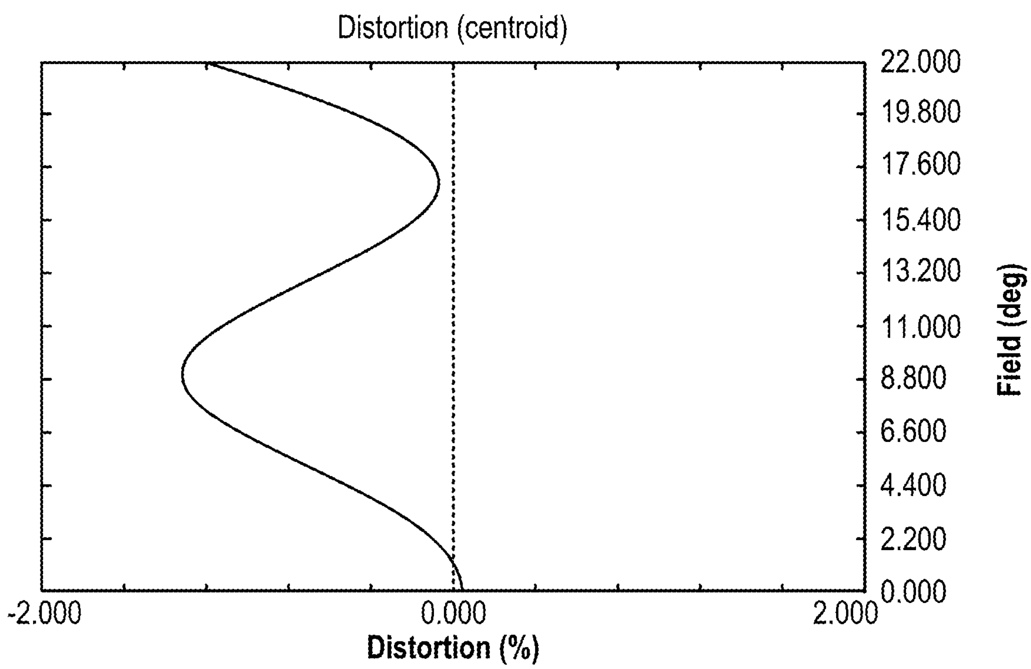

300
301
302
304
306
308
310
306a
308a
L11
302b
306b
308b
302a
304a
304b
310b
L1e
310a
312
314

FIG. 3A



Polychromatic Diffraction Through Focus MTF
Angle 6/9/2013
Data for 0.4350 to 0.6560 μm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 3B



30/06/2013
Maximum distortion = 1.3%

FIG. 3C

Electronic Acknowledgement Receipt

EFS ID:	28331268
Application Number:	15418925
International Application Number:	
Confirmation Number:	5957
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Customer Number:	92342
Filer:	Menachem Nathan
Filer Authorized By:	
Attorney Docket Number:	COREPH-0080 US CIP
Receipt Date:	12-FEB-2017
Filing Date:	30-JAN-2017
Time Stamp:	02:47:12
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	Applicant Response to Pre-Exam Formalities Notice	Notice_to_file_corrected.pdf	233186 cf69c4550241be0b4f10a5459e5cecd5d10d0e91	no	2

Warnings:

Information:					
2	Applicant Response to Pre-Exam Formalities Notice	Response_11_2_2017.pdf	29693 95350f7f2f53eb20f30a8bb3754ac653ca8c00ea	no	1
Warnings:					
Information:					
3	Drawings-only black and white line drawings	Figures_corrected.pdf	2311035 ba4f56714a9093e387deb6359ede9042cdce08a7	no	6
Warnings:					
Information:					
		Total Files Size (in bytes):	2573914		

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.

UNITED STATES PATENT AND TRADEMARK OFFICE

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

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
15/418,925	01/30/2017	2872	730	COREPH-0080 US CIP	5	1

CONFIRMATION NO. 5957

FILING RECEIPT

OC000000089024711

92342
Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

Date Mailed: 02/08/2017

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. 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)

Michael Dror, Nes Ziona, ISRAEL;
Ephraim Goldenberg, Ashdod, ISRAEL;
Gal Shabtay, Tel Aviv, ISRAEL;

Applicant(s)

Corephotonics Ltd., Tel-Aviv, ISRAEL;

Power of Attorney: The patent practitioners associated with Customer Number 92342

Domestic Priority data as claimed by applicant

This application is a CIP of 15/170,472 06/01/2016 PAT 9568712
which is a CON of 14/932,319 11/04/2015 PAT 9402032
which is a CON of 14/367,924 09/19/2014 ABN *
which is a 371 of PCT/IB2014/062465 06/20/2014
which claims benefit of 61/842,987 07/04/2013
(*)Data provided by applicant is not consistent with PTO records.

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 02/06/2017

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 15/418,925**

Projected Publication Date: To Be Determined - pending completion of Corrected Papers

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

MINIATURE TELEPHOTO LENS ASSEMBLY

Preliminary Class

359

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

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

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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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 U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number
15/418,925

APPLICATION AS FILED - PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	70		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	300		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	360		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	5 minus 20 =	*	x 40 =	0.00	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	1 minus 3 =	*	x 210 =	0.00			
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).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	730		TOTAL	

APPLICATION AS AMENDED - PART II

AMENDMENT A		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

AMENDMENT B		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** 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 found in the appropriate box in column 1.

UNITED STATES PATENT AND TRADEMARK OFFICE

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

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
15/418,925	01/30/2017	Michael Dror	COREPH-0080 US CIP

CONFIRMATION NO. 5957

92342
Nathan & Associates Patent Agents Ltd
P.O.Box 10178
Tel Aviv, 6110101
ISRAEL

FORMALITIES LETTER

OC000000089024712

Date Mailed: 02/08/2017

NOTICE TO FILE CORRECTED APPLICATION PAPERS

Filing Date Granted

An application number and filing date have been accorded to this application. The application is informal since it does not comply with the regulations for the reason(s) indicated below. Applicant is given TWO MONTHS from the date of this Notice within which to correct the informalities indicated below. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

The required item(s) identified below must be timely submitted to avoid abandonment:

- Replacement drawings in compliance with 37 CFR 1.84 and 37 CFR 1.121(d) are required. The drawings submitted are not acceptable because:
  - More than one figure is present and each figure is not labeled "Fig." with a consecutive Arabic numeral (1, 2, etc.) or an Arabic numeral and capital letter in the English alphabet (A, B, etc.)(see 37 CFR 1.84(u)(1)). See Figure(s) 2C. A brief description of the several views of the drawings (see 37 CFR 1.74) should be added or amended to correspond to the corrected numbering of the figures. See also 37 CFR 1.77(b)(9).

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

Replies must be received in the USPTO within the set time period or must include a proper Certificate of Mailing or Transmission under 37 CFR 1.8 with a mailing or transmission date within the set time period. For more information and a suggested format, see Form PTO/SB/92 and MPEP 512.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web, including a copy of this Notice and selecting the document description "Applicant response to Pre-Exam Formalities Notice". https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at 1-866-217-9197 or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

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

/amanalac/

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	COREPH-0080 US CIP
	Application Number	
Title of Invention	MINIATURE TELEPHOTO LENS ASSEMBLY	

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
	Michael		Dror	

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

City	Nes Ziona	Country of Residence i	IL

Mailing Address of Inventor:

Address 1	5 Eliyahu Meron St.		
Address 2			
City	Nes Ziona	**State/Province**	
Postal Code	7401905	**Country** i	IL

Inventor 2 (Remove)

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Ephraim		Goldenberg	

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

City	Ashdod	Country of Residence i	IL

Mailing Address of Inventor:

Address 1	Ashdod		
Address 2			
City	32 Tel Chai St.	**State/Province**	
Postal Code	7751025	**Country** i	IL

Inventor 3 (Remove)

Legal Name

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	COREPH-0080 US CIP
	Application Number	
Title of Invention	MINIATURE TELEPHOTO LENS ASSEMBLY	

Prefix	Given Name	Middle Name	Family Name	Suffix
	Gal		Shabtay	

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

City	Tel Aviv	Country of Residence i	IL

Mailing Address of Inventor:

Address 1	4 Shmuel Shnitzer St.		
Address 2			
City	Tel Aviv	**State/Province**	
Postal Code	6958313	**Country** i	IL

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).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	92342
Email Address	Add Email Remove Email

Application Information:

Title of the Invention	MINIATURE TELEPHOTO LENS ASSEMBLY		
Attorney Docket Number	COREPH-0080 US CIP	**Small Entity Status Claimed**	☒
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	6	**Suggested Figure for Publication (if any)**	A1

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country i

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	COREPH-0080 US CIP
	Application Number	
Title of Invention	MINIATURE TELEPHOTO LENS ASSEMBLY	

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	92342		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim 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" field blank.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	Continuation in part of	15170472	2016-06-01

Prior Application Status	Patented				Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)	Patent Number	Issue Date (YYYY-MM-DD)
15170472	Continuation of	14932319	2015-11-04	9402032	2016-07-26

Prior Application Status	Abandoned		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
14932319	Continuation of	14367924	2014-06-22

Prior Application Status	Expired		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
14367924	a 371 of international	PCT/IB2014/062465	2014-06-20

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	COREPH-0080 US CIP
	Application Number	
Title of Invention	MINIATURE TELEPHOTO LENS ASSEMBLY	

Prior Application Status	Expired		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
PCT/IB2014/062465	Claims benefit of provisional	61842987	2013-07-04
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.			Add

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. 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(i)(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.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	COREPH-0080 US CIP
	Application Number	
Title of Invention	MINIATURE TELEPHOTO LENS ASSEMBLY	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is 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 State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	COREPH-0080 US CIP
	Application Number	
Title of Invention	MINIATURE TELEPHOTO LENS ASSEMBLY	

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.	☒
Organization Name	Corephotonics Ltd.

