UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/079,481	03/24/2015	8989517	2200-15777-CINC	8099

34904 7590 03/04/2015
CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

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):

CANON KABUSHIKI KAISHA, Tokyo, JAPAN, Assignee (with 37 CFR 1.172 Interest);
David Peter MORGAN-MAR, Wollstonecraft, AUSTRALIA;
Kieran Gerard LARKIN, Putney, AUSTRALIA;
Matthew Raphael ARNISON, Umina Beach, AUSTRALIA;

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

IR103 (Rev. 10/09)

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)

34904 7590 11/24/2014
CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

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.
14/079,481	11/13/2013	David Peter MORGAN-MAR	2200-15777-CINC	8099

TITLE OF INVENTION: BOKEH AMPLIFICATION

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	02/24/2015

EXAMINER	ART UNIT	CLASS-SUBCLASS
OSINSKI, MICHAEL S	2662	382-280000

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 Canon U.S.A., Inc.
   2 IP Division
   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: Canon Kabushiki Kaisha

(B) RESIDENCE: (CITY and STATE OR COUNTRY): Tokyo, Japan

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 502456 (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 /Susan Moon/ Date 2015-02-17

Typed or printed name Susan Moon Registration No. 66,933

Electronic Patent Application Fee Transmittal

Application Number:	14079481
Filing Date:	13-Nov-2013
Title of Invention:	BOKEH AMPLIFICATION
First Named Inventor/Applicant Name:	David Peter MORGAN-MAR
Filer:	Susan C. Moon/Christina Ellis
Attorney Docket Number:	2200-15777-CINC

Filed as Large 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	1501	1	960	960

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**960**

Electronic Acknowledgement Receipt

EFS ID:	21514621
Application Number:	14079481
International Application Number:	
Confirmation Number:	8099
Title of Invention:	BOKEH AMPLIFICATION
First Named Inventor/Applicant Name:	David Peter MORGAN-MAR
Customer Number:	34904
Filer:	Susan C. Moon/Christina Ellis
Filer Authorized By:	Susan C. Moon
Attorney Docket Number:	2200-15777-CINC
Receipt Date:	17-FEB-2015
Filing Date:	13-NOV-2013
Time Stamp:	19:27:50
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$960
RAM confirmation Number	4309
Deposit Account	502456
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.19 (Document supply fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.20 (Post Issuance fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

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)	2200-15777-CINC_SM_Request_to_Pay_Issue_Fee_Due022415.pdf	91999 a135a62d6fd23de3d494d72eb0937b58b19056d3	no	1
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	30572 250df422fa27bf656a20223544fd33e7c89bb58a	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	122571		

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.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/079,481	11/13/2013	David Peter MORGAN-MAR	2200-15777-CINC	8099

34904 7590 12/08/2014
CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

EXAMINER	
OSINSKI, MICHAEL S	

ART UNIT	PAPER NUMBER
2662	

NOTIFICATION DATE	DELIVERY MODE
12/08/2014	ELECTRONIC

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

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

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

mklein@cusa.canon.com
skalminov@cusa.canon.com
IPDocketing@cusa.canon.com

PTOL-90A (Rev. 04/07)

Corrected **Notice of Allowability**	**Application No.** 14/079,481	**Applicant(s)** MORGAN-MAR ET AL.	
	Examiner MICHAEL OSINSKI	**Art Unit** 2662	**AIA (First Inventor to File) Status** No

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

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

1. ☒ This communication is responsive to *communications filed on 11/13/2013*.
   ☐ 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 *1-15*. 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 *11/25/2014* .
5. ☒ Examiner's Amendment/Comment
6. ☒ Examiner's Statement of Reasons for Allowance
7. ☐ Other _____.

/MICHAEL OSINSKI/
Primary Examiner, Art Unit 2662

UNITED STATES DEPARTMENT OF COMMERCE
U.S. Patent and Trademark Office
Address : COMMISSIONER FOR PATENTS
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Alexandria, Virginia 22313-1450

APPLICATION NO./ CONTROL NO.	FILING DATE	FIRST NAMED INVENTOR / PATENT IN REEXAMINATION	ATTORNEY DOCKET NO.
14/079,481	13 November, 2013	MORGAN-MAR ET AL.	2200-15777-CINC

CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

EXAMINER	
MICHAEL OSINSKI	
ART UNIT	PAPER
2662	20141125

DATE MAILED:

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

Commissioner for Patents

Attached is a corrected Notice of Allowability that corrects the typo found in the Examiner's Amendment mailed on 11/24/2014.

/MICHAEL OSINSKI/
Primary Examiner, Art Unit 2662

PTO-90C (Rev.04-03)

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

DETAILED ACTION

1. The following Office action is in response to communications filed on 11/13/2013. Claims 1-15 are currently pending.

Foreign Priority

2. Acknowledgement is made of applicant's claim for foreign priority under 35 U.S.C 119(a-d) based on AU-2012258467, filed on **12/3/2012.**

Information Disclosure Statement

3. The information disclosure statement filed on 11/13/2013 is in compliance with the provisions of 37 CFR 1.97, and has been considered and a copy is enclosed with this Office action.

Examiner's Amendment

4. An examiner's amendment to the record appears below. Should the changes and/or additions be unacceptable to applicant, an amendment may be filed as provided by 37 CFR 1.312. To ensure consideration of such an amendment, it MUST be submitted no later than the payment of the issue fee.

The Application is amended as follows:

- Claim 1 (Original), Line 1: Delete “the”
- Claim 13 (Original), Line 3: Delete “the”
- Claim 14 (Original), Line 3: Insert “to” before “capture”

Allowable Subject Matter

5. Claims 1-15 are allowed.

6. The following is an Examiner’s statement for the reasons of allowance:

7. Independent claims 1 and 13-15 are directed toward a method, camera, camera system, and non-transitory computer readable medium that include “capturing at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image

patch, wherein the amount of modification with respect to blur varies across different regions of the image patch."

The cited and considered prior art fails to teach individually or suggest through a combination of obviousness the above listed claimed features of "capturing at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch" in conjunction with the other claimed limitations as claimed in the instant application, and therefore independent claims 1 and 13-15 are allowed.

Claims 2-12 are allowed for being dependent upon allowed base claim 1.

Conclusion

8. Any inquiry concerning this communication or earlier communications from the examiner should be directed to MICHAEL OSINSKI whose telephone number is

(571)270-3949. The examiner can normally be reached on Monday - Thursday, 9am-6pmIf attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Roberto Velez can be reached on (571)272-8597. 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.

MO

/MICHAEL OSINSKI/

Primary Examiner, Art Unit 2662

Applicant-Initiated Interview Summary	Application No. 14/079,481	Applicant(s) MORGAN-MAR ET AL.	
	Examiner MICHAEL OSINSKI	Art Unit 2662	

All participants (applicant, applicant's representative, PTO personnel):

(1) *MICHAEL OSINSKI*. (3)_____.

(2) *Susan Moon*. (4)_____.

Date of Interview: *25 November 2014*.

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

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

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

Claim(s) discussed: *13*.

Identification of prior art discussed: _____.

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

Applicant's representative contacted the Examiner to inquire about a change made to claim 13 in an Examiner's Amendment to the claims mailed on 11/24/2014, specifically that the change was made to the correct claim. The Examiner verified that the change was intended for claim 14, not claim 13 as indicated, and the correction would be made in a supplemental notice of allowability.

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

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

☐ Attachment

/MICHAEL OSINSKI/
Primary Examiner, Art Unit 2662

Summary of Record of Interview Requirements

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

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

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

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

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

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

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

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

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

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

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

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

Examiner to Check for Accuracy

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

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
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Alexandria, Virginia 22313-1450
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NOTICE OF ALLOWANCE AND FEE(S) DUE

34904 7590 11/24/2014
CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

EXAMINER	
OSINSKI, MICHAEL S	
ART UNIT	PAPER NUMBER
2662	

DATE MAILED: 11/24/2014

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/079,481	11/13/2013	David Peter MORGAN-MAR	2200-15777-CINC	8099

TITLE OF INVENTION: BOKEH AMPLIFICATION

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	02/24/2015

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: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

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)

34904 7590 11/24/2014
CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

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.
14/079,481	11/13/2013	David Peter MORGAN-MAR	2200-15777-CINC	8099

TITLE OF INVENTION: BOKEH AMPLIFICATION

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	02/24/2015

EXAMINER	ART UNIT	CLASS-SUBCLASS
OSINSKI, MICHAEL S	2662	382-280000

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.
14/079,481	11/13/2013	David Peter MORGAN-MAR	2200-15777-CINC	8099

34904 7590 11/24/2014

CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

EXAMINER	
OSINSKI, MICHAEL S	
ART UNIT	PAPER NUMBER
2662	

DATE MAILED: 11/24/2014

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

Notice of Allowability	**Application No.** 14/079,481	**Applicant(s)** MORGAN-MAR ET AL.	
	Examiner MICHAEL OSINSKI	**Art Unit** 2662	**AIA (First Inventor to File) Status** No

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

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

1. ☒ This communication is responsive to *communications filed on 11/13/2013*.
   ☐ 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 *1-15*. 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 11/13/2013
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 _____.

/MICHAEL OSINSKI/
Primary Examiner, Art Unit 2662

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

DETAILED ACTION

1. The following Office action is in response to communications filed on 11/13/2013. Claims 1-15 are currently pending.

Foreign Priority

2. Acknowledgement is made of applicant's claim for foreign priority under 35 U.S.C 119(a-d) based on AU-2012258467, filed on **12/3/2012.**

Information Disclosure Statement

3. The information disclosure statement filed on 11/13/2013 is in compliance with the provisions of 37 CFR 1.97, and has been considered and a copy is enclosed with this Office action.

Examiner's Amendment

4. An examiner's amendment to the record appears below. Should the changes and/or additions be unacceptable to applicant, an amendment may be filed as provided by 37 CFR 1.312. To ensure consideration of such an amendment, it MUST be submitted no later than the payment of the issue fee.

The Application is amended as follows:

- Claim 1 (Original), Line 1: Delete “the”
- Claim 13 (Original), Line 3: Delete “the”
- Claim 13 (Original), Line 3: Insert “to” before “capture”

Allowable Subject Matter

5. Claims 1-15 are allowed.

6. The following is an Examiner’s statement for the reasons of allowance:

7. Independent claims 1 and 13-15 are directed toward a method, camera, camera system, and non-transitory computer readable medium that include “capturing at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image

patch, wherein the amount of modification with respect to blur varies across different regions of the image patch."

The cited and considered prior art fails to teach individually or suggest through a combination of obviousness the above listed claimed features of "capturing at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch" in conjunction with the other claimed limitations as claimed in the instant application, and therefore independent claims 1 and 13-15 are allowed.

Claims 2-12 are allowed for being dependent upon allowed base claim 1.

Conclusion

8. Any inquiry concerning this communication or earlier communications from the examiner should be directed to Michael Osinski whose telephone number is (571) 270-

3949. The examiner can normally be reached on Monday to Thursday 10 a.m. to 6 p.m. If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Roberto Velez can be reached on (571) 272-8597. 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.

MO

/MICHAEL OSINSKI/

Primary Examiner, Art Unit 2662

Notice of References Cited	Application/Control No. 14/079,481	Applicant(s)/Patent Under Reexamination MORGAN-MAR ET AL.	
	Examiner MICHAEL OSINSKI	Art Unit 2662	Page 1 of 2

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2001/0008418 A1	07-2001	Yamanaka et al.	348/222
*	B	US-2002/0145671 A1	10-2002	Alon et al.	348/241
*	C	US-2003/0002746 A1	01-2003	Kusaka, Yosuke	382/255
*	D	US-2007/0036427 A1	02-2007	Nakamura et al.	382/154
*	E	US-2008/0013861 A1	01-2008	Li et al.	382/286
*	F	US-2008/0175508 A1	07-2008	Bando et al.	382/255
*	G	US-2009/0115860 A1	05-2009	Nakashima et al.	348/208.99
*	H	US-2009/0297056 A1	12-2009	Lelescu et al.	382/261
*	I	US-2011/0033132 A1	02-2011	Ishii et al.	382/275
*	J	US-2011/0090352 A1	04-2011	Wang et al.	348/208.6
*	K	US-2011/0205382 A1	08-2011	Kanaris et al.	348/222.1
*	L	US-2012/0206630 A1	08-2012	Nguyen et al.	348/241
*	M	US-2013/0063566 A1	03-2013	Morgan-Mar et al.	348/46

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

Notice of References Cited	Application/Control No. 14/079,481	Applicant(s)/Patent Under Reexamination MORGAN-MAR ET AL.	
	Examiner MICHAEL OSINSKI	Art Unit 2662	Page 2 of 2

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-8,422,827 B2	04-2013	Ishii et al.	382/299
*	B	US-8,498,483 B2	07-2013	Noguchi et al.	382/181
*	C	US-2013/0266210 A1	10-2013	MORGAN-MAR et al.	382/154
*	D	US-8,624,986 B2	01-2014	Li, Pingshan	348/208.13
*	E	US-8,704,909 B2	04-2014	Kanaris et al.	348/222.1
*	F	US-8,737,756 B2	05-2014	DaneshPanah et al.	382/255
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
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	M	US-			

FOREIGN PATENT DOCUMENTS

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	O					
	P					
	Q					
	R					
	S					
	T					

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*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
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	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

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BIB DATA SHEET

CONFIRMATION NO. 8099

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
14/079,481	11/13/2013 **RULE**	348	2662	2200-15777-CINC

APPLICANTS
CANON KABUSHIKI KAISHA, Tokyo, JAPAN, Assignee (with 37 CFR 1.172 Interest);

INVENTORS
David Peter MORGAN-MAR, Wollstonecraft, AUSTRALIA;
Kieran Gerard LARKIN, Putney, AUSTRALIA;
Matthew Raphael ARNISON, Umina Beach, AUSTRALIA;

** **CONTINUING DATA** *************************

** **FOREIGN APPLICATIONS** *************************
AUSTRALIA 2012258467 12/03/2012

** **IF REQUIRED, FOREIGN FILING LICENSE GRANTED** **
11/25/2013

		STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
Foreign Priority claimed ☑ Yes ☐ No 35 USC 119(a-d) conditions met ☑ Yes ☐ No Verified and Acknowledged /MICHAEL S OSINSKI/ Examiner's Signature	☐ Met after Allowance Initials	AUSTRALIA	13	15	4

ADDRESS

CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731
UNITED STATES

TITLE

BOKEH AMPLIFICATION

FILING FEE RECEIVED		
2020	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).