Mailing Address Information For Applicant:

Address 1	25 Habarzel St.		
Address 2	Ramat Hachayal		
City	Tel-Aviv	**State/Province**	
Country	IL	Postal Code	6971035
Phone Number		Fax Number	
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 substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	COREPH-0080 US CIP
	Application Number	
Title of Invention	MINIATURE TELEPHOTO LENS ASSEMBLY	

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 Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the <u>INITIAL</u> filing of the application <u>and</u> either box A or B is <u>not</u> checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Menachem Nathan/			Date (YYYY-MM-DD)	2017-01-30
First Name	MENACHEM	Last Name	NATHAN	Registration Number	65392

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

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	COREPH-0080 US CIP
	Application Number	
Title of Invention	MINIATURE TELEPHOTO LENS ASSEMBLY	

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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.

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 CooperationTreaty.

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.

PTO/AIA/08 (11-15)
Approved for use through 4/30/2017. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

☒ Declaration Submitted With Initial Filing OR ☐ Declaration Submitted After Initial Filing (surcharge (37 CFR 1.16(f)) required)

Attorney Docket Number	COREPH-0080 US CIP
First Named Inventor	MICHAEL DROR
COMPLETE IF KNOWN	
Application Number	
Filing Date	
Art Unit	
Examiner Name	

MINIATURE TELEPHOTO LENS ASSEMBLY

(Title of the Invention)

As a below named inventor, I hereby declare that:

This declaration is directed to:

☒ The attached application,

OR

☐ United States Application Number or PCT International application number ____________________

filed on ____________________.

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

I believe 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.

Direct all correspondence to:	☒ The address associated with Customer Number:	92342	OR	☐ Correspondence address below

Name		
Address		
City	State	Zip
Country	Telephone	Email

DECLARATION — Utility or Design Patent Application

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. Petitioner/applicant is advised that documents which form the record of a patent application (such as the PTO/SB/01) are placed into the Privacy Act system of records DEPARTMENT OF COMMERCE, COMMERCE-PAT-7, System name: *Patent Application Files* . Documents not retained in an application file (such as the PTO-2038) are placed into the Privacy Act system of COMMERCE/PAT-TM-10, System name: *Deposit Accounts and Electronic Funds Transfer Profiles.*

LEGAL NAME OF SOLE OR FIRST INVENTOR:

(*E.g.*, Given Name (first and middle if any) and Family Name or Surname)
Michael Dror

Inventor's Signature	Date (Optional)
/Michael Dror/	

Residence: City	State	Country
Nes Ziona		IL

Mailing Address
5 Eliyahu Meron St.

City	State	Zip	Country
Nes Ziona		7401905	IL

☒ Additional inventors are being named on the 1 Supplemental sheet(s) PTO/AIA/10 attached hereto

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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).
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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.

SUPPLEMENTAL SHEET FOR DECLARATION | **ADDITIONAL INVENTOR(S)** **Supplemental Sheet (for PTO/AIA/08,09)** Page 1 of 1

Legal Name of Additional Joint Inventor, if any:			
(*E.g.*, Given Name (first and middle (if any)) and Family Name or Surname) EPHRAIM GOLDENBERG			
Inventor's Signature /EPHRAIM GOLDENBERG/		Date (Optional)	
Residence: City Ashdod	State	Country IL	
Mailing Address 32 Tel Chai St.			
City Ashdod	State	Zip 7751025	Country IL
Legal Name of Additional Joint Inventor, if any:			
(*E.g.*, Given Name (first and middle (if any)) and Family Name or Surname) GAL SHABTAY			
Inventor's Signature /GAL SHABTAY/		Date (Optional)	
Residence: City Tel Aviv	State	Country IL	
Mailing Address 4 Shmuel Shnitzer St.			
City Tel Aviv	State	Zip 6958313	Country IL
Legal Name of Additional Joint Inventor, if any:			
(*E.g.*, Given Name (first and middle (if any)) and Family Name or Surname)			
Inventor's Signature		Date (Optional)	
Residence: City	State	Country	
Mailing Address			
City	State	Zip	Country

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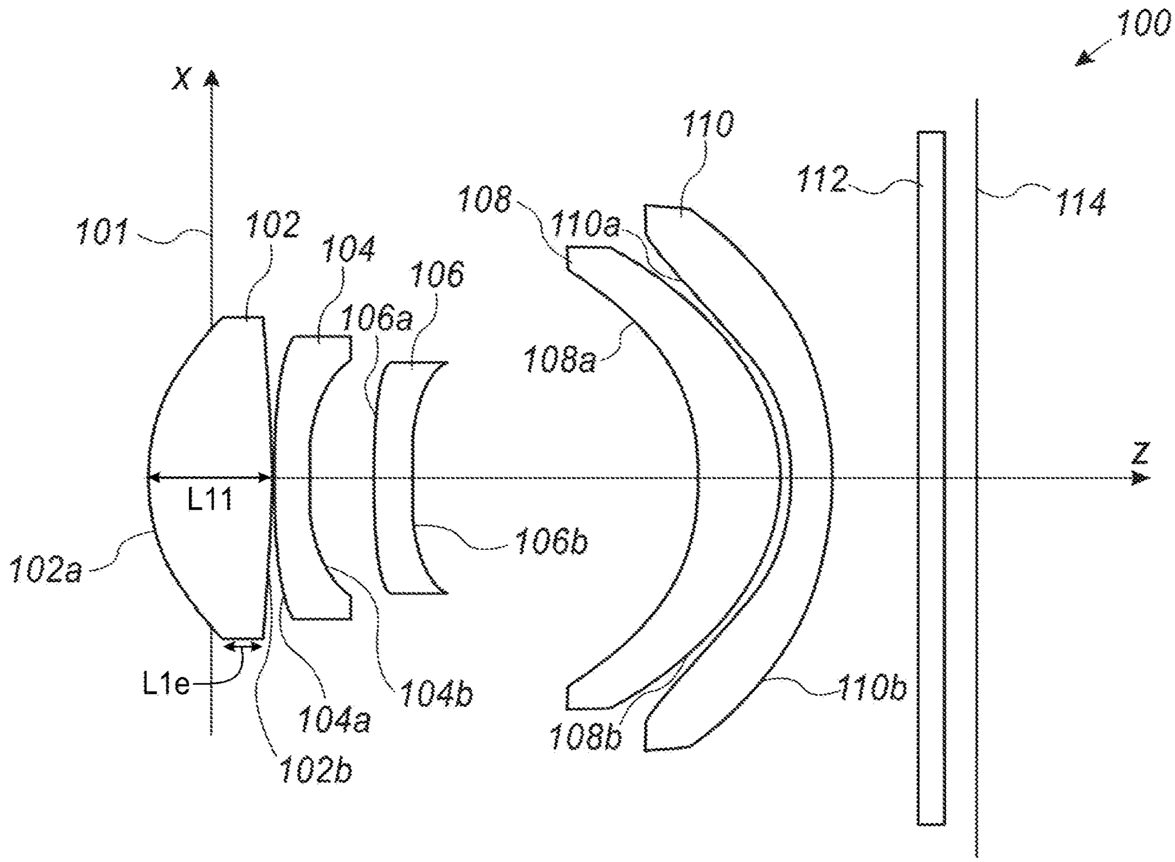
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.