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

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99**)		
	Application Number	
	Filing Date	
	First Named Inventor	David Peter MORGAN-MAR
	Art Unit	
	Examiner Name	
	Attorney Docket Number	2200-15777-CINC

U.S.PATENTS Remove

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
/M.O./	1	7065256	B2	2006-06-20	Alex ALON et al.	

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/M.O./	1	20090141163	A1	2009-06-04	Ziv ATTAR et al.	

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Examiner Initial*	Cite No	Foreign Document Number3	Country Code2 j	Kind Code4	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T5
/M.O./	1	2008/149363	WO	A2	2008-12-11	DBLUR TECHNOLOGIES LTD.		☐

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

Receipt date: 11/13/2013	Application Number		14079481 - GAU: 2662
INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99)**	Filing Date		
	First Named Inventor	David Peter MORGAN-MAR	
	Art Unit		
	Examiner Name		
	Attorney Docket Number		2200-15777-CINC

/M.O./	1	Bae, Soonmin, and Durand, Frédo. "Defocus Magnification." Computer Graphics Forum: Proceedings of Eurographics 2007, Prague, 3-7 September 2007. Ed. Cohen-Or, D and Slavik, P. Oxford, UK: Blackwell Publishing, 2007. 26.3: 571-579.	☐
/M.O./	2	Kubota, Akira, and Aizawa, Kiyoharu. "Reconstructing Arbitrarily Focused Images From Two Differently Focused Images Using Linear Filters." IEEE Transactions on Image Processing 14.11 (2005): 1848-1859.	☐

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EXAMINER SIGNATURE

Examiner Signature	/Michael Osinski/	Date Considered	11/14/2014

*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.

Receipt date: 11/13/2013	Application Number		14079481 - GAU: 2662
INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99)**	Filing Date		
	First Named Inventor	David Peter MORGAN-MAR	
	Art Unit		
	Examiner Name		
	Attorney Docket Number		2200-15777-CINC

CERTIFICATION STATEMENT

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

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

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

☐ See attached certification statement.

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

☒ A certification statement is not submitted herewith.

SIGNATURE

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

Signature	/Jiaxiao Zhang/	Date (YYYY-MM-DD)	2013-11-12
Name/Print	Jiaxiao ZHANG	Registration Number	63235

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

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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.

Index of Claims	Application/Control No. 14079481	Applicant(s)/Patent Under Reexamination MORGAN-MAR ET AL.
	Examiner MICHAEL OSINSKI	**Art Unit** 2662

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

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

CLAIM		DATE								
Final	Original	11/15/2014								
1	1	=								
2	2	=								
3	3	=								
4	4	=								
5	5	=								
6	6	=								
7	7	=								
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9	9	=								
10	10	=								
11	11	=								
12	12	=								
13	13	=								
14	14	=								
15	15	=								

Issue Classification	Application/Control No. 14079481	Applicant(s)/Patent Under Reexamination MORGAN-MAR ET AL.
	Examiner MICHAEL OSINSKI	Art Unit 2662

CPC

Symbol					Type	Version
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CPC Combination Sets

Symbol					Type	Set	Ranking	Version
			/					
			/					

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 15	
/MICHAEL OSINSKI/ Primary Examiner.Art Unit 2662 (Primary Examiner)	11/15/2014 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1, 10

U.S. Patent and Trademark Office

Part of Paper No. 20141115

Issue Classification	Application/Control No. 14079481	Applicant(s)/Patent Under Reexamination MORGAN-MAR ET AL.
	Examiner MICHAEL OSINSKI	Art Unit 2662

US ORIGINAL CLASSIFICATION

CLASS	SUBCLASS
382	280

CROSS REFERENCE(S)

CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				
348	207.1	222.1	239		
382	255	276			

INTERNATIONAL CLASSIFICATION

CLAIMED					NON-CLAIMED
G	0	6	K	9 / 36 (2006.01.01)	
G	0	6	K	9 / 40 (2006.01.01)	
H	0	4	N	5 / 225 (2006.01.01)	
H	0	4	N	5 / 228 (2006.01.01)	
H	0	4	N	5 / 262 (2006.01.01)	

NONE (Assistant Examiner)	(Date)	Total Claims Allowed: 15	
/MICHAEL OSINSKI/ Primary Examiner.Art Unit 2662 (Primary Examiner)	11/15/2014 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1, 10

U.S. Patent and Trademark Office Part of Paper No. 20141115

Issue Classification	Application/Control No. 14079481	Applicant(s)/Patent Under Reexamination MORGAN-MAR ET AL.
	Examiner MICHAEL OSINSKI	Art Unit 2662

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

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1														
2	2														
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15	15														

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 15	
/MICHAEL OSINSKI/ Primary Examiner.Art Unit 2662 (Primary Examiner)	11/15/2014 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1, 10

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
S2	108	(MORGAN-MAR adj DAVID adj PETER).in. (LARKIN adj KIERAN adj GERARD).in. (ARNISON adj MATTHEW adj RAPHAEL).in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 13:38
S3	11	"7065256".pn. "20090141163"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 13:53
S4	22	("20020145671" | "4532548" | "5023641" | "5535291" | "5580728" | "5748491" | "5867410" | "6240219" | "6333990" | "6545714" | "6567570").PN. OR ("7065256").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2014/11/14 13:56

S5	17	(camera imager processor ((imag$3 captur$3 record$3 pickup pick-up process$3 sens$3 photograph$3) NEAR5 (device apparatus system component unit element module))) AND ((modify modifying modification modified alter alteration altering altered change changing changed adjust adjustment adjusting adjusted repair repairing repaired reparation add adding added introduce introducing introduction introduced control controlling controlled vary varying varied variation transform transformation transforming transformed adapt adapting adaptation adapted set setting) WITH (blur blurring blurred bokeh) WITH (image picture photo photograph frame field data info information movie video)) AND ((capture capturing captured generate generating generation generated acquire acquiring acquirement acquired obtain obtaining obtainment obtained attain attaining attained attainment get getting gotten receive reception receiving received produce producing production produced create creating created creation imaging imaged record recording recorded sense sensing sensed take taking taken) WITH (image picture photo photograph frame field data info information movie video) WITH ((different vary varying various multiple numerous variety dissimilar unlike distinct distinctive diverge diverging diverged divergent diverse particular second two separate separately deviate deviating deviated deviation differential discrepant second variable differs) NEAR5 (focus focal lens depth aperture fstop f-stop ISO zoom zooming zoomed expose exposure exposing exposed parameter setting iris))) AND ((identify identifying identification identified select selection selecting selected choose chosen choosing pick picking picked pickout pick-out decide decision decided deciding elect electing election elected take taken taking took determine determining determination determined designate designating designation designated find finding found) WITH (region patch area section zone sector block division ROI) WITH (image picture photo photograph frame field data info information movie video)) AND ((calculate calculating calculation calculated derive deriving derivation derived compute computing computation computed estimate estimating estimation estimated determine determining determined determination approximate approximating approximation approximated obtain obtaining obtained obtainment acquire acquiring acquirement acquired)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 14:10

EAST Search History (Prior Art)

S6	2	12/988890	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 14:15
S7	8	("20010008418" | "20030002746" | "20050243350" | "20080175508" | "20090076754" | "20090174782" | "6021221").PN. OR ("8422827").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2014/11/14 14:16
S8	9	("20030117511" | "20070019883" | "20070036427" | "20070274570" | "20080013861" | "20090268985" | "20100039538" | "7957599" | "8422827"). PN. OR ("8624986").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2014/11/14 14:18

S9	2	(camera imager processor ((imag$3 captur$3 record$3 pickup pick-up process$3 sens$3 photograph$3) NEAR5 (device apparatus system component unit element module))) AND ((modify modifying modification modified alter alteration altering altered change changing changed adjust adjustment adjusting adjusted repair repairing repaired reparation add adding added introduce introducing introduction introduced control controlling controlled vary varying varied variation transform transformation transforming transformed adapt adapting adaptation adapted set setting) WITH (blur blurring blurred bokeh) WITH (image picture photo photograph frame field data info information movie video)) AND ((capture capturing captured generate generating generation generated acquire acquiring acquirement acquired obtain obtaining obtainment obtained attain attaining attained attainment get getting gotten receive reception receiving received produce producing production produced create creating created creation imaging imaged record recording recorded sense sensing sensed take taking taken) WITH (image picture photo photograph frame field data info information movie video) WITH ((different vary varying various multiple numerous variety dissimilar unlike distinct distinctive diverge diverging diverged divergent diverse particular second two separate separately deviate deviating deviated deviation differential discrepant second variable differs) NEAR5 (focus focal lens depth aperture fstop f-stop ISO zoom zooming zoomed expose exposure exposing exposed parameter setting iris))) AND ((identify identifying identification identified select selection selecting selected choose chosen choosing pick picking picked pickout pick-out decide decision decided deciding elect electing election elected take taken taking took determine determining determination determined designate designating designation designated find finding found) WITH (region patch area section zone sector block division ROI) WITH (image picture photo photograph frame field data info information movie video)) AND ((raise raising raised increase increasing increased amplify amplifying amplification amplified boost boosting boosted) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (power level degree grade magnitude)) AND ((combine combining combination combined integrate integrating integration integrated sum summing summation summed add adding	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 14:24

EAST Search History (Prior Art)

S10	47	("348".clas. "382".clas.) AND ((capture capturing captured generate generating generation generated acquire acquiring acquirement acquired obtain obtaining obtainment obtained attain attaining attained attainment get getting gotten receive reception receiving received produce producing production produced create creating created creation imaging imaged record recording recorded sense sensing sensed take taking taken) WITH (image picture photo photograph frame field data info information movie video) WITH ((different vary varying various multiple numerous variety dissimilar unlike distinct distinctive diverge diverging diverged divergent diverse particular second two separate separately deviate deviating deviated deviation differential discrepant second variable differs) NEAR5 (focus focal lens depth aperture fstop f-stop ISO zoom zooming zoomed expose exposure exposing exposed parameter setting iris))) AND ((identify identifying identification identified select selection selecting selected choose chosen choosing pick picking picked pickout pick-out decide decision decided deciding elect electing election elected take taken taking took determine determining determination determined designate designating designation designated find finding found) WITH (region patch area section zone sector block division ROI) WITH (image picture photo photograph frame field data info information movie video)) AND ((calculate calculating calculation calculated derive deriving derivation derived compute computing computation computed estimate estimating estimation estimated determine determining determined determination approximate approximating approximation approximated obtain obtaining obtained obtainment acquire acquiring acquirement acquired) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (region patch area section zone sector block division ROI)) AND ((fourier NEAR3 (transform transforming transformation transformed)) WITH (region patch area section zone sector block division ROI))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 17:35

EAST Search History (Prior Art)

S11	2	("348".clas. "382".clas.) AND ((identify identifying identification identified select selection selecting selected choose chosen choosing pick picking picked pickout pick-out decide decision decided deciding elect electing election elected take taken taking took determine determining determination determined designate designating designation designated find finding found) WITH (region patch area section zone sector block division ROI) WITH (image picture photo photograph frame field data info information movie video)) AND ((calculate calculating calculation calculated derive deriving derivation derived compute computing computation computed estimate estimating estimation estimated determine determining determined determination approximate approximating approximation approximated obtain obtaining obtained obtainment acquire acquiring acquirement acquired) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (region patch area section zone sector block division ROI)) AND ((fourier NEAR3 (transform transforming transformation transformed)) WITH (region patch area section zone sector block division ROI)) AND ((raise raising raised increase increasing increased amplify amplifying amplification amplified boost boosting boosted) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (power level degree grade magnitude)) AND ((combine combining combination combined integrate integrating integration integrated sum summing summation summed add adding addition added) WITH (raise raising raised increase increasing increased amplify amplifying amplification amplified boost boosting boosted) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (region patch area section zone sector block division ROI))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 17:48

S12	7	((identify identifying identification identified select selection selecting selected choose chosen choosing pick picking picked pickout pick-out decide decision decided deciding elect electing election elected take taken taking took determine determining determination determined designate designating designation designated find finding found) WITH (region patch area section zone sector block division ROI) WITH (image picture photo photograph frame field data info information movie video)) AND ((calculate calculating calculation calculated derive deriving derivation derived compute computing computation computed estimate estimating estimation estimated determine determining determined determination approximate approximating approximation approximated obtain obtaining obtained obtainment acquire acquiring acquirement acquired) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (region patch area section zone sector block division ROI)) AND ((fourier NEAR3 (transform transforming transformation transformed)) WITH (region patch area section zone sector block division ROI)) AND ((raise raising raised increase increasing increased amplify amplifying amplification amplified boost boosting boosted) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (power level degree grade magnitude)) AND ((combine combining combination combined integrate integrating integration integrated sum summing summation summed add adding addition added) WITH (raise raising raised increase increasing increased amplify amplifying amplification amplified boost boosting boosted) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (region patch area section zone sector block division ROI))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 17:50

EAST Search History (Prior Art)

S14	59	(348/207.1-207.11,208.99-208.16,222.1, 239,241,345-357,362-368.ccls. 382/162-167,173-180,254-280.ccls. "396". clas.) AND ((capture capturing captured generate generating generation generated acquire acquiring acquirement acquired obtain obtaining obtainment obtained attain attaining attained attainment get getting gotten receive reception receiving received produce producing production produced create creating created creation imaging imaged record recording recorded sense sensing sensed take taking taken) WITH (image picture photo photograph frame field data info information movie video) WITH ((different vary varying various multiple numerous variety dissimilar unlike distinct distinctive diverge diverging diverged divergent diverse particular second two separate separately deviate deviating deviated deviation differential discrepant second variable differs) NEAR5 (focus focal lens depth aperture fstop f-stop ISO zoom zooming zoomed expose exposure exposing exposed parameter setting iris))) AND ((identify identifying identification identified select selection selecting selected choose chosen choosing pick picking picked pickout pick-out decide decision decided deciding elect electing election elected take taken taking took determine determining determination determined designate designating designation designated find finding found) WITH (region patch area section zone sector block division ROI) WITH (image picture photo photograph frame field data info information movie video)) AND ((calculate calculating calculation calculated derive deriving derivation derived compute computing computation computed estimate estimating estimation estimated determine determining determined determination approximate approximating approximation approximated obtain obtaining obtained obtainment acquire acquiring acquirement acquired) WITH ((frequency NEAR3 domain) (spectral NEAR3 ratio)) WITH (region patch area section zone sector block division ROI))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 18:13
S15	38	S14 not S10	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2014/11/14 18:14

EAST Search History (Prior Art)

S16	16	("20080075444" | "20110228070" | "3639041" | "4952815" | "5231443" | "5594768" | "5878152" | "5883703" | "5985495" | "6219461" | "6229913" | "6806899" | "6842290" | "7379621" | "7558709" | "7977625").PN. OR ("8737756").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2014/11/14 18:20
S17	12	("20020057349" | "20050275736" | "20060050080" | "20060274156" | "20070070216" | "5142380" | "6104430" | "6721006" | "6785335" | "7254276" | "7286703" | "7456843").PN. OR ("8704909").URPN.	US-PGPUB; USPAT; USOCR	OR	ON	2014/11/14 18:22

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp

EAST Search History (Interference)

L2	1	((camera imager processor ((imag$3 captur$3 record$3 pickup pick-up process$3 sens$3 photograph$3) NEAR5 (device apparatus system component unit element module))) AND ((modify modifying modification modified alter alteration altering altered change changing changed adjust adjustment adjusting adjusted repair repairing repaired reparation add adding added introduce introducing introduction introduced control controlling controlled vary varying varied variation transform transformation transforming transformed adapt adapting adaptation adapted set setting) WITH (blur blurring blurred bokeh) WITH (image picture photo photograph frame field data info information movie video)) AND ((capture capturing captured generate generating generation generated acquire acquiring acquirement acquired obtain obtaining obtainment obtained attain attaining attained attainment get getting gotten receive reception receiving received produce producing production produced create creating created creation imaging imaged record recording recorded sense sensing sensed take taking taken) WITH (image picture photo photograph frame field data info information movie video) WITH ((different vary varying various multiple numerous variety dissimilar unlike distinct distinctive diverge diverging diverged divergent diverse particular second two separate separately deviate deviating deviated deviation differential discrepant second variable differs) NEAR5 (focus focal lens depth aperture fstop f-stop ISO zoom zooming zoomed expose exposure exposing exposed parameter setting iris))) AND ((identify identifying identification identified select selection selecting selected choose chosen choosing pick picking picked pickout pick-out decide decision decided deciding elect electing election elected take taken taking took determine determining determination determined designate designating designation designated find finding found) WITH (region patch area section zone sector block division ROI) WITH (image picture photo photograph frame field data info information movie video)) AND ((calculate calculating calculation calculated derive deriving derivation derived compute computing computation computed estimate estimating estimation estimated determine determining determined determination approximate approximating approximation approximated obtain obtaining obtained obtainment acquire acquiring acquirement acquired)	US-PGPUB; USPAT; UPAD	OR	ON	2014/11/15 13:06

Search Notes	Application/Control No. 14079481	Applicant(s)/Patent Under Reexamination MORGAN-MAR ET AL.
	Examiner MICHAEL OSINSKI	**Art Unit** 2662

CPC- SEARCHED

Symbol	Date	Examiner

CPC COMBINATION SETS - SEARCHED

Symbol	Date	Examiner

US CLASSIFICATION SEARCHED

Class	Subclass	Date	Examiner
348	All (with associted text)	11/14/14	MO
382	All (with associted text)	11/14/14	MO
348	207.1-207.11,208.99-208.16,222.1,239,241,345-357,362-368	11/14/14	MO
382		11/14/14	MO
396	All (with associted text)	11/14/14	MO

SEARCH NOTES

Search Notes	Date	Examiner
Inventor Search	11/14/14	MO
EAST Search	11/14/14	MO

INTERFERENCE SEARCH

US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner
All	See EAST History	11/15/14	MO

	/MICHAEL OSINSKI/ Primary Examiner.Art Unit 2662

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
14/079,481	11/13/2013	David Peter MORGAN-MAR	2200-15777-CINC

CONFIRMATION NO. 8099

PUBLICATION NOTICE

OC000000068839819

34904
CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

Title:BOKEH AMPLIFICATION

Publication No.US-2014-0152886-A1
Publication Date:06/05/2014

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/.

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ALITA CLARK
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BOKEH AMPLIFICATION

TECHNICAL FIELD

[0001] The current invention relates to digital image processing and, in particular, to rendering a photographic image with modified blur characteristics.

BACKGROUND

[0002] Single-lens reflex (SLR) and digital single-lens reflex (DSLR) cameras have large aperture optics which can produce a narrow depth of field. Depth of field measures the distance from the nearest object to the camera which is in focus, to the farthest object from the camera which is in focus. (D)SLR cameras typically have a depth of filed of order significantly less than 1 metre for a typical portrait scenario of a subject a few metres from the camera. This allows the foreground subject of a photo to be rendered in sharp focus, while the background is blurred by defocus. The result is visually pleasing as it provides a separation between the subject and any distracting elements in the background. The aesthetic quality of background blur (encompassing both the quantity and "look" of the blur) is known as *bokeh*. Bokeh is especially important for photos of people, or portraits.

[0003] Compact digital cameras are more popular than DSLRs with consumers because of their smaller size, lighter weight, and lower cost. However, the smaller optics on a compact camera produce a large depth of field, of order greater than approximately 1 metre for the same typical portrait scenario, which renders the background in typical portrait shots as sharp and distracting.

[0004] Depth of field varies significantly depending on the geometry of the photographic scene. The following examples are for taking a photo of a person about 3 metres from the camera:

(i) the depth of field for a full frame SLR camera at 50mm focal length and aperture *f*/2.8 is about 0.5 metres. For a portrait scenario, a photographer would typically want to use a depth of field this size, or even smaller, maybe 0.2 metres or even 0.1 metres. An SLR camera can also be configured with a smaller aperture to achieve very large depth of field, though this is not usually done for portraits.

(ii) the depth of field for a small compact camera (e.g. Canon™ IXUS™ model) at 50mm full-frame equivalent focal length and aperture f/2.8, is 6 metres.

(iii) a large compact camera (e.g. Canon™ G12) at 50mm full-frame equivalent focal length and aperture f/4 is 1.6 metres. (This camera cannot achieve f/2.8 aperture – if it could, its

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depth of field would be 1.2 metres.) It is practically impossible for a camera with a compact form factor to achieve a depth of field under about 1 metre, for a subject at 3 metres distance. Technically, such is possible, but would require very large and expensive lenses. Depth of field for compact cameras under normal conditions can easily be tens of metres or even infinity, meaning that everything from the subject to the far distance is in focus.

[0005] If the person is closer to the camera than 3 metres, all the depth of field distances discussed above will be smaller, and if the person is further away, they will all be larger. Importantly, an SLR camera will always be able to achieve a significantly smaller depth of field than a compact camera. The depth of field is largely dictated by the size of the camera sensor.

[0006] A method of producing *artificial bokeh* with a compact camera, mimicking the amount and quality of background blur produced by an SLR camera, would provide a major improvement in image quality for compact camera users.

[0007] Camera manufacturers and professional photographers have recognised the depth of field limitations of small format cameras for decades. With the advent of digital camera technology, it has become feasible to process camera images after capture to modify the appearance of the photo. The generation of SLR-like bokeh from compact camera images has been an early target for research in the field of digital camera image processing. However, no solution providing results of high (i.e. visually acceptable) aesthetic quality has been demonstrated.

[0008] To accurately mimic small depth of field given a large depth of field photo, objects in the image must be blurred by an amount that varies with distance from the camera. The most common prior approach tackles this problem in two steps:

(1a). Estimate the distance of regions in the image from the camera to produce a *depth map*.

(1b). Apply a blurring operation using a blur kernel size that varies with the estimated distance.

[0009] Step (1a) is a difficult problem in itself, and the subject of active research by many groups. The three main methods of depth map estimation from camera images (i.e. excluding active illumination methods) are:

(i) Stereo: taking photos from different camera positions and extracting depth from parallax. A major disadvantage of this approach is the requirement to take photos from multiple viewpoints, making it impractical for compact cameras.

(ii) Depth from focus (DFF): taking a series of many images focused at different distances and measuring in patches which photo corresponds to a best focus at that patch, usually using maximal contrast as the best focus criterion. A major disadvantage of this approach is that many exposures are required, necessitating a long elapsed time. During the exposures the camera or subject may inadvertently move, potentially blurring the subject and introducing additional problems caused by image misalignment.

(iii) Depth from defocus (DFD): quantifying the difference in amount of blur between two images taken with different focus and equating the blur difference to a distance. This is the most suitable approach for implementation in a compact camera, as it does not require stereo camera hardware and can be performed with as few as two photos. However, it has the disadvantages that accuracy is typically relatively low, particularly around the boundaries of objects in the scene, and that consistency is adversely affected by differing object textures in the scene. Some DFD methods show better accuracy around object edges, at the cost of using computationally expensive algorithms unsuited to implementation in camera hardware.

[0010] Step (1b) is computationally expensive for optically realistic blur kernel shapes. A fallback is to use a Gaussian blur kernel, which produces a blur that looks optically unrealistic, making the resulting image aesthetically unpleasing.

[0011] To more easily approach artificial bokeh, many prior methods use a simplified version of the above two-step method, being:

(2a). Segment the image into a foreground region and a background region.

(2b). Apply a constant blurring operation to the background region only.

[0012] Assuming step (2a) is done correctly, step (2b) is straightforward. However, step (2a) is still difficult and has not been achieved satisfactorily within the constraints of a compact camera. In particular, the accuracy of segmentation around the edges of objects at different depths in the scene is poor. Even if this simplified method can be achieved without error, the resulting images can look artificial, since intermediate levels of blur between the foreground and background will be absent.

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[0013] An alternative approach to artificial bokeh is to:

(3a). Estimate the amount of blur at different places in an image, compared to a blur-free representation of the subject scene.

(3b). Apply a blurring operation using a blur kernel size that varies with the estimated blur amount.

[0014] A compact camera does not have an infinite depth of field, so the background will show a small amount of blurring relative to an in-focus foreground object. If such blurred regions can be identified accurately, they can be blurred more, producing increased blur in the background.

[0015] Step (3a) can be performed with a single image, or by using multiple images of the scene captured with different camera parameters. Estimating blur from a single image is under-constrained and can only be achieved under certain assumptions. For example, one assumption is that edges detected in the image are step function edges in the scene, blurred by the camera optics, and that regions away from edges may be accurately infilled from the edge blur estimates. These assumptions are often false, resulting in poor blur estimates. Estimating blur from multiple images is akin to DFF or DFD, because blur amount is directly related to depth, and shares the same problems.

SUMMARY

[0016] According to the present disclosure there is provided a method of modifying the blur in at least a part of an image of a scene, said method comprising: capturing at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; raising each of the pixel values in the set of frequency domain pixel values to a predetermined power (1050), thereby forming an amplified set of frequency domain pixel values; and combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

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[0017] Preferably, the set of frequency domain pixel values are modified before being raised to the predetermined power. Generally the modification includes a median filtering operation. Alternatively the modification may include a smoothing filtering operation. The modification may include a normalisation operation and/or a weighting operation. The weights for the weighting operation are determined by the phases of the set of frequency domain pixel values.

[0018] Typically the at least two images of the scene are divided into a plurality of corresponding image patches in each of the captured images; and the output image patches are combined to produce an output image. Desirably the plurality of corresponding image patches in each of the captured images form a tiling substantially covering the area of the captured images, and the output image is formed by tiling the output image patches. Generally the plurality of corresponding image patches in each of the captured images overlap, and the output image is formed by combining the pixel values of the output image patches.

[0019] In a specific implementation the plurality of corresponding image patches in each of the captured images cover part of the area of the captured images; and the output image patches are combined with the area of at least one of the captured images not covered by the plurality of corresponding image patches to produce an output image. Desirably at least part of the area of the at least one of the captured images not covered by the plurality of corresponding image patches is blurred by convolution with a blur kernel.