100
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104
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106a
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110
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L1e
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104b
102b
108b
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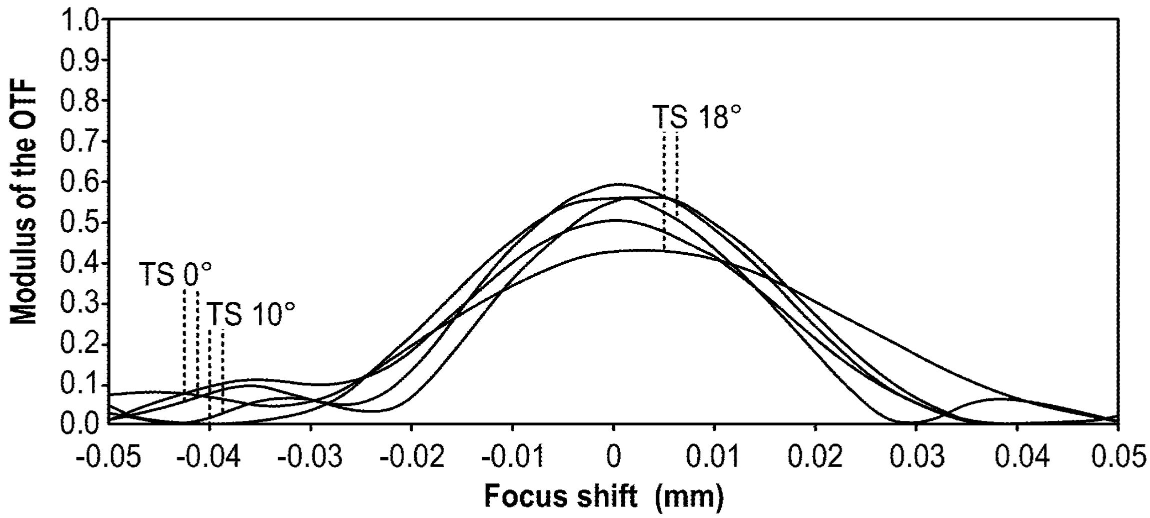
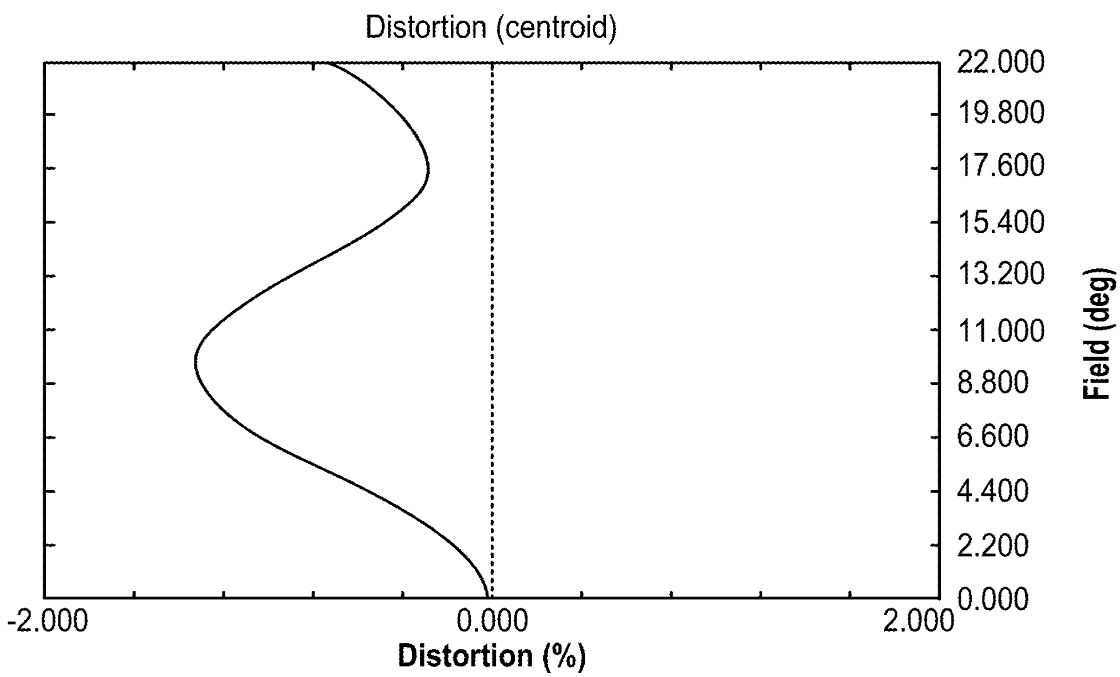
FIG. 1A



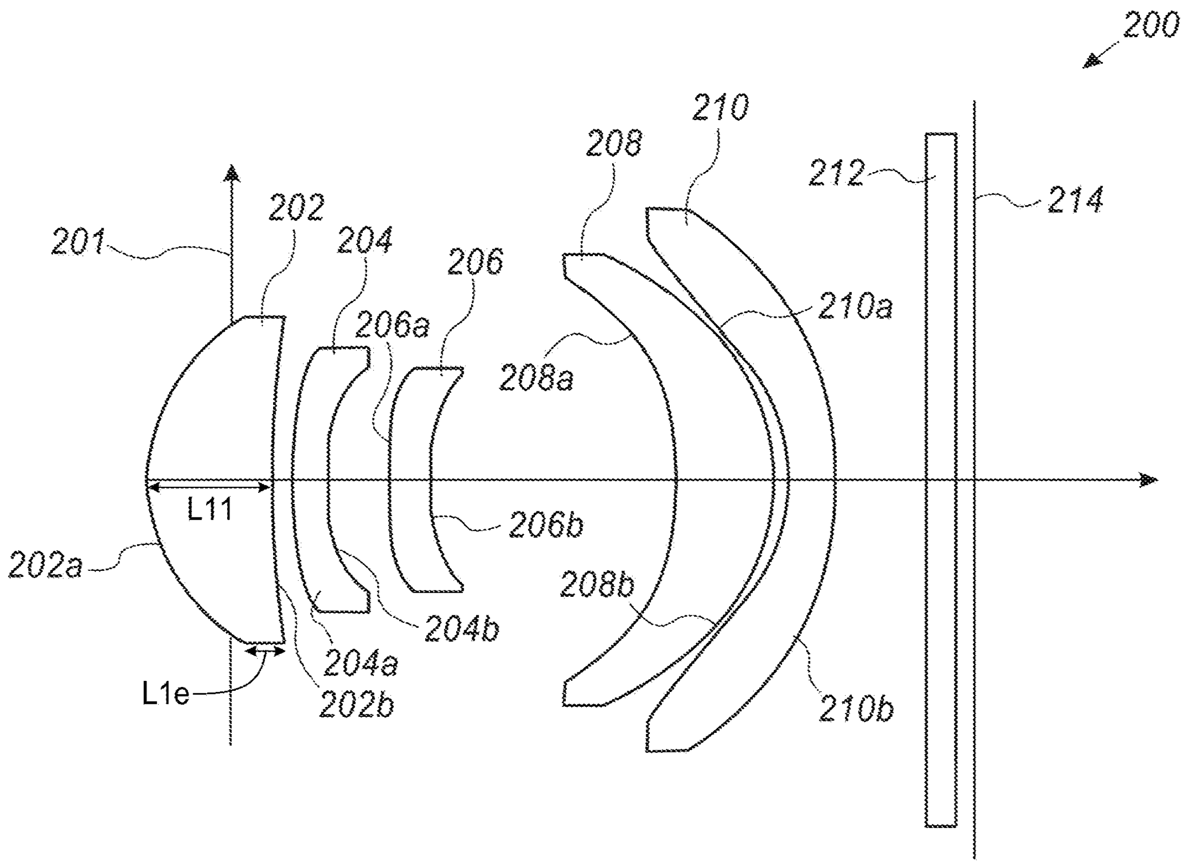
Polychromatic Diffraction Through Focus MTF
Angle 6/2/2013
Data for 0.4350 to 0.6560 μm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 1B



30/06/2013
Maximum distortion = 1.3%

FIG. 1C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201
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208b
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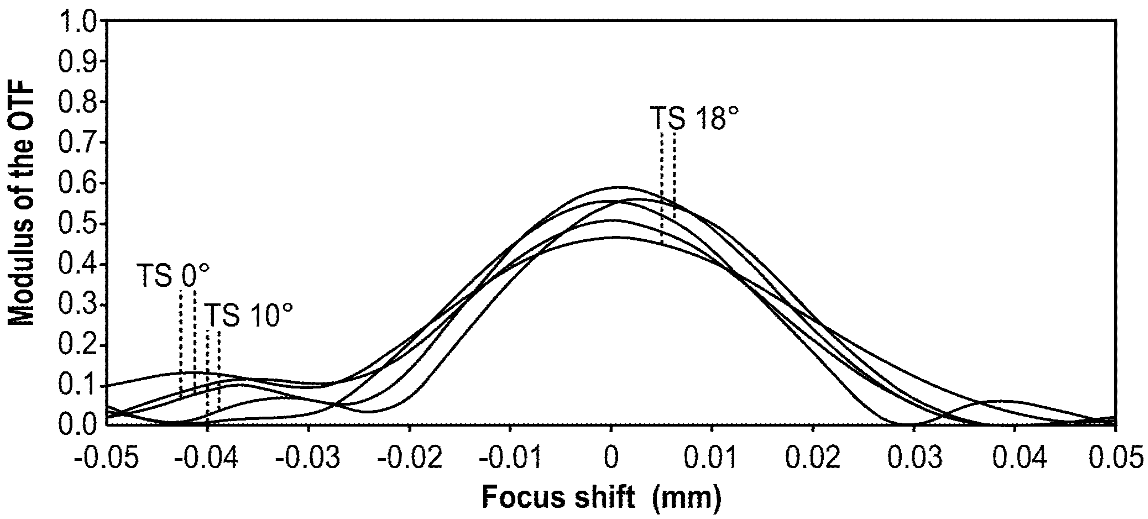
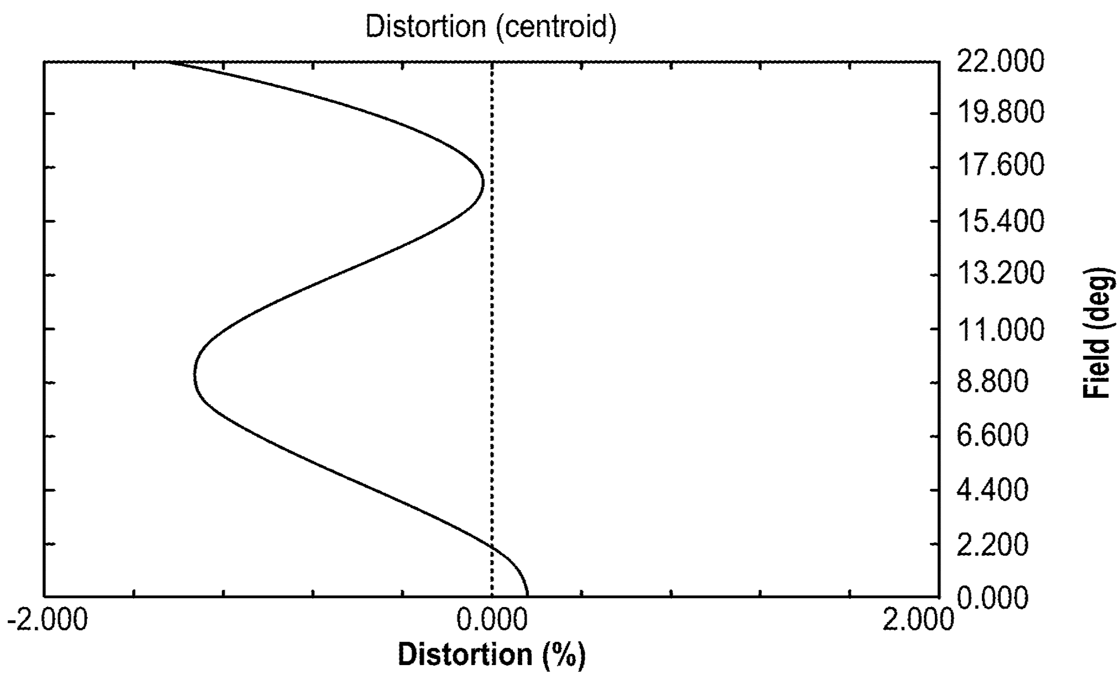
202b
210b

FIG. 2A



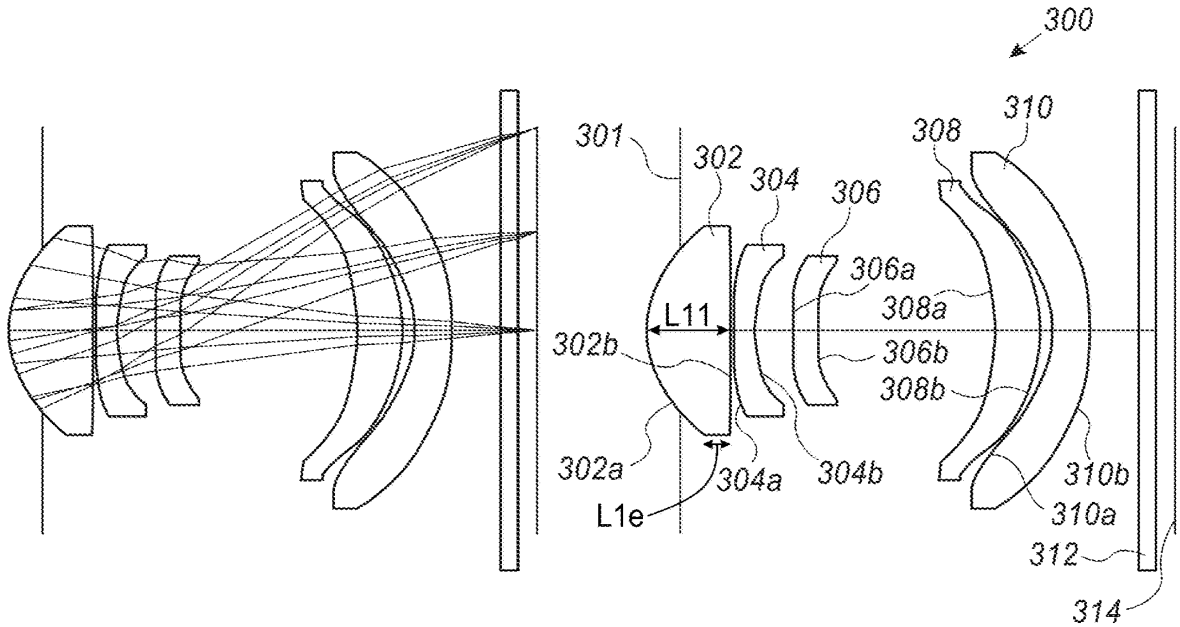
Polychromatic Diffraction Through Focus MTF
Angle 6/2/2013
Data for 0.4350 to 0.6560 µm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 2B



30/06/2013
Maximum distortion = 1.5%

FIG. 1C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302
304
306
308
310
306a
308a
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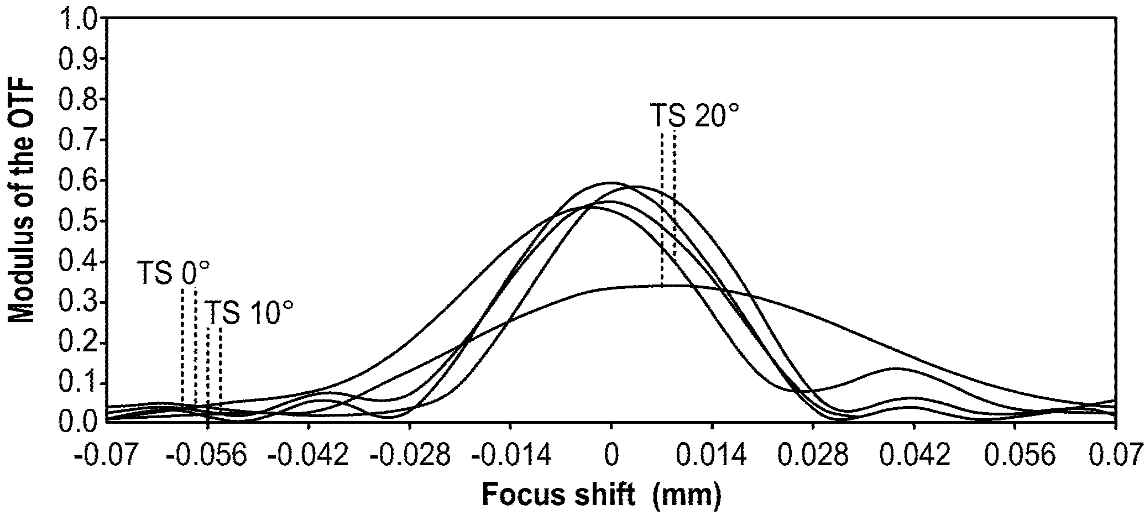
302b
306b
308b
302a
304a
304b
310b
L1e
310a
312
314