[0020] According to another aspect, disclosed is a camera comprising an image capture system coupled to memory in which captured images are stored, a processor, and a program executable by the processor to modify the blur in at least a part of an image of a scene, said program comprising: code for causing the capture system to capture at least two images of the scene, said images being captured with different camera parameters (820,840) to produce a different amount of blur in each of the captured images; code for selecting a corresponding image patch (642,652) in each of the captured images, each of the selected image patches having an initial amount of blur; code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to

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the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

[0021] Another aspect is a camera system comprising: a lens formed of optics producing a relatively large depth of field; a sensor configured capture an image of a scene focussed through the lens; a memory in which images captured by the sensor are stored; a capture mechanism configured to capture at least two images of the scene with different capture parameters and to store the images in the memory; a processor; a program stored in the memory and executable by the processor to modify blur in at least a part of one of the captured images of the scene, said program comprising: code for causing the capture system to capture at least two images of the scene with different camera parameters (820,840) to produce a different amount of blur in each of the captured images; code for selecting a corresponding image patch (642,652) in each of the captured images, each of the selected image patches having an initial amount of blur; code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

[0022] In another aspect disclosed is a computer readable storage medium having a program recorded thereon, the program being executable by a processor to modify blur in at least a part of an image of a scene, the program comprising: code for receiving at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; code for selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power (1050), thereby forming an amplified set of frequency domain pixel values; and code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to

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the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

[0023] Other aspects are disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] At least one embodiment of the invention will now be described with reference to the following drawings, in which:

[0025] Fig. 1 is a schematic diagram of a scene and an image capture device positioned to capture an image of the scene;

[0026] Fig. 2 is a schematic diagram illustrating the geometry of a lens forming two different images at two different focal planes;

[0027] Figs. 3A and 3B illustrate a two-dimensional Gaussian function and a two-dimensional pillbox function, and one-dimensional cross-sections thereof;

[0028] Figs. 4A and 4B collectively form a schematic block diagram of a general purpose computer on which various implementations may be practised;

[0029] Figs. 5A, 5B, and 5C illustrate example images upon which artificial bokeh processing according to the present disclosure may be performed;

[0030] Fig. 6 is a diagram illustrating the correspondence between pixels and image patches within a first image and a second image of a scene;

[0031] Fig. 7 is a schematic flow diagram illustrating an exemplary method of determining an artificial bokeh image from two images of a scene, according to the present disclosure;

[0032] Fig. 8 is a schematic flow diagram illustrating one example of a method of capturing two images as used in the method of Fig. 7;

[0033] Fig. 9 is a schematic flow diagram illustrating one example of a method of asymmetrical patch selection as used in the method of Fig. 7;

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[0034] Fig. 10 is a schematic flow diagram illustrating one example of a method of determining an artificial bokeh image patch from two corresponding patches of two images of a scene as used in the method of Fig. 7;

[0035] Fig. 11 is a schematic flow diagram illustrating one example of a method of assembling artificial bokeh patches into an artificial bokeh image as used in the method of Fig. 7; and

[0036] Fig. 12 is a schematic flow diagram illustrating a second exemplary method of determining an artificial bokeh image from two images of a scene, according to the present disclosure.

DETAILED DESCRIPTION INCLUDING BEST MODE

Introduction

[0037] The present disclosure is directed to providing methods of rendering a photographic image taken with large depth of field so as to mimic a photo taken with a smaller depth of field by modifying blur already present in the image taken with a large depth of field. The methods seek to offer one or more of improved accuracy, improved tolerance to imaging noise, improved tolerance to differences of object texture in the image, and improved aesthetic appearance of the final image, all of these particularly in regions at and near the boundaries of objects in the scene.

Context

Thin lens equation, basic geometry

[0038] The technical details of accurately rendering artificial bokeh rely on key aspects of the geometry and optics of imaging devices. Most scenes that are captured using an imaging device, such as a camera, contain multiple objects, which are located at various distances from the lens of the device. Commonly, the imaging device is focused on an object of interest in the scene. The object of interest shall be referred to as the *subject* of the scene. Otherwise, objects in the scene, which may include the subject, shall simply be referred to as *objects*.

[0039] Fig. 1 is a schematic diagram showing the geometrical relationships between key parts of an imaging device and objects in a scene to be captured. Fig. 1 shows an imaging device or

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system (e.g. a camera) 100 which includes a lens 110, and a sensor 115. For the purposes of this description, the camera 100 is typically a compact digital camera and the lens 110 has relatively small optics producing a large depth of field, particularly in comparison to an SLR camera. Fig. 1 also shows an in-focus plane 130 and a general object 140 formed by sphere positioned upon a rectangular prism, forming part of the scene but not necessarily the subject of the scene to be captured. The image plane 120 of the imaging device 100, also referred to as the focal plane, is defined to be at the location of the sensor 115. When projected through the lens 110, the image plane 120 forms the *in-focus plane* 130, which can be considered to be a virtual plane in the geometrical region of the object 140. A distance 150 from the lens 110 to the image plane 120 is related to a distance 160 from the lens 110 to the in-focus plane 130, by the thin lens law according to the equation

$$\frac{1}{z_i}+\frac{1}{z_o}=\frac{1}{f} \qquad (1)$$

where f is the focal length of the lens 110, z_i is the lens-to-sensor distance 150, and z_o is the distance 160 from the lens 110 to the in-focus plane 130. The general scene object 140 is located at a distance 170 from the lens 110 and at a distance 180 from the in-focus plane 130. This distance 170 is referred to as z_s. The distance 180 from the object 140 to the in-focus plane 130 is given by $z_s - z_o$ and may be positive, zero, or negative. If the object 140 is focused onto the image plane 120, then $z_s = z_o$ and the object 140 is located in the in-focus plane 130. If z_s is less than or greater than z_o, then the object 140 is located behind or in front of the in-focus plane 130 respectively, and the image of the object 140 will appear blurred on the image plane 120.

a. Fig. 1 illustrates a relatively simple geometrical optics model of imaging. This model relies on approximations including the thin lens approximation, paraxial imaging rays, and a lens free of aberrations. These approximations ignore some aspects of the optics that are inherent in actual imaging systems, but are sufficient for general understanding of imaging behaviour, as is understood by those skilled in the art.

b. Focusing is carried out either manually by the user or by using an autofocus mechanism that is built into the imaging device 100. Focusing typically

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manipulates the lens-to-sensor distance 150 in order to place the in-focus plane 130 such that the distance z_o 160 is equal to the distance z_s 170 to a specific object of interest, *i.e.* to place the subject in the in-focus plane 130. Other objects in the scene that have a distance z_s from the lens 110 that is different from that of the subject are located either behind or in front of the in-focus plane 130. These other objects will appear blurred to some degree on the image plane 120 and thus in the image captured on the sensor 115. This blur is referred to as *defocus blur*.

Defocus blur

[0040] The amount of defocus blurring of an imaged object 140 increases with the distance 180 of the object 140 from the in-focus plane 130. The amount of defocus blur present in a given patch or portion of a captured 2D image can be characterised by the point spread function (PSF). The PSF is the response of the imaging system to a point source, defined such that the integral of the PSF over the image plane is equal to unity. The PSF of an optical system is generally a spatially restricted two-dimensional function of spatial coordinates (x, y) that approaches zero beyond a certain radial distance from the origin. The amount of blur can be characterised by measures of the shape of the PSF. Typical measures of the amount of blur are the full-width-at-half-maximum (FWHM) of the PSF, or the standard deviation of the PSF.

[0041] A basic understanding of the principles behind image blurring may be gained by assuming a mathematically simple model for the PSF of a camera lens 110. To achieve this simplicity, prior art analyses often model the PSF as a two-dimensional Gaussian function. This assumption is followed in the present description for explanatory purposes only, noting that the PSFs of physical optical systems are typically not well approximated by Gaussian functions. Under this assumption, the standard deviation σ of the Gaussian can be regarded as a *blur radius*, providing a convenient quantitative measure of the concept of "amount of blur". It can be shown that the relationship of the Gaussian blur radius σ, object distance z_s, and the camera image capture parameters of focal length f and lens aperture A_V is given by

$$z_s = \frac{f z_i}{z_i - f - 2\sigma A_V} \qquad (2)$$

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where A_V is the relative aperture (also known as the *f*-number) of the lens 110. If the blur radius σ of a point located at pixel coordinates (x_i, y_i) in a captured image of a scene can be measured, the distance z_s to an object at the corresponding point in the scene can be determined using equation (2), provided the remaining quantities in equation (2) are known. Through this relationship, knowledge of the blur radius is effectively equivalent to knowledge of the object depth, since the remaining quantities in equation (2) are usually known.

[0042] However, determining the blur radius σ from a single image of a scene without detailed prior knowledge of the scene to be imaged is known to be an unsolvable problem. This is because determining the blur radius σ is not possible from a single image unless details of the unblurred scene image are known. For example, an image feature resembling a blurred disc may be caused by a disc of some indeterminate smaller size that has been blurred by some unknown amount, or by an object in the scene that resembles a blurred disc, rendered in sharp focus. Given this ambiguity, it is impossible to determine the blur radius σ. Thus, in terms of equation (2), even if the parameters z_i, f, and A_V are known, it is not possible to determine depth from a single image of an unconstrained scene.

[0043] In the majority of circumstances, scenes are imaged without detailed knowledge of the structure of the objects in the scene. It is a general requirement for many imaging applications to work with unconstrained scenes, and even under carefully controlled imaging environments, such as portrait studios, it is very difficult to estimate the required information needed to obtain a depth map from a single image. However, referring to equation (2), it is theoretically possible to extract information about the blur radius (or equivalently the depth) using two captured images of the same scene, provided that the value of at least one of the parameters, in addition to blur radius σ, differs between the two captured images. This is the basic principle that underpins depth from defocus (DFD) methods, which rely on calculating the relative defocus blur between two images of a scene.

Practical considerations

[0044] In practice, images of a scene are captured with some amount of imaging noise. This affects the accuracy of any measurements made by processing the image data. The simple optical models, such as Gaussian PSFs, used to derive the principles of many prior art artificial bokeh methods are not realistic. Real lenses contain aberrations other than defocus, objects are

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imaged with large field angles, and diffraction effects can be important. There are also considerations of the amount of visual texture in the scene objects. For example, if an area of an object is uniform in colour and reflectivity, then it is impossible to distinguish any amount of blurring within this area. Further, the combination of different visual textures with varying amounts of imaging noise produces widely varying responses for many artificial bokeh methods. Particularly problematical is when different visual textures at the same depth produce different estimates of the amount of blur.

[0045] For combinations of these reasons, artificial bokeh methods in practice have shown limited success at rendering enhanced background blur in realistic photographic scenes. Much of the reported success of artificial bokeh methods has been restricted to highly constrained test scenes.

Overview

[0046] The arrangements presently described improve on the prior art by utilising more realistic theoretical modelling of the behaviour of lens optics in real world conditions, and by providing a more robust means of rendering enhanced background blur in a scene independent manner and in the presence of imaging noise particularly in regions at and near the boundaries of objects in the scene.

[0047] Figs. 3A and 3B illustrate two simple two-dimensional functions that are commonly assumed as approximations to lens PSFs. Fig. 3A shows a two-dimensional Gaussian function 300, whose one-dimensional cross section is a one-dimensional Gaussian function 310. The two-dimensional Gaussian function 300 is illustrated schematically in a dithered fashion, to assist with photocopy reproduction of this patent specification. Fig. 3B shows a circular pillbox function 320, whose one-dimensional cross section is a square function 330.

[0048] Prior art modelling of the lens behaviour in the context of artificial bokeh commonly assumes that the PSF of defocus blur is well modelled by a two-dimensional Gaussian function 300. In general this is not true. The defocus blur PSF of a photographic camera lens often more closely resembles a circular pillbox 320, with relatively sharp edges compared to the gradual fall-off of a Gaussian function. In reality, the shape of the defocus blur PSF is more complex than either of these approximations, and varies significantly from lens to lens and with different camera parameters for a single lens. The PSF also varies with field angle such that the PSF in

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one region of the image plane 120 may be different to the PSF in some other region of the image plane 120.

[0049] Also in particular, prior art modelling of the lens behaviour in the context of artificial bokeh assumes that consideration of the modulation transfer function (MTF), which is the modulus of the optical transfer function (OTF), is adequate to determine accurate blur estimates from a comparison of two images. This assumption neglects the important contribution of the phase of the OTF, effectively disregarding half of the available data. By fully utilising the phase information, the arrangements presently disclosed can achieve significantly more accurate results than the prior art.

[0050] The presently disclosed arrangements facilitate artificial bokeh rendering from a pair of images taken of the same scene with different camera parameters: (a) without making any assumption about the shape of the defocus blur PSF, (b) without discarding the information present in the phases of the image spectrum and OTF, and (c) using an improved method of characterising the relative blur between two image patches which is less sensitive to imaging noise than prior methods. These features will be explained in detail in the following sections.

Theory

Spectral ratio and relative point spread function

[0051] A method of rendering enhanced blur from two images of the same scene can be developed by considering the theory of image formation. Consider a patch f_0 of the scene to be imaged, the patch being small enough such that any variation in object depth or PSF of the imaging system within the patch is small and thus can be ignored. The two-dimensional intensity distribution of the corresponding patch of an image f_1 of the intensity distribution of the patch f_0 can be modelled using a fully general point spread function (PSF) by a spatial convolution operation as follows:

$$f_1(x,y) = f_0(x,y) \otimes PSF_1(x,y) \tag{3}$$

where PSF_1 is the defocus blur PSF of the scene patch f_0 when it is projected on to the image patch f_1. Taking the Fourier transform of both sides of equation (3) gives

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$$F_1(u,v) = F_0(u,v)OTF_1(u,v) \quad (4)$$

where (u, v) are spatial frequency coordinates, F_1 is the Fourier transform of f_1, F_0 is the Fourier transform of f_0, and OTF_1 is the Fourier transform of PSF_1. By the Fourier convolution theorem the spatial convolution operation has become a product. The function OTF_1 is known as the optical transfer function (OTF). The OTF is a complex-valued function, with modulus and phase components.