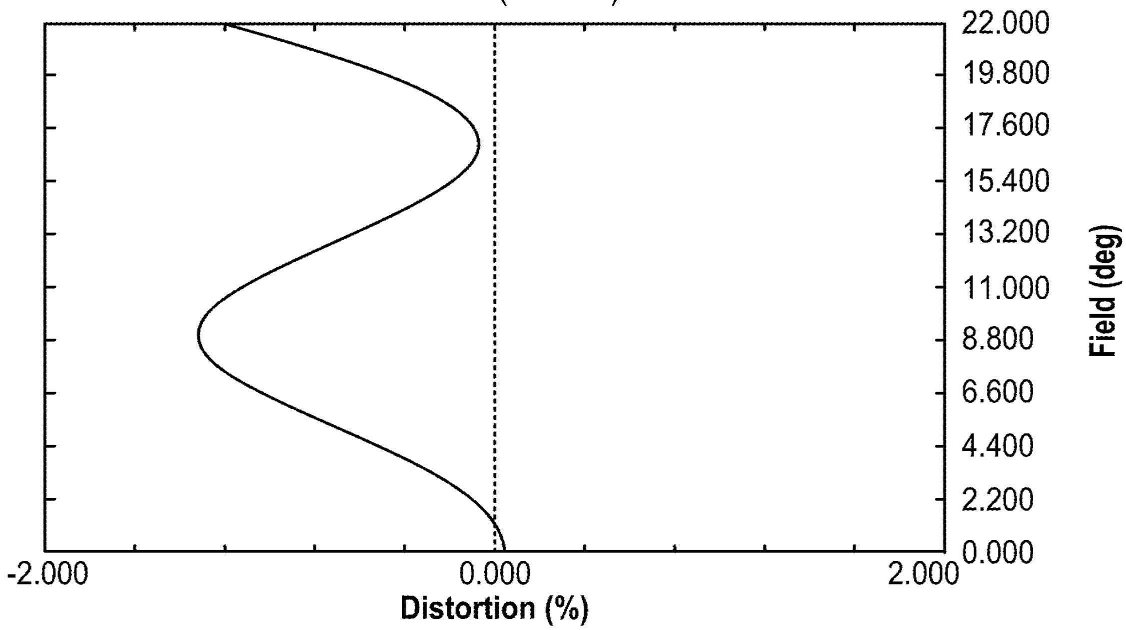
FIG. 3A



Polychromatic Diffraction Through Focus MTF
Angle 6/9/2013
Data for 0.4350 to 0.6560 µm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 3B

Distortion (centroid)



30/06/2013
Maximum distortion = 1.3%

FIG. 3C

MINIATURE TELEPHOTO LENS ASSEMBLY

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation in Part (CIP) application of US patent application No. 15/170,472 filed June 1, 2016, which was a Continuation application of US patent application No. 14/932319 filed November 4, 2015, which was a Continuation application of US patent application No. 14/367924 filed June 22, 2014, which was a 371 of international application PCT/IB2014/062465 filed June 20, 2014, and is related to and claims priority from US Provisional Patent Application No. 61/842,987 filed July 4, 2013, which is incorporated herein by reference in its entirety.

FIELD

Embodiments disclosed herein relate to an optical lens system and lens assembly, and more particularly, to a miniature telephoto lens assembly included in such a system and used in a portable electronic product such as a cellphone.

BACKGROUND

Digital camera modules are currently being incorporated into a variety of host devices. Such host devices include cellular telephones, personal data assistants (PDAs), computers, and so forth. Consumer demand for digital camera modules in host devices continues to grow. Cameras in cellphone devices in particular require a compact imaging lens system for good quality imaging and with a small total track length (TTL). Conventional lens assemblies comprising four lens elements are no longer sufficient for good quality imaging in such devices. The latest lens assembly designs, e.g. as in US 8,395,851, use five lens elements. However, the design in US 8,395,851 suffers from at least the fact that the TTL/EFL (effective focal length) ratio is too large.

Therefore, a need exists in the art for a five lens element optical lens assembly that can provide a small TTL/EFL ratio and better image quality than existing lens assemblies.

SUMMARY

Embodiments disclosed herein refer to an optical lens assembly comprising, in order from an object side to an image side: a first lens element with positive refractive power having a convex object-side surface, a second lens element with negative refractive power having a thickness d_2 on an optical axis and separated from the first lens element by a first air gap, a third lens element with negative refractive power and separated from the second lens element by a second air gap, a fourth lens element having a positive refractive power and separated from the third lens element by a third air gap, and a fifth lens element having a negative refractive power, separated from the fourth lens element by a fourth air gap, the fifth lens element having a thickness d_5 on the optical axis.

An optical lens system incorporating the lens assembly may further include a stop positioned before the first lens element, a glass window disposed between the image-side surface of the fifth lens element and an image sensor with an image plane on which an image of the object is formed.

The effective focal length of the lens assembly is marked "EFL" and the total track length on an optical axis between the object-side surface of the first lens element and the electronic sensor is marked "TTL". In all embodiments, TTL is smaller than the EFL, i.e. the TTL/EFL ratio is smaller than 1.0. In some embodiments, the TTL/EFL ratio is smaller than 0.9. In an embodiment, the TTL/EFL ratio is about 0.85. In all embodiments, the lens assembly has an F number F# < 3.2. In an embodiment, the focal length of the first lens element f1 is smaller than TTL/2, the first, third and fifth lens elements have each an Abbe number ("Vd") greater than 50, the second and fourth lens elements have each an Abbe number smaller than 30, the first air gap is smaller than $d_2/2$, the third air gap is greater than TTL/5 and the fourth air gap is smaller than $1.5d_5$. In some embodiments, the surfaces of the lens elements may be aspheric.

In an optical lens assembly disclosed herein, the first lens element with positive refractive power allows the TTL of the lens system to be favorably reduced. The combined design of the first, second and third lens elements plus the relative short distances between them enable a long EFL and a short TTL. The same combination, together with the high dispersion (low Vd) for the second lens element and low dispersion (high Vd) for the first and third lens elements, also helps to reduce chromatic

aberration. In particular, the ratio TTL/EFL < 1.0 and minimal chromatic aberration are obtained by fulfilling the relationship $1.2x|f3| > |f2| > 1.5xf1$, where "f" indicates the lens element effective focal length and the numerals 1, 2, 3, 4, 5 indicate the lens element number.

The conditions TTL/EFL < 1.0 and F# < 3.2 can lead to a large ratio L11/L1e (e.g. larger than 4) between the largest width (thickness) L11 and the smallest width (thickness) of the first lens element (facing the object) L1e. The largest width is along the optical axis and the smallest width is of a flat circumferential edge of the lens element. L11 and L1e are shown in each of elements **102**, **202** and **302**. A large L11/L1e ratio (e.g. > 4) impacts negatively the manufacturability of the lens and its quality. Advantageously, the present inventors have succeeded in designing the first lens element to have a L11/L1e ratio smaller than 4, smaller than 3.5, smaller than 3.2, smaller than 3.1 (respectively 3.01 for element **102** and 3.08 for element **302**) and even smaller than 3.0 (2.916 for element **202**). The significant reduction in the L11/L1e ratio improves the manufacturability and increases the quality of lens assemblies disclosed herein.

The relatively large distance between the third and the fourth lens elements plus the combined design of the fourth and fifth lens elements assist in bringing all fields' focal points to the image plane. Also, because the fourth and fifth lens elements have different dispersions and have respectively positive and negative power, they help in minimizing chromatic aberration.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows a first embodiment of an optical lens system disclosed herein;

FIG. 1B shows the modulus of the optical transfer function (MTF) vs. focus shift of the entire optical lens assembly for various fields in the first embodiment;

FIG. 1C shows the distortion vs. field angle (+Y direction) in percent in the first embodiment;

FIG. 2A shows a second embodiment of an optical lens system disclosed herein;

FIG. 2B shows the MTF vs. focus shift of the entire optical lens assembly for various fields in the second embodiment;

FIG. 2C shows the distortion +Y in percent in the second embodiment;

FIG. 3A shows a third embodiment of an optical lens system disclosed herein;

FIG. 3B shows the MTF vs. focus shift of the entire optical lens system for various fields in the third embodiment;

FIG. 3C shows the distortion +Y in percent in the third embodiment.

DETAILED DESCRIPTION

In the following description, the shape (convex or concave) of a lens element surface is defined as viewed from the respective side (i.e. from an object side or from an image side). FIG. 1A shows a first embodiment of an optical lens system disclosed herein and marked **100**. FIG. 1B shows the MTF vs. focus shift of the entire optical lens system for various fields in embodiment **100**. FIG. 1C shows the distortion +Y in percent vs. field. Embodiment **100** comprises in order from an object side to an image side: an optional stop **101**; a first plastic lens element **102** with positive refractive power having a convex object-side surface **102a** and a convex or concave image-side surface **102b**; a second plastic lens element **104** with negative refractive power and having a meniscus convex object-side surface **104a**, with an image side surface marked **104b**; a third plastic lens element **106** with negative refractive power having a concave object-side surface **106a** with an inflection point and a concave image-side surface **106b**; a fourth plastic lens element **108** with positive refractive power having a positive meniscus, with a concave object-side surface marked **108a** and an image-side surface marked **108b**; and a fifth plastic lens element **110** with negative refractive power having a negative meniscus, with a concave object-side surface marked **110a** and an image-side surface marked **110b**. The optical lens system further comprises an optional glass window **112** disposed between the image-side surface **110b** of fifth lens element **110** and an image plane **114** for image formation of an object. Moreover, an image sensor (not shown) is disposed at image plane **114** for the image formation.

In embodiment **100**, all lens element surfaces are aspheric. Detailed optical data is given in Table 1, and the aspheric surface data is given in Table 2, wherein the units of the radius of curvature (R), lens element thickness and/or distances between elements along the optical axis and diameter are expressed in mm. "Nd" is the refraction index. The equation of the aspheric surface profiles is expressed by:

$$z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \alpha_1 r^2 + \alpha_2 r^4 + \alpha_3 r^6 + \alpha_4 r^8 + \alpha_5 r^{10} + \alpha_6 r^{12} + \alpha_7 r^{14}$$

where r is distance from (and perpendicular to) the optical axis, k is the conic coefficient, c = 1/R where R is the radius of curvature, and α are coefficients given in Table 2. In the equation above as applied to embodiments of a lens assembly disclosed herein, coefficients α_1 and α_7 are zero. Note that the maximum value of r "max r" = Diameter/2. Also note that Table 1 (and in Tables 3 and 5 below), the distances between various elements (and/or surfaces) are marked "Lmn" (where *m* refers to the lens element number, *n* =1 refers to the element thickness and *n* = 2 refers to the air gap to the next element) and are measured on the optical axis z, wherein the stop is at z = 0. Each number is measured from the previous surface. Thus, the first distance -0.466 mm is measured from the stop to surface **102a**, the distance L11 from surface **102a** to surface **102b** (i.e. the thickness of first lens element **102**) is 0.894 mm, the gap L12 between surfaces **102b** and **104a** is 0.020 mm, the distance L21 between surfaces **104a** and **104b** (i.e. thickness d2 of second lens element **104**) is 0.246 mm, etc. Also, L21 = d_2 and L51 = d_5. L11 for lens element **102** is indicated in FIG. 1A. Also indicated in FIG. 1A is a width L1e of a flat circumferential edge (or surface) of lens element **102.** L11 and L1e are also indicated for each of first lens elements **202** and **302** in, respectively, embodiments **200** (FIG. 2A) and **300** (FIG. 3A).

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	-0.466		2.4
2	L11	1.5800	0.894	1.5345/57.095	2.5
3	L12	-11.2003	0.020		2.4
4	L21	33.8670	0.246	1.63549/23.91	2.2
5	L22	3.2281	0.449		1.9
6	L31	-12.2843	0.290	1.5345/57.095	1.9
7	L32	7.7138	2.020		1.8
8	L41	-2.3755	0.597	1.63549/23.91	3.3
9	L42	-1.8801	0.068		3.6
10	L51	-1.8100	0.293	1.5345/57.095	3.9
11	L52	-5.2768	0.617		4.3
12	Window	Infinite	0.210	1.5168/64.17	3.0
13		Infinite	0.200		3.0

Table 1

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	-0.4668	7.9218E-03	2.3146E-02	-3.3436E-02	2.3650E-02	-9.2437E-03
3	-9.8525	2.0102E-02	2.0647E-04	7.4394E-03	-1.7529E-02	4.5206E-03
4	10.7569	-1.9248E-03	8.6003E-02	1.1676E-02	-4.0607E-02	1.3545E-02
5	1.4395	5.1029E-03	2.4578E-01	-1.7734E-01	2.9848E-01	-1.3320E-01
6	0.0000	2.1629E-01	4.0134E-02	1.3615E-02	2.5914E-03	-1.2292E-02
7	-9.8953	2.3297E-01	8.2917E-02	-1.2725E-01	1.5691E-01	-5.9624E-02
8	0.9938	-1.3522E-02	-7.0395E-03	1.4569E-02	-1.5336E-02	4.3707E-03
9	-6.8097	-1.0654E-01	1.2933E-02	2.9548E-04	-1.8317E-03	5.0111E-04
10	-7.3161	-1.8636E-01	8.3105E-02	-1.8632E-02	2.4012E-03	-1.2816E-04
11	0.0000	-1.1927E-01	7.0245E-02	-2.0735E-02	2.6418E-03	-1.1576E-04

Table 2

Embodiment **100** provides a field of view (FOV) of 44 degrees, with EFL = 6.90 mm, F# = 2.80 and TTL of 5.904 mm. Thus and advantageously, the ratio TTL/EFL = 0.855. Advantageously, the Abbe number of the first, third and fifth lens element is 57.095. Advantageously, the first air gap between lens elements **102** and **104** (the gap between surfaces **102b** and **104a**) has a thickness (0.020 mm) which is less than a tenth of thickness d_2 (0.246 mm). Advantageously, the Abbe number of the second and fourth lens elements is 23.91. Advantageously, the third air gap between lens elements **106** and **108** has a thickness (2.020 mm) greater than TTL/5 (5.904/5 mm). Advantageously, the fourth air gap between lens elements **108** and **110** has a thickness (0.068 mm) which is smaller than $1.5d_5$ (0.4395 mm).

The focal length (in mm) of each lens element in embodiment **100** is as follows: f1 = 2.645, f2 = -5.578, f3 = -8.784, f4 = 9.550 and f5 = -5.290. The condition 1.2x|f3| > |f2| < 1.5xf1 is clearly satisfied, as 1.2x8.787 > 5.578 > 1.5x2.645. f1 also fulfills the condition f1< TTL/2, as 2.645 < 2.952.

Using the data from row #2 in Tables 1 and 2, L1e in lens element **102** equals 0.297 mm, yielding a center-to-edge thickness ratio L11/L1e of 3.01.

FIG. 2A shows a second embodiment of an optical lens system disclosed herein and marked **200**. FIG. 2B shows the MTF vs. focus shift of the entire optical lens system for various fields in embodiment **200**. FIG. 2C shows the distortion +Y in percent vs. field. Embodiment **200** comprises in order from an object side to an image side: an optional stop **201**; a first plastic lens element **202** with positive refractive power having a convex object-side surface **202a** and a convex or concave image-side surface **202b**; a second glass lens element **204** with negative refractive power, having a meniscus convex object-side surface **204a**, with an image side surface marked **204b**; a third plastic lens element **206** with negative refractive power having a concave object-side surface **206a** with an inflection point and a concave image-side surface **206b**; a fourth plastic lens element **208** with positive refractive power having a positive meniscus, with a concave object-side surface marked **208a** and an image-side surface marked **208b**; and a fifth plastic lens element **210** with negative refractive power having a negative meniscus, with a concave object-side surface marked **110a** and an image-side surface marked **210b**. The optical lens system further comprises an optional glass window **212** disposed between the image-side surface **210b** of fifth lens element **210** and an image plane **214** for image formation of an object.

In embodiment **200**, all lens element surfaces are aspheric. Detailed optical data is given in Table 3, and the aspheric surface data is given in Table 4, wherein the markings and units are the same as in, respectively, Tables 1 and 2. The equation of the aspheric surface profiles is the same as for embodiment **100**.

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	-0.592		2.5
2	L11	1.5457	0.898	1.53463/56.18	2.6
3	L12	-127.7249	0.129		2.6
4	L21	6.6065	0.251	1.91266/20.65	2.1
5	L22	2.8090	0.443		1.8
6	L31	9.6183	0.293	1.53463/56.18	1.8
7	L32	3.4694	1.766		1.7
8	L41	-2.6432	0.696	1.632445/23.35	3.2
9	L42	-1.8663	0.106		3.6
10	L51	-1.4933	0.330	1.53463/56.18	3.9
11	L52	-4.1588	0.649		4.3
12	Window	Infinite	0.210	1.5168/64.17	5.4
13		Infinite	0.130		5.5

Table 3

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	0.0000	-2.7367E-03	2.8779E-04	-4.3661E-03	3.0069E-03	-1.2282E-03
3	-10.0119	4.0790E-02	-1.8379E-02	2.2562E-02	-1.7706E-02	4.9640E-03
4	10.0220	4.6151E-02	5.8320E-02	-2.0919E-02	-1.2846E-02	8.8283E-03
5	7.2902	3.6028E-02	1.1436E-01	-1.9022E-02	4.7992E-03	-3.4079E-03
6	0.0000	1.6639E-01	5.6754E-02	-1.2238E-02	-1.8648E-02	1.9292E-02
7	8.1261	1.5353E-01	8.1427E-02	-1.5773E-01	1.5303E-01	-4.6064E-02
8	0.0000	-3.2628E-02	1.9535E-02	-1.6716E-02	-2.0132E-03	2.0112E-03
9	0.0000	1.5173E-02	-1.2252E-02	3.3611E-03	-2.5303E-03	8.4038E-04
10	-4.7688	-1.4736E-01	7.6335E-02	-2.5539E-02	5.5897E-03	-5.0290E-04
11	0.00E+00	-8.3741E-02	4.2660E-02	-8.4866E-03	1.2183E-04	7.2785E-05

Table 4

Embodiment **200** provides a FOV of 43.48 degrees, with EFL = 7 mm, F# = 2.86 and TTL = 5.90mm. Thus and advantageously, the ratio TTL/EFL = 0.843. Advantageously, the Abbe number of the first, third and fifth lens elements is 56.18. The first air gap between lens elements **202** and **204** has a thickness (0.129 mm) which is about half the thickness d_2 (0.251 mm). Advantageously, the Abbe number of the second lens element is 20.65 and of the fourth lens element is 23.35. Advantageously, the third air gap between lens elements **206** and **208** has a thickness (1.766 mm) greater than TTL/5 (5.904/5 mm). Advantageously, the fourth air gap between lens elements **208** and **210** has a thickness (0.106 mm) which is less than $1.5xd_5$ (0.495 mm).