[0052] Assume we have two images of the same scene taken with different camera parameters, but without moving the camera or any objects in the scene so that the images are in alignment with one another. Then the second image patch f_2 of the same scene patch f_0 may be modelled in the same way as equation (3), replacing the 1 subscripts with 2 subscripts. Taking the ratio of the Fourier transforms of corresponding patches in the two images gives

$$\frac{F_1(u,v)}{F_2(u,v)} = \frac{OTF_1(u,v)}{OTF_2(u,v)} \quad (5)$$

where the Fourier transform $F_0(u, v)$ of the scene is common to the numerator and denominator of the right hand side and has been cancelled from the ratio. This ratio may be called the *spectral ratio*. When no noise is present, the spectral ratio is scene independent because all contributions of the scene have been cancelled out. In the presence of imaging or quantisation noise, the cancellation may not be perfect, and the spectral ratio may be biased by the noise.

[0053] The spectral ratio can be formed with an arbitrary assignment of the image patches as f_1 and f_2. However, as explained further below, it is advantageous to use asymmetric patch selection, based on which of the two image patches f_1 and f_2 is less blurred than the other image patch. Such a determination can be made by, for example, calculating the variance of the pixel intensities or brightness in each image patch, with the patch with the higher variance deemed to be less blurred, and thus the most focussed representation of the scene. Other methods of determining which patch is less blurred may be used, for example if the images are taken at different apertures and diffraction can be ignored, the patch captured with the narrower aperture may be deemed to be less blurred.

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[0054] Once determination has been made of which patch is less blurred, the less blurred patch may be assigned as patch f_2, with the patch deemed to be more blurred assigned as f_1. This assignment allows an interpretation in which it is possible to consider f_1 as a more blurred version of f_2, related by a relative optical transfer function OTF_r given by the spectral ratio:

$$\begin{aligned} F_1(u,v) &= F_2(u,v)\frac{OTF_1(u,v)}{OTF_2(u,v)} \\ &= F_2(u,v)OTF_r(u,v) \end{aligned} \tag{6}$$

Taking the inverse Fourier transform of equation (6) gives the following relationship

$$f_1(x,y) = f_2(x,y) \otimes PSF_r(x,y) \tag{7}$$

where PSF_r is defined to be the *relative point spread function* (relative PSF) which when convolved with the image patch f_2 produces the image patch f_1. The relative point spread function PSF_r is not simply related to PSF_1 and PSF_2, but is the result of a non-linear combination of the two. The relative point spread function PSF_r varies with parameters of the imaging system such as focus and aperture, with the depth of the object imaged in patch f_0, and with field angle across the image plane 120.

Application to artificial bokeh

[0055] The space-varying relative point spread function PSF_r is the inverse Fourier transform of (OTF_1/OTF_2). PSF_r operates on the image patch f_2 to increase the amount of blur in the image, but in a very specific way:

(a) where an object is in focus in both images (for example, the subject of the photo, usually in the foreground), there is very little blur difference, so the relative PSF is close to a delta function; and

(b) where an object is more in focus in f_2 than in f_1, the relative PSF produces the necessary amount of relative blurring in f_1. For objects at distances similar to the subject, this is a small amount of blur, while for objects at distances very different to the subject (e.g. the distant background) this is a larger amount of blur.

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[0056] The goal of rendering artificial bokeh simulating a shallower depth of field from such a pair of images can be expressed as:

(i) where an object is in focus in both images (e.g. the subject of the photo), do not blur; and

(ii) where an object is more in focus in f_2 than in f_1, apply a variable amount of blurring. For objects at distances similar to the subject, apply a relatively small amount of blur, while for objects at distances very different to the subject (e.g. the distant background) apply a larger amount of blur.

[0057] The present inventors observe the similarity in the two sets of points above, and deduce it is possible to achieve the goal of rendering a shallower depth of field image $f_{(N)}$ by applying the relative PSF to the image patch f_2 multiple times, in other words by convolving f_2 with the relative PSF N times:

$$f_{(N)} = f_2 \otimes \overbrace{PSF_r \otimes PSF_r \otimes \cdots \otimes PSF_r}^{N} \tag{8}$$

Expressed in the Fourier domain, this becomes:

$$F_{(N)} = \left(\frac{OTF_1}{OTF_2} \right)^N F_2 \tag{9}$$

[0058] The amount of additional blurring of background regions can be controlled by adjusting the amplification factor N. In the Fourier domain, N is not constrained to being an integer. As long as $N > 1$, the blurring of the background is increased. If $N < 1$, the blurring of the background is reduced; in other words the background is sharpened, mimicking the effect of a greater depth of field than the original images. Equation (9) must be implemented using complex arithmetic to preserve the phase information that is crucial to the reconstruction of an image.

[0059] The present inventors have thus determined it is possible to produce a shallow depth of field or artificial bokeh image by dividing the input images into patches f_1 and f_2, and then, for each patch:

(i) calculate the spectral ratio F_1/F_2;

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(ii) raise the spectral ratio to some power $N > 1$ and multiply by the patch Fourier transform F_2 to obtain the Fourier domain patch $F_{(N)}$; and

(iii) inverse Fourier transform the Fourier domain patch $F_{(N)}$ to obtain the output image patch $f_{(N)}$.

[0060] The resulting patches may then be reassembled to give the final image, which will appear to be a shallow depth of field image of the scene, with objects away from the focal plane blurred more than in the input images.

[0061] Advantageously, the resulting patches produce an image in which objects near the focal plane are not blurred, while objects far from the focal plane are blurred in proportion to their distance from the focal plane. This tends to hold even when a single patch covers objects or parts of objects at multiple distances. The frequency domain information from discrete objects or parts of objects at different distances from the camera, visible in the same patch, tend to separate out into discrete spatial frequencies. Each of the spatial frequencies is amplified independently by an amount required to produce the appropriate amount of blur for an object at the corresponding distance. For spatial frequencies present in multiple discrete objects, the amplification is intermediate, and the combination of other amplified frequencies and the original phase information from patch F_2 tends to construct the desired differential blurring appropriately. The result is that a single pair of input patches f_1 and f_2 covering objects at different distances will produce an output image patch $f_{(N)}$ containing an additional amount of blur that varies across the patch, the variation in additional blur being appropriate for the differing distances of the various objects within the patch.

Normalisation

[0062] A complication arises if the mean intensity levels of the two image patches f_1 and f_2 are not the same as each other. In most cases the mean intensity levels of the two patches will be similar, since the two images will preferentially have been captured with a short time interval between the exposures (for example, typically less than 1 second), and with similar photographic exposures. However due to variations in illumination intensity, motion of objects in the scene, or the effects of imaging noise, the mean intensity levels of the two image patches f_1 and f_2 are unlikely to be identical. By properties of the Fourier transform, the pixels of the Fourier transforms F_1 and F_2 corresponding to zero spatial frequency in the Fourier domain

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(known as the DC pixel) contain a real number equal to the mean intensity level of the corresponding image patches f_1 and f_2. By the construction of the spectral ratio, the DC pixel of the spectral ratio contains the ratio of the mean intensity levels of the image patches f_1 and f_2.

[0063] In the ideal case in which the image patches f_1 and f_2 have equal mean intensities, the DC pixel of the spectral ratio is equal to 1. In this case, raising the spectral ratio to a power N will preserve the unity value of the DC pixel. Then when the spectral ratio is multiplied by the Fourier transformed patch F_2 to form $F_{(N)}$, the DC value of $F_{(N)}$ will be equal to the DC value of the Fourier transformed patch F_2. Then when $F_{(N)}$ is inverse Fourier transformed to form $f_{(N)}$, the resulting artificial bokeh patch will have the same mean intensity level as the original patch f_2. If this ideal case holds across all of patches in the original images, then when the artificial bokeh patches are assembled, the intensity of the resulting composite image will be consistent with the original image in all regions.

[0064] On the other hand, if the image patches f_1 and f_2 have unequal mean intensities, the DC pixel of the spectral ratio is not equal to 1. In this case, raising the spectral ratio to a power N will change the value of the DC pixel. Then, when the spectral ratio is multiplied by the Fourier transformed patch F_2 to form $F_{(N)}$, the DC value of $F_{(N)}$ will not be equal to the DC value of the Fourier transformed patch F_2. Then, when $F_{(N)}$ is inverse Fourier transformed to form $f_{(N)}$, the resulting artificial bokeh patch will have a different mean intensity level compared to the original patch f_2. If this more realistic case holds across all of patches in the original images, then when the artificial bokeh patches are assembled, the intensity of the resulting composite image will be inconsistent with the original image. Furthermore, the inconsistencies in mean intensity level will likely vary from patch to patch. The resulting composite image will have a distracting blocky appearance.

[0065] To avoid this blocky appearance artefact, the spectral ratio may be normalised by dividing all pixels of the spectral ratio by the DC value of the spectral ratio, before raising it to the power N. This ensures that the mean intensity levels of the patches composing the final output image will be consistent and the resulting composite image will not have this blocky appearance.

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Noise reduction

[0066] Digital images are typically subject to imaging noise. The process of raising the spectral ratio to a power may tend to amplify the effects of noise. If noise perturbs the amplitude of a particular spatial frequency to a higher value in the spectral ratio, that noise will be enhanced when the spectral ratio is raised to a power, resulting in increased noise in the final image. It is therefore advantageous to apply one or more noise reduction steps to the processing.

[0067] In one implementation, the spectral ratio may be smoothed by a filtering process to remove outlying pixel values before raising to a power, for example using a block-based median filter, a Gaussian filter, or some other smoothing filter. A median filter may operate on complex numbers either by selecting real and imaginary parts independently and combining them to give a complex result, or by selecting a complex value by consideration of the modulus while ignoring the phase.

[0068] In another implementation, the spectral ratio may be modified by multiplying the pixel values by a weighting function, which varies from pixel to pixel, before raising to a power. Weights for the weighting operation are determined by the phases of the set of frequency domain pixel values. An example weighting function may be constructed by considering the complex phase value ϕ of each pixel in the spectral ratio. The complex phase ϕ of each pixel is an angular value which may be mapped on to the range $-\pi$ to $+\pi$ radians. An example weighting function $W(\phi)$ is then given by

$$W(\phi) = \left(\frac{\pi - |\phi|}{\pi} \right)^k \tag{10}$$

where k is a real number. Preferred values of k include 1, 2, and other positive integers. Such a weighting function reduces the amplitude of pixels in the spectral ratio in a manner such that pixels with absolute phase values closer to π have their amplitudes reduced by a greater amount than do pixels with absolute phase values closer to 0. Pixels with absolute phase values approaching π tend to correspond to spatial frequencies with little spectral energy in the original images, meaning the spectral ratio amplitude may be substantially adversely affected by imaging noise. Weighting such pixels with a small weighting value reduces their influence on the final

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image. Other weighting functions based on the phases of pixels of the spectral ratio may also be used.

[0069] In another implementation, the patches selected for processing may overlap, thus producing multiple potential values for output pixels in the final image. The value of each pixel in the final image may be calculated using some combination of the potential values produced by different overlapping patches, for example the mean or the median of the values.

[0070] In a further implementation, a combination of the above noise reduction methods may be used. The noise reduction methods provide a further advantage in that they allow better differentiation of blurring amount between objects at different depths than may appear in a single image patch. The use of overlapping patches in particular allows fine detail around the edges of in-focus objects to be rendered accurately.

Processing speed

[0071] To reduce the number of Fourier transforms required and speed up processing, the methods described above may be applied selectively to subregions of the input images. A main advantage of the methods is accuracy of artificial bokeh around the edges of object boundaries. In regions away from object boundaries, alternative methods may provide a speed advantage while not reducing the aesthetic quality of the final output image.

[0072] In one implementation, the input images may be segmented into "foreground" and "background" regions. This may be done, for example, by using a known DFD method to produce a depth map, then thresholding to produce a binary segmentation. The "foreground" region should contain objects close to the focal plane, while the "background" region should contain objects far from the focal plane. A "boundary" region may then be defined by selecting pixels within a predetermined distance from the segmentation edge between the foreground and background regions. The foreground region is left unblurred, the background region may be blurred using a large blur kernel, and the boundary region may be rendered using the artificial bokeh methods described above. The three regions may then be composited into a final output image. This provides for an advantageous combination of relatively computationally inexpensive processing for much of the image, with accurate rendering of edges around object boundaries.

Example 1

[0073] The arrangements presently disclosed may be implemented on a variety of hardware platforms, including in an imaging device such as a camera, or on a general purpose computer (PC), or in a cloud computing implementation. This example relates to a general purpose computing implementation.

[0074] Figs. 4A and 4B depict a general-purpose computer system 400, upon which the various arrangements described can be practiced.

[0075] As seen in Fig. 4A, the computer system 400 includes: a computer module 401; input devices such as a keyboard 402, a mouse pointer device 403, a scanner 426, a camera 427 (such as a compact camera 110), and a microphone 480; and output devices including a printer 415, a display device 414 and loudspeakers 417. An external Modulator-Demodulator (Modem) transceiver device 416 may be used by the computer module 401 for communicating to and from a communications network 420 via a connection 421. The communications network 420 may be a wide-area network (WAN), such as the Internet, a cellular telecommunications network, or a private WAN. Where the connection 421 is a telephone line, the modem 416 may be a traditional "dial-up" modem. Alternatively, where the connection 421 is a high capacity (e.g., cable) connection, the modem 416 may be a broadband modem. A wireless modem may also be used for wireless connection to the communications network 420.

[0076] The computer module 401 typically includes at least one processor unit 405, and a memory unit 406. For example, the memory unit 406 may have semiconductor random access memory (RAM) and semiconductor read only memory (ROM). The computer module 401 also includes an number of input/output (I/O) interfaces including: an audio-video interface 407 that couples to the video display 414, loudspeakers 417 and microphone 480; an I/O interface 413 that couples to the keyboard 402, mouse 403, scanner 426, camera 427 and optionally a joystick or other human interface device (not illustrated); and an interface 408 for the external modem 416 and printer 415. In some implementations, the modem 416 may be incorporated within the computer module 401, for example within the interface 408. The computer module 401 also has a local network interface 411, which permits coupling of the computer system 400 via a connection 423 to a local-area communications network 422, known as a Local Area Network (LAN). As illustrated in Fig. 4A, the local communications network 422 may also couple to the

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wide network 420 via a connection 424, which would typically include a so-called "firewall" device or device of similar functionality. The local network interface 411 may comprise an Ethernet™ circuit card, a Bluetooth™ wireless arrangement or an IEEE 802.11 wireless arrangement; however, numerous other types of interfaces may be practiced for the interface 411.