The focal length (in mm) of each lens element in embodiment **200** is as follows: f1 = 2.851, f2 = -5.468, f3 = -10.279, f4 = 7.368 and f5 = -4.536. The condition 1.2x|f3| > |f2| < 1.5xf1 is clearly satisfied, as 1.2x10.279 > 5.468 > 1.5x 2.851. f1 also fulfills the condition f1< TTL/2, as 2.851 < 2.950.

Using the data from row #2 in Tables 3 and 4, L1e in lens element **202** equals 0.308 mm, yielding a center-to-edge thickness ratio L11/L1e of 2.916.

FIG. 3A shows a third embodiment of an optical lens system disclosed herein and marked **300**. FIG. 3B shows the MTF vs. focus shift of the entire optical lens system for various fields in embodiment **300**. FIG. 3C shows the distortion +Y in percent vs. field. Embodiment **300** comprises in order from an object side to an image side: an optional stop **301**; a first glass lens element **302** with positive refractive power having a convex object-side surface **302a** and a convex or concave image-side surface **302b**; a second plastic lens element **204** with negative refractive power, having a meniscus convex object-side surface **304a**, with an image side surface marked **304b**; a third plastic lens element **306** with negative refractive power having a concave object-side surface **306a** with an inflection point and a concave image-side surface **306b**; a fourth plastic lens element **308** with positive refractive power having a positive meniscus, with a concave object-side surface marked **308a** and an image-side surface marked **308b**; and a fifth plastic lens element **310** with negative refractive power having a negative meniscus, with a concave object-side surface marked **310a** and an image-side surface marked **310b**. The optical lens system further comprises an optional glass window **312** disposed between the image-side surface **310b** of fifth lens element **310** and an image plane **314** for image formation of an object.

In embodiment **300**, all lens element surfaces are aspheric. Detailed optical data is given in Table 5, and the aspheric surface data is given in Table 6, wherein the markings and units are the same as in, respectively, Tables 1 and 2. The equation of the aspheric surface profiles is the same as for embodiments **100** and **200**.

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	-0.38		2.4
2	L11	1.5127	0.919	1.5148/63.1	2.5
3	L12	-13.3831	0.029		2.3
4	L21	8.4411	0.254	1.63549/23.91	2.1
5	L22	2.6181	0.426		1.8
6	L31	-17.9618	0.265	1.5345/57.09	1.8
7	L32	4.5841	1.998		1.7
8	L41	-2.8827	0.514	1.63549/23.91	3.4
9	L42	-1.9771	0.121		3.7
10	L51	-1.8665	0.431	1.5345/57.09	4.0
11	L52	-6.3670	0.538		4.4
12	Window	Infinite	0.210	1.5168/64.17	3.0
13		Infinite	0.200		3.0

Table 5

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	-0.534	1.3253E-02	2.3699E-02	-2.8501E-02	1.7853E-02	-4.0314E-03
3	-13.473	3.0077E-02	4.7972E-03	1.4475E-02	-1.8490E-02	4.3565E-03
4	-10.132	7.0372E-04	1.1328E-01	1.2346E-03	-4.2655E-02	8.8625E-03
5	5.180	-1.9210E-03	2.3799E-01	-8.8055E-02	2.1447E-01	-1.2702E-01
6	0.000	2.6780E-01	1.8129E-02	-1.7323E-02	3.7372E-02	-2.1356E-02
7	10.037	2.7660E-01	-1.0291E-02	-6.0955E-02	7.5235E-02	-1.6521E-02
8	1.703	2.6462E-02	-1.2633E-02	-4.7724E-04	-3.2762E-03	1.6551E-03
9	-1.456	5.7704E-03	-1.8826E-02	5.1593E-03	-2.9999E-03	8.0685E-04
10	-6.511	-2.1699E-01	1.3692E-01	-4.2629E-02	6.8371E-03	-4.1415E-04
11	0.000	-1.5120E-01	8.6614E-02	-2.3324E-02	2.7361E-03	-1.1236E-04

Table 6

Embodiment **300** provides a FOV of 44 degrees, EFL = 6.84 mm, F# = 2.80 and TTL = 5.904 mm. Thus and advantageously, the ratio TTL/EFL = 0.863. Advantageously, the Abbe number of the first lens element is 63.1, and of the third and fifth lens elements is 57.09. The first air gap between lens elements **302** and **304** has a thickness (0.029 mm) which is about 1/10th the thickness d_2 (0.254 mm). Advantageously, the Abbe number of the second and fourth lens elements is 23.91. Advantageously, the third air gap between lens elements **306** and **308** has a thickness (1.998 mm) greater than TTL/5 (5.904/5 mm). Advantageously, the fourth air gap between lens elements **208** and **210** has a thickness (0.121 mm) which is less than $1.5d_5$ (0.6465 mm).

The focal length (in mm) of each lens element in embodiment **300** is as follows: f1 = 2.687, f2 = -6.016, f3 = -6.777, f4 = 8.026 and f5 = -5.090. The condition 1.2x|f3| > |f2| < 1.5xf1 is clearly satisfied, as 1.2x6.777> 6.016 > 1.5x 2.687. f1 also fulfills the condition f1< TTL/2, as 2.687 < 2.952.

Using the data from row #2 in Tables 5 and 6, L1e in lens element **302** equals 0.298 mm, yielding a center-to-edge thickness ratio L11/L1e of 3.08.

While this disclosure has been described in terms of certain embodiments and generally associated methods, alterations and permutations of the embodiments and methods will be apparent to those skilled in the art. The disclosure is to be understood as not limited by the specific embodiments described herein, but only by the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A lens assembly, comprising: a plurality of refractive lens elements arranged along an optical axis with a first lens element on an object side, wherein at least one surface of at least one of the plurality of lens elements is aspheric, wherein the lens assembly has an effective focal length (EFL), a total track length (TTL) of 6.5 millimeters or less, a ratio TTL/EFL of less than 1.0, a F number smaller than 3.2 and a ratio between a largest optical axis thickness L11 and a circumferential edge thickness L1e of the first lens element of $L11/L1e < 4$.

2. The lens assembly according to claim 1, wherein the ratio $L11/L1e < 3.5$.

3. The lens assembly according to claim 1, wherein the ratio $L11/L1e < 3.2$.

4. The lens assembly according to claim 1, wherein the ratio $L11/L1e < 3.1$.

5. The lens assembly according to claim 1, wherein the ratio $L11/L1e < 3.0$.

ABSTRACT

An optical lens assembly includes five lens elements and provides a TTL/EFL < 1.0. In an embodiment, the focal length of the first lens element f1 < TTL/2, an air gap between first and second lens elements is smaller than half the second lens element thickness, an air gap between the third and fourth lens elements is greater than TTL/5 and an air gap between the fourth and fifth lens elements is smaller than about 1.5 times the fifth lens element thickness. All lens elements may be aspheric.