[0077] The I/O interfaces 408 and 413 may afford either or both of serial and parallel connectivity, the former typically being implemented according to the Universal Serial Bus (USB) standards and having corresponding USB connectors (not illustrated). Storage devices 409 are provided and typically include a hard disk drive (HDD) 410. Other storage devices such as a floppy disk drive and a magnetic tape drive (not illustrated) may also be used. An optical disk drive 412 is typically provided to act as a non-volatile source of data. Portable memory devices, such optical disks (e.g., CD-ROM, DVD, Blu-ray Disc™), USB-RAM, portable, external hard drives, and floppy disks, for example, may be used as appropriate sources of data to the system 400.

[0078] The components 405 to 413 of the computer module 401 typically communicate via an interconnected bus 404 and in a manner that results in a conventional mode of operation of the computer system 400 known to those in the relevant art. For example, the processor 405 is coupled to the system bus 404 using a connection 418. Likewise, the memory 406 and optical disk drive 412 are coupled to the system bus 404 by connections 419. Examples of computers on which the described arrangements can be practised include IBM-PC's and compatibles, Sun Sparcstations, Apple Mac™ or a like computer systems.

[0079] The methods of artificial bokeh rendering may be implemented using the computer system 400 wherein the artificial bokeh processes of Figs. 8 to 13, to be described, may be implemented as one or more software application programs 433 executable within the computer system 400. In particular, the steps of the method of artificial bokeh rendering are effected by instructions 431 (see Fig. 4B) in the software 433 that are carried out within the computer system 400. The software instructions 431 may be formed as one or more code modules, each for performing one or more particular tasks. The software may also be divided into two separate parts, in which a first part and the corresponding code modules performs the artificial bokeh rendering methods and a second part and the corresponding code modules manage a user interface between the first part and the user.

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[0080] The software may be stored in a computer readable medium, including the storage devices described below, for example. The software is loaded into the computer system 400 from the computer readable medium, and then executed by the computer system 400. A computer readable medium having such software or computer program recorded on the computer readable medium is a computer program product. The use of the computer program product in the computer system 400 preferably effects an advantageous apparatus for artificial bokeh rendering.

[0081] The software 433 is typically stored in the HDD 410 or the memory 406. The software is loaded into the computer system 400 from a computer readable medium, and executed by the computer system 400. Thus, for example, the software 433 may be stored on an optically readable disk storage medium (e.g., CD-ROM) 425 that is read by the optical disk drive 412. A computer readable medium having such software or computer program recorded on it is a computer program product. The use of the computer program product in the computer system 400 preferably effects an apparatus for artificial bokeh rendering.

[0082] In some instances, the application programs 433 may be supplied to the user encoded on one or more CD-ROMs 425 and read via the corresponding drive 412, or alternatively may be read by the user from the networks 420 or 422. Still further, the software can also be loaded into the computer system 400 from other computer readable media. Computer readable storage media refers to any non-transitory tangible storage medium that provides recorded instructions and/or data to the computer system 400 for execution and/or processing. Examples of such storage media include floppy disks, magnetic tape, CD-ROM, DVD, Blu-ray™ Disc, a hard disk drive, a ROM or integrated circuit, USB memory, a magneto-optical disk, or a computer readable card such as a PCMCIA card and the like, whether or not such devices are internal or external of the computer module 401. Examples of transitory or non-tangible computer readable transmission media that may also participate in the provision of software, application programs, instructions and/or data to the computer module 401 include radio or infra-red transmission channels as well as a network connection to another computer or networked device, and the Internet or Intranets including e-mail transmissions and information recorded on Websites and the like.

[0083] The second part of the application programs 433 and the corresponding code modules mentioned above may be executed to implement one or more graphical user interfaces (GUIs) to

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be rendered or otherwise represented upon the display 414. Through manipulation of typically the keyboard 402 and the mouse 403, a user of the computer system 400 and the application may manipulate the interface in a functionally adaptable manner to provide controlling commands and/or input to the applications associated with the GUI(s). Other forms of functionally adaptable user interfaces may also be implemented, such as an audio interface utilizing speech prompts output via the loudspeakers 417 and user voice commands input via the microphone 480.

[0084] Fig. 4B is a detailed schematic block diagram of the processor 405 and a "memory" 434. The memory 434 represents a logical aggregation of all the memory modules (including the HDD 409 and semiconductor memory 406) that can be accessed by the computer module 401 in Fig. 4A.

[0085] When the computer module 401 is initially powered up, a power-on self-test (POST) program 450 executes. The POST program 450 is typically stored in a ROM 449 of the semiconductor memory 406 of Fig. 4A. A hardware device such as the ROM 449 storing software is sometimes referred to as firmware. The POST program 450 examines hardware within the computer module 401 to ensure proper functioning and typically checks the processor 405, the memory 434 (1409, 406), and a basic input-output systems software (BIOS) module 451, also typically stored in the ROM 449, for correct operation. Once the POST program 450 has run successfully, the BIOS 451 activates the hard disk drive 410 of Fig. 4A. Activation of the hard disk drive 410 causes a bootstrap loader program 452 that is resident on the hard disk drive 410 to execute via the processor 405. This loads an operating system 453 into the RAM memory 406, upon which the operating system 453 commences operation. The operating system 453 is a system level application, executable by the processor 405, to fulfil various high level functions, including processor management, memory management, device management, storage management, software application interface, and generic user interface.

[0086] The operating system 453 manages the memory 434 (1409, 406) to ensure that each process or application running on the computer module 401 has sufficient memory in which to execute without colliding with memory allocated to another process. Furthermore, the different types of memory available in the system 400 of Fig. 4A must be used properly so that each process can run effectively. Accordingly, the aggregated memory 434 is not intended to illustrate how particular segments of memory are allocated (unless otherwise stated), but rather

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to provide a general view of the memory accessible by the computer system 400 and how such is used.

[0087] As shown in Fig. 4B, the processor 405 includes a number of functional modules including a control unit 439, an arithmetic logic unit (ALU) 440, and a local or internal memory 448, sometimes called a cache memory. The cache memory 448 typically includes a number of storage registers 444 - 446 in a register section. One or more internal busses 441 functionally interconnect these functional modules. The processor 405 typically also has one or more interfaces 442 for communicating with external devices via the system bus 404, using a connection 418. The memory 434 is coupled to the bus 404 using a connection 419.

[0088] The application program 433 includes a sequence of instructions 431 that may include conditional branch and loop instructions. The program 433 may also include data 432 which is used in execution of the program 433. The instructions 431 and the data 432 are stored in memory locations 428, 429, 430 and 435, 436, 437, respectively. Depending upon the relative size of the instructions 431 and the memory locations 428- 430, a particular instruction may be stored in a single memory location as depicted by the instruction shown in the memory location 430. Alternately, an instruction may be segmented into a number of parts each of which is stored in a separate memory location, as depicted by the instruction segments shown in the memory locations 428 and 429.

[0089] In general, the processor 405 is given a set of instructions which are executed therein. The processor 405 waits for a subsequent input, to which the processor 405 reacts to by executing another set of instructions. Each input may be provided from one or more of a number of sources, including data generated by one or more of the input devices 402, 403, data received from an external source across one of the networks 420, 422, data retrieved from one of the storage devices 406, 409 or data retrieved from a storage medium 425 inserted into the corresponding reader 412, all depicted in Fig. 4A. The execution of a set of the instructions may in some cases result in output of data. Execution may also involve storing data or variables to the memory 434.

[0090] The disclosed artificial bokeh rendering arrangements use input variables 454, which are stored in the memory 434 in corresponding memory locations 455, 456, 457. The arrangements produce output variables 461, which are stored in the memory 434 in corresponding memory

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locations 462, 463, 464. Intermediate variables 458 may be stored in memory locations 459, 460, 466 and 467.

[0091] Referring to the processor 405 of Fig. 4B, the registers 444, 445, 446, the arithmetic logic unit (ALU) 440, and the control unit 439 work together to perform sequences of micro-operations needed to perform "fetch, decode, and execute" cycles for every instruction in the instruction set making up the program 433. Each fetch, decode, and execute cycle comprises:

(a) a fetch operation, which fetches or reads an instruction 431 from a memory location 428, 429, 430;

(b) a decode operation in which the control unit 439 determines which instruction has been fetched; and

(c) an execute operation in which the control unit 439 and/or the ALU 440 execute the instruction.

[0092] Thereafter, a further fetch, decode, and execute cycle for the next instruction may be executed. Similarly, a store cycle may be performed by which the control unit 439 stores or writes a value to a memory location 432.

[0093] Each step or sub-process in the processes of Figs. 8 to 13 is associated with one or more segments of the program 433 and is performed by the register section 444, 445, 447, the ALU 440, and the control unit 439 in the processor 405 working together to perform the fetch, decode, and execute cycles for every instruction in the instruction set for the noted segments of the program 433.

[0094] The method of artificial bokeh techniques may alternatively be implemented in whole or part in dedicated hardware such as one or more integrated circuits performing the functions or sub functions to be described. Such dedicated hardware may include graphic processors, digital signal processors, or one or more microprocessors and associated memories.

[0095] In another example, a camera may implement the artificial bokeh algorithmic processes to be described in hardware or firmware in order to capture pairs of images with different camera parameters and to process the captured images to provide images with artificial bokeh. In this case, the camera hardware can include a capture mechanism to capture multiple images of a scene. Where the images are suitable for application of artificial bokeh processing,

processing can occur in the embedded processor devices of the camera, and results would be retained in a memory of the camera or written to a memory card or other memory storage device connectable to the camera. The embedded devices may be generally equivalent in function to the processor 405 of the computer 401.

[0096] The capture of multiple images of a scene with different capture parameters may be performed by capturing multiple images with a single user operation (a single depression of a capture button of the camera 427) which causes one image to be captured and stored in a memory of the camera, the parameter to be changed, for example the focus of the lens 110 being changed, and a further image to be then captured and stored in the camera memory. Such capturing may occur within approximately 0.001 – 1.0 seconds causing both images to include substantially the same if not identical content and thus substantial common image content upon which artificial bokeh rendering may then be performed.

[0097] In another example, a desktop computer or the like may implement the artificial bokeh processing in software to enable post-capture processing of photos to generate artificial bokeh, which a user can use for image segmentation or further image processing operations. In this case, the camera 427 would capture multiple images of a scene in a traditional fashion, the images being suitable for application of the artificial bokeh process, and the images would be retained in memory or written to a memory card or other memory storage device. At a later time, the images would be transferred to the computer (e.g. 401), where subsequent steps of the artificial bokeh process would use them as input.

[0098] In yet another example, a cloud computing server or the like may implement the artificial bokeh processing in software to enable post-capture processing of photos to generate artificial bokeh. In this case, the camera 427 would capture multiple images of a scene in a traditional fashion, but with different capture parameters. The images would be uploaded to a cloud computing server, where subsequent steps of the artificial bokeh process would receive and use them as input. The cloud computing server would produce the artificial bokeh images and may then download them back to the camera, or store them for later retrieval by the user.

[0099] Other implementations may capture two images with different camera parameters, the varying parameters being one or more of: focus, zoom, aperture, or any other camera setting that influences the amount of blur in the captured image. In the case of some parameters, such as

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zoom in particular but also focus and potentially other parameters, the magnification of the captured images may be different. In this case one or more of the images may be scaled to bring the images substantially into registration before applying the artificial bokeh algorithm to render an artificial bokeh image.

[00100] Figs. 5A and 5B illustrate a first pair of exemplary images 501 and 502 respectively upon which the artificial bokeh processing may be performed. The scene content captured by the images 501 and 502 is identical, but the images 501 and 502 capture different image content in view of the image 502 being captured with at least one camera parameter different to the capture of image 501. For example, image 502 may be differently focused relative to the image 501.

[00101] Figs. 5A and 5C illustrate a second pair of exemplary images 501 and 503 respectively upon which artificial bokeh processing may also be performed. The scene content captured by the images 501 and 503 is not identical in total content, however the images 501 and 503 capture a scene that is common, or includes common scene content, to both images. That common scene content is indicated by dashed rectangles 511 and 513 in Figs 5A and 5C respectively and shows a person standing adjacent to a tree. The common scene content may appear at different positions within the images 501 and 503. The differences in position of the common scene content between the images 501 and 503 may result from, for example, slight camera movement between capture of the two images. The image content of images 501 and 503 within the regions 511 and 513 capturing common scene content may further be different in view of image 503 being captured with at least one camera parameter different to the capture of image 501. For example, image 503 may be differently focused relative to image 501.

[00102] Significantly, in each of Figs. 5A – 5C, a common part of the scene content (being the person adjacent the tree) is captured in each image. Artificial bokeh processing may therefore be performed on pairs of the images to determine a rendered artificial bokeh image for the common part. Note that Figs. 5B and 5C may also represent an image pair upon which artificial bokeh processing may be performed.

[00103] Certain implementations may capture more than two images, with one or more pairs of the images used to render artificial bokeh images using the presently disclosed artificial bokeh algorithm.