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Filer:	Menachem Nathan
Attorney Docket Number:	COREPH-0080 US CIP

Filed as Small Entity

Filing Fees for **Utility under 35 USC 111(a)**

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
UTILITY FILING FEE (ELECTRONIC FILING)	4011	1	70	70
UTILITY SEARCH FEE	2111	1	300	300
UTILITY EXAMINATION FEE	2311	1	360	360
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		730

Electronic Acknowledgement Receipt

EFS ID:	28201201
Application Number:	15418925
International Application Number:	
Confirmation Number:	5957
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Customer Number:	92342
Filer:	Menachem Nathan
Filer Authorized By:	
Attorney Docket Number:	COREPH-0080 US CIP
Receipt Date:	30-JAN-2017
Filing Date:	
Time Stamp:	11:57:32
Application Type:	Utility under 35 USC 111(a)

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Payment Type	CARD
Payment was successfully received in RAM	$730
RAM confirmation Number	013017INTEFSW12003500
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1	Application Data Sheet	ADS.pdf	1823896 1bab4961171df6b5751d22a540de9ee3125b58e4	no	9
Warnings:					
Information:					
2	Oath or Declaration filed	Declaration.pdf	1932911 6460d144b2fdea299730e80eaec404afbe87aa17	no	3
Warnings:					
Information:					
3	Oath or Declaration filed	Declaration_AI.pdf	219701 f19ab727e231c000b861bf1186a83be7f8266b60	no	2
Warnings:					
Information:					
4	Drawings-only black and white line drawings	Drawings.pdf	4795671 9d625229acee14b5b9f1fd77aacc02c95a947720	no	6
Warnings:					
Information:					
5		Application.pdf	114319 60b59a4214d7d40c4ed3802381a3182c3e39fa51	yes	12

Multipart Description/PDF files in .zip description

Document Description	Start	End
Specification	1	10
Claims	11	11
Abstract	12	12

Warnings:					
Information:					
6	Fee Worksheet (SB06)	fee-info.pdf	34671 9959b8a8c3b350ac003e5eb7383a3ad965ffa170	no	2
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			Total Files Size (in bytes):	8921169	

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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.

Electronic Acknowledgement Receipt

EFS ID:	28201201
Application Number:	15418925
International Application Number:	
Confirmation Number:	5957
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Customer Number:	92342
Filer:	Menachem Nathan
Filer Authorized By:	
Attorney Docket Number:	COREPH-0080 US CIP
Receipt Date:	30-JAN-2017
Filing Date:	
Time Stamp:	11:57:32
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$730
RAM confirmation Number	013017INTEFSW12003500
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	Application Data Sheet	ADS.pdf	1823896 1bab4961171df6b5751d22a540de9ee3125b58e4	no	9
Warnings:					
Information:					
2	Oath or Declaration filed	Declaration.pdf	1932911 6460d144b2fdea299730e80eaec404afbe87aa17	no	3
Warnings:					
Information:					
3	Oath or Declaration filed	Declaration_AI.pdf	219701 f19ab727e231c000b861bf1186a83be7f8266b60	no	2
Warnings:					
Information:					
4	Drawings-only black and white line drawings	Drawings.pdf	4795671 9d625229acee14b5b9f1fd77aacc02c95a947720	no	6
Warnings:					
Information:					
5		Application.pdf	114319 60b59a4214d7d40c4ed3802381a3182c3e39fa51	yes	12

Multipart Description/PDF files in .zip description

Document Description	Start	End
Specification	1	10
Claims	11	11
Abstract	12	12

Warnings:					
Information:					
6	Fee Worksheet (SB06)	fee-info.pdf	34671 9959b8a8c3b350ac003e5eb7383a3ad965ffa170	no	2
Warnings:					
Information:					
			Total Files Size (in bytes):	8921169	

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POWER OF ATTORNEY TO PROSECUTE APPLICATIONS BEFORE THE USPTO

I hereby revoke all previous powers of attorney given in the application identified in the attached statement under 37 CFR 3.73(c).

I hereby appoint:

■ Practitioners associated with Customer Number: 92342

OR

☐ Practitioner(s) named below (if more than ten patent practitioners are to be named, then a customer number must be used):

Name	Registration Number	Name	Registration Number

As attorney(s) or agent(s) to represent the undersigned before the United States Patent and Trademark Office (USPTO) in connection with any and all patent applications assigned only to the undersigned according to the USPTO assignment records or assignments documents attached to this form in accordance with 37 CFR 3.73(c).

Please change the correspondence address for the application identified in the attached statement under 37 CFR 3.73(c) to:

■ The address associated with Customer Number: 92342

OR

☐

Firm or Individual Name			
Address			
City		State	Zip
Country			
Telephone		Email	

Assignee Name and Address: Corephotonics Ltd.
25 Habarzel St.
Ramat Hachayal, Tel-Aviv, 6971035
Israel

A copy of this form, together with a statement under 37 CFR 3.73(c) (Form PTO/AIA/96 or equivalent) is required to be Filed in each application in which this form is used. The statement under 37 CFR 3.73(c) may be completed by one of The practitioners appointed in this form, and must identify the application in which this Power of Attorney is to be filed.

SIGNATURE of Assignee of Record

The individual whose signature and title is supplied below is authorized to act on behalf of the assignee

Signature	/GAL SHABTAY/	Date	01-30-2017
Name	GAL SHABTAY	Telephone	
Title	VP-R&D		

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.

STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: Corephotonics Ltd.

Application No./Patent No.: 15418925 Filed/Issue Date: 01-30-2017

Titled: MINIATURE TELEPHOTO LENS ASSEMBLY

Corephotonics Ltd., a COMPANY

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose **one** of options 1, 2, 3 or 4 below):

1. ☑ The assignee of the entire right, title, and interest.

2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):

☐ The extent (by percentage) of its ownership interest is ____________%. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (*e.g.*, bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose **one** of options A or B below):

A. ☑ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel ____________, Frame ____________, or for which a copy thereof is attached.

B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: ________________________ To: ________________________

The document was recorded in the United States Patent and Trademark Office at

Reel ____________, Frame ____________, or for which a copy thereof is attached.

2. From: ________________________ To: ________________________

The document was recorded in the United States Patent and Trademark Office at

Reel ____________, Frame ____________, or for which a copy thereof is attached.

STATEMENT UNDER 37 CFR 3.73(c)

3. From: ________________________________ To: ________________________________

The document was recorded in the United States Patent and Trademark Office at

Reel ____________, Frame ____________, or for which a copy thereof is attached.

4. From: ________________________________ To: ________________________________

The document was recorded in the United States Patent and Trademark Office at

Reel ____________, Frame ____________, or for which a copy thereof is attached.

5. From: ________________________________ To: ________________________________

The document was recorded in the United States Patent and Trademark Office at

Reel ____________, Frame ____________, or for which a copy thereof is attached.

6. From: ________________________________ To: ________________________________

The document was recorded in the United States Patent and Trademark Office at

Reel ____________, Frame ____________, or for which a copy thereof is attached.

☐ Additional documents in the chain of title are listed on a supplemental sheet(s).

☐ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/GAL SHABTAY/	01-30-2017
Signature	Date
GAL SHABTAY	VP-R&D
Printed or Typed Name	Title or Registration Number

[Page 2 of 2]

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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).
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Electronic Acknowledgement Receipt

EFS ID:	28201338
Application Number:	15418925
International Application Number:	
Confirmation Number:	5957
Title of Invention:	MINIATURE TELEPHOTO LENS ASSEMBLY
First Named Inventor/Applicant Name:	Michael Dror
Correspondence Address:	Nathan & Associates Patent Agents Ltd - P.O.Box 10178 - Tel Aviv - 6110101 IL 516-442-9736 info@natpatent.com
Filer:	Menachem Nathan
Filer Authorized By:	
Attorney Docket Number:	COREPH-0080 US CIP
Receipt Date:	30-JAN-2017
Filing Date:	
Time Stamp:	12:04:48
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Assignee showing of ownership per 37 CFR 3.73	Assignment.pdf	17179 caa7010b8a7a4fcb3ee536af073805a2649bb654	no	1
Warnings:					
Information:					
2	Power of Attorney	POA.pdf	80502 52ff9b69ecd24313e5a780caf0e010d7b0f6781c	no	2
Warnings:					
Information:					
3	Assignee showing of ownership per 37 CFR 3.73	STATEMENT.pdf	117601 6855f9da0f2316ff7f2708af0bd98664fa488667	no	3
Warnings:					
Information:					
		Total Files Size (in bytes):	215282		

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ASSIGNMENT

For good and valuable consideration, the receipt and sufficiency of which is hereby acknowledged, the undersigned:

MICHAEL DROR EPHRAIM GOLDENBERG GAL SHABTAY

(hereinafter called the "assignor(s)"), hereby sell(s), assign(s) and transfer(s) to:

Corephotonics Ltd.
25 Habarzel St.
Ramat Hachayal, Tel-Aviv, 6971035
Israel

(hereinafter called the "assignee(s)"), its/his successors, assignees, nominees or other legal representatives, the Assignor's entire right, title and interest in and to the invention entitled:

MINIATURE TELEPHOTO LENS ASSEMBLY

described and claimed in the following US Continuation in part Application No. 15/418,925 identified as Attorney docket No. COREPH-0080 US CIP filed 01-30-2017;
and in and to said Patent Applications, and all original and reissued Patents granted therefor, and all divisions and continuations thereof, including the right to apply and obtain Patents in all other countries, the priority rights under International Conventions, and the Letters Patent which may be granted thereon;

Signed and sealed this 30 day of January 2017

MICHAEL DROR / Michael Dror /

EPHRAIM GOLDENBERG / Ephraim Goldenberg /

GAL SHABTAY / Gal Shabtay /