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[00104] A method of producing an artificial bokeh image from two images of a scene will now be described in detail with reference to Fig. 6 and Fig. 7 and the arrangements of Fig. 4A and 4B where substantive processing occurs within the computer 401. Fig. 6 illustrates a first image 600 of a scene and a second image 610 of the same scene (not illustrated). A selected pixel 620 in the first image 600 is highlighted and a corresponding selected pixel 630 in the second image 610 is highlighted. The correspondence is such that the selected pixel 620 in the first image 600 and the selected pixel 630 in the second image 610 largely correspond to the same point in the scene being imaged. This may be achieved in practice by ensuring that no objects in the scene move in the time between the exposures used to capture the first image 600 and the second image 610 and also that the camera 427 which captures the images 600 and 610 does not move in the time between the exposures, and then selecting pixels from the same (x, y) coordinates on the image sensor. It may also be achieved by an alignment process which explicitly determines which pixels in the first image 600 correspond to pixels in the second image 610. This alignment may address issues such as motion of objects within the scene between the two exposures, motion of the camera 427 between the two exposures, and changes in the magnification or distortion or both between the two exposures. The alignment may be global across the entire images 600 and 610, local within subregions of the images 600 and 610, or both. Many such alignment processes are known to those skilled in the art.

[00105] Also shown in Fig. 6 are two image patches, which are subsets of the pixels in each image. The first image patch 640 is from the first image 600 and is referred to as f_1. The second image patch 650 is from the second image 610 and is referred to as f_2. The first patch f_1 640 is defined with reference to the first selected pixel 620 in the first image 600 such that the first selected pixel 620 occurs at coordinates (x_1, y_1) with respect to a pixel 642 at the upper left corner of the first patch f_1 640. The second patch f_2 650 is defined with reference to the selected pixel 630 in the second image 610 such that the selected pixel 630 occurs at coordinates (x_2, y_2) with respect to a pixel 652 at the upper left corner of the second patch f_2 650, where $(x_2, y_2) = (x_1, y_1)$. In alternative implementations it may be the case that $(x_2, y_2) \neq (x_1, y_1)$. The patches should be the same size to ensure appropriate comparison of image content contained therein.

[00106] Returning to Figs. 5A to 5C, the patches may be formed by simple division of the images or parts of the images into blocks. In the example of the image pair 501 and 502 shown in Figs. 5A and 5B respectively, the image content is sufficiently aligned that the patches may be formed

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by dividing the images into a 4×4 configuration of blocks. In the example of the image pair 501 and 503 shown in Figs. 5A and 5C respectively, the regions 511 and 513 showing common scene content may be divided into patches in a similar blockwise manner (not illustrated). Alternatively, the patches may be formed in a manner such that the patches vary in size across the images.

[00107] Fig. 7 illustrates an artificial bokeh process 700 in which an artificial bokeh rendered image 775 is determined. The process 700 operates to modify the blur in at least part of an image of a scene. In an image capture step 710, two images 600 and 610 of a scene are captured by an image capture device 100, such as the camera 427. The images 600 and 610 should include image content of a common part of the scene content. For example, with reference to Fig. 1 the common part could be the object 140. In Figs. 5A and 5C the common part is the person next to the tree, whereas in Figs. 5A and 5B, the common part is the entirety of the images. The images are captured with at least one of the camera parameters of focus, aperture, zoom, or some other parameter that influences the amount of blur in the image being different, so that the amount of blur is different between the images. Ideally the images are captured such that any motion of the objects in the scene and any relative motion of the camera 427 with respect to the scene is minimised. For example, with reference to Figs. 5A and 5C, which are representative of such relative motion, an alignment process may be performed on the two images to provide that the common parts as found in each image are appropriately aligned prior to artificial bokeh processing. This may involve, for example, aligning the image data within the rectangles 511 and 513 with each other, or cropping the images to those rectangles.

[00108] A specific implementation of the image capture step 710 is described in more detail below with reference to Fig. 8. Typically the images 600 and 610 are captured by the camera 427 and communicated to and received by the computer 401 for storage in one or both of the HDD 410 and memory 406. Where the process 700 is performed within the camera 427, the images 600 and 610 are stored in a memory of the camera 427 for subsequent processing by an embedded processor thereof.

[00109] Steps 720 – 780 of the process 700 may be preferably embodied in and implemented by an embedded processor in the camera 427. Steps 720 – 780 of the process 700 in the present implementation are embodied in and implemented by software, for example stored on the HDD 410 and executable by the processor 405 in concert with the memory 406. In a patch selection

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step 720 which follows the capture step 710, the corresponding patches f_1 640 and f_2 650 of the two images 600 and 610 are selected and received by the processor 405 from the memory 406.

[00110] In an asymmetric patch selection step 740 which then follows, a determination is made regarding which of the patches f_1 or f_2 is the less blurred patch of the two. Details of a specific implementation of the asymmetric patch selection step 740 will be described below with reference to Fig. 9.

[00111] An artificial bokeh rendering step 750 is then performed in which an artificial bokeh patch $f_{(N)}$ is determined by the processor 405 processing the pixel data in the first patch f_1 640 and the second patch f_2 650. In practice, the artificial bokeh rendering step 750 may be performed multiple times iteratively for many different pairs of input patches f_1 and f_2, thus producing a set $S\{f_{(N)}\}$ of artificial bokeh patches $f_{(N)}$, each artificial bokeh patch associated with specific input patches f_1 and f_2. The artificial bokeh patches are typically stored in the memory 406. The details of an implementation of the artificial bokeh rendering step 750 will be described below with reference to Fig. 10.

[00112] A patch decision step 760 then follows where a decision is made by the processor 405 on whether there remain any patches in the first image 600 and the second image 610 that have not yet been selected in the patch selection step 720. If there remain patches that have not yet been selected, the artificial bokeh process 700 returns to the patch selection step 720. In practice, the patches may be selected in a systematic order such as by iterating along the rows and down the columns of the first image f_1 600. Accordingly, the steps 720-760 proceed for a current patch of all the patches desired to be processed for artificial bokeh purposes. Each current patch represents a current part of the common part of the scene captured by the images. In some instances, for example the image pair of Figs. 5A and 5B, because all is common, image patches may span the entirety of the images. In an alternative approach, only a subset of the first image f_1 600 may be chosen to be selected, for example by the processor 405 selecting a subset of pixels of the first image f_1 600 to avoid any of the resulting patches from covering areas outside the images, thus avoiding any edge effects. In another alternative, a subset of pixels of the first image f_1 600 may be chosen to be selected by some other means. Once all required patches have been selected ('NO' in step 760), the artificial bokeh process 700 continues to an assembly step 770.

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[00113] In the assembly step 770, the artificial bokeh rendered patches calculated in the artificial bokeh rendering step 750 are assembled by the processor 405 to produce an artificial bokeh rendering of the scene captured by the image capture device 100. Such reveals an artificial bokeh image 775 that may be stored by the processor 405 in the memory 406 or HDD 410, and/or reproduced upon the video display 414 or by the printer 415. The details of an implementation of the assembly step 770 will be described below with reference to Fig. 11.

[00114] The artificial bokeh process 700 then ends at end step 780.

Image capture

[00115] One example of the image capture step 710 will now be described with reference to Fig. 8. In a camera set up step 810, the image capture device (camera 427) is aimed at the desired scene. This can be done for example by aiming a hand-held camera, or by setting up a camera on a tripod.

[00116] In a camera setting step 820, various settings associated with the image capture device are set. This refers to settings that have some effect on the amount of blur recorded in the image and includes setting the lens focus position, the zoom position of the lens if it is capable of zooming, and the aperture of the lens. Other image capture device settings which change the amount of blur in the image are possible. These settings may be performed manually by the operator, or automatically by control software executing within the camera based on the scene to be captured.

[00117] A first image taking step 830 then follows, where a (first) image of the scene is captured using the settings set in the camera setting step 820.

[00118] A camera setting change step 840 follows where the settings of the image capture device are changed from the values set in the camera setting step 820. This may involve changing one or more of: the lens focus position, the lens zoom position, the lens aperture setting, and any other setting which affects the amount of blur recorded in the image. This change may be performed manually or by the camera control software.

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[00119] In a second image taking step 850, a (second) image of the scene is captured using the settings set in the camera setting change step 840. The image capture process 710 then ends at end step 870.

[00120] In one implementation, the first image taking step 830, the camera setting change step 840, and the second image taking step 850 are performed automatically by the image capture device 100 in response to a single activation of an image capture function of the device 100, for example pressing the shutter button on a camera.

Asymmetric patch selection

[00121] One implementation of the asymmetric patch selection step 740 will now be described with reference to Fig. 9. The asymmetric patch selection process 740 begins with the first image patch f_1 620 and the second image patch f_2 640 as data inputs.

[00122] In a first variance calculation step 910, the variance σ_1^2 of the pixel values in the patch f_1 620 is calculated, using the well-known definition of variance. In a second variance calculation step 920, the variance σ_2^2 of the pixel values in the patch f_2 640 is calculated.

[00123] In a variance comparison step 930, the variance σ_1^2 of the pixel values in patch f_1 620 is compared to the variance σ_2^2 of the pixel values in patch f_2 640. If the variance σ_1^2 of the pixel values in patch f_1 620 is greater than or equal to the variance σ_2^2 of the pixel values in patch f_2 640, processing continues with a first patch selection step 940. On the other hand, if the variance σ_1^2 of the pixel values in patch f_1 620 is less than the variance σ_2^2 of the pixel values in patch f_2 640, processing continues to a second patch selection step 945.

[00124] In the first patch selection step 940, patch f_1 is selected as the less blurred patch. In the second patch selection step 945, patch f_2 is selected as the less blurred patch. The asymmetric patch selection process 740 then ends at end step 950.

[00125] Other approaches to performing the asymmetric patch selection step 740 are possible. For example, the patches may first be smoothed using a filter to reduce the effects of outlying pixel values caused by imaging noise. The variances of the filtered patches may then be calculated, and the patch with the highest variance after filtering may then be selected as the less

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blurred patch. In another example, a two-dimensional gradient operator, such as the Laplacian operator, may be applied to the patches, and then the patch with the greatest range of pixel values (*i.e.* maximum pixel value minus minimum pixel value) in the Laplacian gradient image may be selected as the less blurred patch. In another example, it may be known that the two images 600 and 610 were captured with the aperture value being the only parameter changed between the captures, in which case the patch from the image captured with the narrower aperture may simply be selected as the less blurred patch.

Artificial bokeh rendering

[00126] One implementation of the artificial bokeh rendering step 750 will now be described with reference to Fig. 10. The artificial bokeh rendering process 750 begins with the image patch f_1 620 and the image patch f_2 640 as data inputs. In a Fourier transform step 1010, the patches f_1 and f_2 are Fourier transformed, for example using a Fast Fourier Transform (FFT) algorithm, to form Fourier transformed patches F_1 and F_2 respectively. The Fourier transformed image patches F_1 and F_2 will contain complex number values at each pixel.

[00127] A first blur determination step 1020 follows where reference is made to which of the patches f_1 or f_2 was selected as the less blurred patch in asymmetric patch selection step 740. If the image patch f_1 620 was selected as the less blurred patch, the artificial bokeh rendering process 750 continues to a first spectral ratio step 1030a. On the other hand, if the image patch f_2 630 was selected as the less blurred patch, the artificial bokeh rendering process 750 continues to a second spectral ratio step 1030b.

[00128] In the first spectral ratio step 1030a, the Fourier transformed patches F_1 and F_2 are divided pixel-wise to form the spectral ratio image patch F_2/F_1, using complex number division. In the second spectral ratio step 1030b, the Fourier transformed patches F_1 and F_2 are divided pixel-wise to form the spectral ratio image patch F_1/F_2, using complex number division. In both of the spectral ratio steps 1030a and 1030b, the Fourier transformed patch in the denominator of the formed ratio is the Fourier transformed patch of the image patch determined to be the least blurred. As such, a combination of data from the first and second patches is used to calculate at least one Fourier transform value which in turn is based on the determination in the asymmetric patch selection step 740 of which of the patches is the more focussed image patch.

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[00129] In a modification step 1040, the spectral ratio formed in step 1030a or step 1030b is modified by a normalisation process, by dividing by the value of the DC pixel of the spectral ratio, forming a normalised spectral ratio. In a variation of the modification step 1040, the spectral ratio is first filtered with a smoothing filter to remove outlying pixel values, before dividing by the value of the DC pixel of the smoothed spectral ratio to achieve the normalisation. The smoothing filter may be a median filter, a Gaussian filter, or some other filter. In another variation of the modification step 1040, the spectral ratio is weighted on a per-pixel basis by multiplication by a weighting function determined by the values of the complex phases of the pixels of the spectral ratio, before dividing by the value of the DC pixel of the weighted spectral ratio to achieve the normalisation.

[00130] A result of steps 1010 – 1040 is the calculation of a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches.

[00131] In an exponentiation step 1050, the normalised spectral ratio is raised to a predetermined power N, in a pixelwise fashion, using complex arithmetic, forming an amplified spectral ratio.

[00132] A second blur determination step 1060 follows where reference is made to which of the patches f_1 or f_2 was selected as the less blurred patch in asymmetric patch selection step 740. If the image patch f_1 620 was selected as the less blurred patch, the artificial bokeh rendering process 750 continues to a first multiplication step 1070a. On the other hand, if the image patch f_2 630 was selected as the less blurred patch, the artificial bokeh rendering process 750 continues to a second multiplication step 1070b.

[00133] In the first multiplication step 1070a, the amplified spectral ratio is multiplied by the Fourier transform F_1 of patch f_1, forming the Fourier domain patch $F_{(N)}$. In the second multiplication step 1070b, the amplified spectral ratio is multiplied by the Fourier transform F_2 of patch f_2, forming the Fourier domain patch $F_{(N)}$.

[00134] In an inverse transform step 1080, the Fourier domain patch $F_{(N)}$ is inverse Fourier transformed, for example using an FFT algorithm, to form the artificial bokeh patch $f_{(N)}$ 1085.

[00135] The artificial bokeh rendering process 750 then ends at end step 1090.

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[00136] In a preferred implementation, the patch 1085 contains pixels with blur modified with respect to the initial amount of blur in the image patch, in which the amount of modification with respect to blur varies across different regions of the image patch.

[00137] Specifically, the input pair of image patches f_1 and f_2 will in general contain pixels representing various different objects or parts of objects within the scene. These objects or parts of objects will in general be at differing distances from the camera. The processing steps of the artificial bokeh rendering process 750 described above, when applied to a single pair of input patches, will produce an artificial bokeh patch 1085 in which the objects at differing distances from the camera are blurred by different amounts, according to the theory described in the section "Application to artificial bokeh" above.

Image assembly

[00138] The artificial bokeh patches are desirably assembled into an image such that there is a geometric correspondence between the patch locations of each patch selected in the patch selection step 720 and the corresponding artificial bokeh patches that are calculated from those patches in the artificial bokeh rendering step 750. For example, if the first image 600 is 100 × 100 pixels and patches of 10 × 10 pixels are selected by iterating adjoining patches across rows and down columns, then the consecutive artificial bokeh rendered patches can be assembled by tiling them into an image 100 × 100 pixels in size by inserting the rendered patches into successive 10 × 10 blocks of pixels, iterating across rows and down columns. In general, the image assembly step 770 may be more complex than this, and is described below.

[00139] One implementation of the image assembly step 770 will now be described with reference to Fig. 11. The input to the image assembly process is the set $S\{f_{(N)}\}$ of all of the artificial bokeh patches $f_{(N)}$ produced by the iterations of the artificial bokeh step 750.

[00140] The image assembly process begins with an output image formation step 1110, in which an output image is formed, ready to hold pixel values of the artificial bokeh image. The output image is preferably an image of pixel size equal to the input images captured in image capture step 710. The output image may alternatively be of a different size to the input images, such as with a number of pixels trimmed from the borders. The pixel coordinates (x_o, y_o) of the output image are related to the pixel coordinates (x_{ik}, y_{ik}) of the kth input image by a relation

$$(x_o, y_o) + (n_{xk}, n_{yk}) = (x_{ik}, y_{ik}) \tag{10}$$

for some fixed pair of integers (n_{xk}, n_{yk}). If there is no shift between the input images, then (n_{xk}, n_{yk}) is the same for all k input images, but this may not be true in the case when there is motion shift between the input images.

[00141] In a pixel selection step 1120, a pixel p_o of the output image is selected, with coordinates (x_o, y_o). The selected pixel p_o is a pixel that has not previously been selected by an earlier iteration of step 1120. In practice, all of the pixels in the output image may be selected in successive iterations of step 1120 by iterating across rows and down columns. Pixels p_{ik} in each of the input images are defined with respect to p_o by equation (10).

[00142] In a patch determining step 1130, it is determined which artificial bokeh patches $f_{(N)}$ from the set of patches $S\{f_{(N)}\}$ calculated in artificial bokeh rendering step 750 were calculated using input patches containing the pixels p_{ik} corresponding to the output image pixel p_o selected in pixel selection step 1120. In other words, which of the patches $f_{(N)}$ were calculated from patches f_1 and f_2 of the original images which contain the pixels p_{ik} with coordinates (x_{ik}, y_{ik}) satisfying equation (10). The patches $f_{(N)}$ that are determined to satisfy this condition are placed in a subset $T\{f_{(N)}\}$ of patches.

[00143] In a patch counting step 1140, a decision is made based on whether the subset $T\{f_{(N)}\}$ of patches determined in patch determining step 1130 contains more than one patch. If the subset $T\{f_{(N)}\}$ contains exactly one patch, processing continues with a first output calculation step 1150a. Alternatively, if the subset $T\{f_{(N)}\}$ contains more than one patch, processing continues with a second output calculation step 1150b. The case where the subset $T\{f_{(N)}\}$ contains no patches should not occur if the output image formed in output image formation step 1110 is sized appropriately.

[00144] In the first output calculation step 1150a, the output pixel p_o is assigned the value of the corresponding pixel from the patch $f_{(N)}$ which is the only member of the subset $T\{f_{(N)}\}$ of patches determined in patch determining step 1130. The correspondence is determined with reference to the input image patches f_1 and f_2 of the original images and equation (10).

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[00145] In the second output calculation step 1150b, the output pixel p_o is assigned a value calculated from the values of the corresponding pixels p^T from each of the patches $f_{(N)}$ which are members of the subset $T\{f_{(N)}\}$ of patches determined in patch determining step 1130. The correspondence is determined with reference to the input image patches f_1 and f_2 of the original images and equation (10). The value of the pixel p_o may be assigned by some mathematical combination of the values of the pixels p^T, for example the mean of the values of the pixels p^T. In an alternative implementation, the value of the pixel p_o may be assigned the median of the values of the pixels p^T. In another alternative implementation, the value of the pixel p_o may be assigned the mean or median of a subset of the values of the pixels p^T after some values are rejected as outliers by some statistical method.

[00146] In a pixel decision step 1160, a decision is made based on whether there are more pixels remaining in the output image that have not yet been assigned values by either the first output calculation step 1150a or the second output calculation step 1150b. If more pixels remain to be assigned values, processing returns to the pixel selection step 1120. If no more pixels remain to be assigned values, the image assembly process 770 terminates at the end step 1170.

Example 2

[00147] Fig. 12 illustrates an artificial bokeh process 1200 in which an artificial bokeh rendered image is determined. In an image capture step 1210, two images 600 and 610 of a scene are captured by an image capture device 100, such as the camera 427. The images 600 and 610 should include image content of a common part of the scene content, as described previously. A specific implementation of the image capture step 1210 is the method 710 described above with reference to Fig. 8.

[00148] Steps 1220 – 1290 of the process 1200 are preferably embodied in and implemented by an embedded processor in the camera 427. Steps 1220 – 1290 of the process 1200 may also be embodied in and implemented by software, for example stored on the HDD 410 and executable by the processor 405 in concert with the memory 406.

[00149] In a segmentation step 1220, at least one of the two images 600 and 610 are segmented into foreground and background regions, preferably such that the foreground region generally comprises image regions corresponding to objects close to the focal plane, while the background

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region generally comprises image regions corresponding to objects far from the focal plane. Note that the background region can include image regions between the focal plane and the camera (in the relatively extreme foreground), as well as those beyond the focal plane. In this regard, 'background' is intended to cover those objects or regions of the captured image that are not the subject of the photograph. Typically this includes ordinary background objects, but can include near foreground objects. For example, the images may be segmented by applying a DFD algorithm to the images to produce a depth map, followed by thresholding the resulting depth map to produce a binary segmentation. Several such binary depth segmentation methods are known in the art, though they often have poor accuracy around the object boundaries.

[00150] In a boundary determination step 1230, a boundary region between the foreground and background regions is determined. For example, the boundary region may be determined by selecting all pixels within a predetermined radius r of the segmentation edge between the foreground and background regions. Preferably, the radius r is a size close to the maximum expected error in the location of the boundary between the foreground and background regions produced in segmentation step 1220, in pixels, plus the size of the patches used in steps 1240 – 1280. The boundary region should separate the foreground and background regions, and may be disjoint if there are several objects in the images.

[00151] In a patch selection step 1240, the corresponding patches f_1 640 and f_2 650 of the two images 600 and 610 are selected and received by the processor 405 from the memory 406. In this implementation, the selected patches f_1 640 and f_2 650 need only cover the boundary region determined in step 1230. Patches which do not contain pixels in the boundary region are not selected.

[00152] In an asymmetric patch selection step 1250 which then follows, a determination is made regarding which of the patches f_1 or f_2 is the less blurred patch of the two. Details of a specific implementation of the asymmetric patch selection step 1250 are described above with reference to the method 740 of Fig. 9.

[00153] An artificial bokeh rendering step 1260 is then performed in which an artificial bokeh patch $f_{(N)}$ is determined by the processor 405 processing the pixel data in the first patch f_1 640 and the second patch f_2 650. In practice, the artificial bokeh rendering step 1260 may be performed multiple times iteratively for many different pairs of input patches f_1 and f_2, thus

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producing a set $S\{f_{(N)}\}$ of artificial bokeh patches $f_{(N)}$, each artificial bokeh patch associated with specific input patches f_1 and f_2. The artificial bokeh patches are typically stored in the memory 406. The details of an exemplary implementation of the artificial bokeh rendering step 1260 are described above with reference to the method 750 of Fig. 10.

[00154] A patch decision step 1270 then follows where a decision is made by the processor 405 on whether there remain any patches in the first image 600 and the second image 610 which include pixels in the boundary region determined in step 1230, and that have not yet been selected in the patch selection step 1240. If there remain patches that have not yet been selected, the artificial bokeh process 1200 returns to the patch selection step 1240. Accordingly, the steps 1250-1270 proceed for a current patch of all the patches which contain pixels in the boundary region. Once all required patches have been selected ('NO' in step 1270), the artificial bokeh process 1200 continues to an assembly step 1280.

[00155] In the assembly step 1280, the artificial bokeh rendered patches calculated in the artificial bokeh rendering step 1260 are assembled by the processor 405 to produce an artificial bokeh rendering 1285 of the boundary region determined in step 1230. The details of an exemplary implementation of the assembly step 1280 are described above with reference to the method 770 of Fig. 11, noting that the assembly 1280 produces pixels only within the boundary region.

[00156] In a composite image step 1290, the artificial bokeh rendering 1285 assembled in step 1280 is combined with the foreground and background regions determined in step 1220 to form a composite rendered image 1292. Before combination, the background region may be blurred by convolution with a blur kernel. The foreground, blurred background, and artificial bokeh rendered boundary regions are then composited to produce a single image 1292. Such reveals an artificial bokeh image that may be stored by the processor 405 in the memory 406 or HDD 410.

[00157] The artificial bokeh process 1200 then ends at end step 1295.

Variations and User Cases

[00158] Many variations of the processes of Figs. 7, 8, 9, 10, 11, and 12 may be performed. For example, the processes may be applied to different colour channels of the input image patches, thereby calculating separate artificial bokeh images for each colour channel, which may then be combined, for example using demosaicing algorithms known to those skilled in the art, to produce a colour artificial bokeh image.

[00159] In another variation, the processes may be applied to a luminance channel and colour difference channels of the input image patches, thereby calculating separate artificial bokeh images for the luminance channel and colour difference channels, which may then be combined to produce a colour artificial bokeh image.

[00160] In another variation, the processes may be applied to a luminance channel of the input image patches, thereby calculating an artificial bokeh images for the luminance channel, which may then be combined with unprocessed colour difference channels to produce a colour artificial bokeh image.

[00161] In another variation, multiple artificial bokeh pixel values may be calculated from each pair of input image patches by using different variations of the processes. Then final pixel values may be obtained from the multiple values, averaged or combined in some other manner, or selected from using some selection criterion, to give a final output artificial bokeh image.

INDUSTRIAL APPLICABILITY

[00162] The arrangements described are applicable to the computer and data processing industries and particularly for the processing of images captured by cameras having a large depth of field, to thereby emulate capture by a camera having a narrow depth of field. The arrangements disclosed therefore have specific utility in the processing of images captured by so-called "compact' digital cameras, and operate to amplify any bokeh present in the captured images. This bokeh amplification can make a compact camera emulate an SLR camera.

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[00163] The foregoing describes only some embodiments of the present invention, and modifications and/or changes can be made thereto without departing from the scope and spirit of the invention, the embodiments being illustrative and not restrictive.

[00164] ***(Australia Only)*** In the context of this specification, the word "comprising" means "including principally but not necessarily solely" or "having" or "including", and not "consisting only of". Variations of the word "comprising", such as "comprise" and "comprises", have correspondingly varied meanings.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of modifying the blur in at least a part of an image of a scene, said method comprising:

capturing at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images;

selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur;

calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches;

raising each of the pixel values in the set of frequency domain pixel values to a predetermined power (1050), thereby forming an amplified set of frequency domain pixel values; and

combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

2. A method according to claim 1, wherein the set of frequency domain pixel values are modified before being raised to the predetermined power.

3. A method according to claim 2, wherein the modification includes a median filtering operation.

4. A method according to claim 2, wherein the modification includes a smoothing filtering operation.

5. A method according to claim 2, wherein the modification includes a normalisation operation.

6. A method according to claim 2, wherein the modification includes a weighting operation.

7. A method according to claim 6, wherein weights for the weighting operation are determined by the phases of the set of frequency domain pixel values.

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8. A method according to claim 1, wherein:

the at least two images of the scene are divided into a plurality of corresponding image patches in each of the captured images; and

the output image patches are combined to produce an output image.

9. A method according to claim 8, wherein the plurality of corresponding image patches in each of the captured images form a tiling substantially covering the area of the captured images, and the output image is formed by tiling the output image patches.

10. A method according to claim 8, wherein the plurality of corresponding image patches in each of the captured images overlap, and the output image is formed by combining the pixel values of the output image patches.

11. A method according to claim 8, wherein:

the plurality of corresponding image patches in each of the captured images cover part of the area of the captured images; and

the output image patches are combined with the area of at least one of the captured images not covered by the plurality of corresponding image patches to produce an output image.

12. A method according to claim 11, wherein at least part of the area of the at least one of the captured images not covered by the plurality of corresponding image patches is blurred by convolution with a blur kernel.

13. A camera comprising an image capture system coupled to memory in which captured images are stored, a processor, and a program executable by the processor to modify the blur in at least a part of an image of a scene, said program comprising:

code for causing the capture system to capture at least two images of the scene, said images being captured with different camera parameters (820,840) to produce a different amount of blur in each of the captured images;

code for selecting a corresponding image patch (642,652) in each of the captured images, each of the selected image patches having an initial amount of blur;

code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches;

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code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and

code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

14. A camera system comprising:

a lens formed of optics producing a relatively large depth of field;

a sensor configured capture an image of a scene focussed through the lens;

a memory in which images captured by the sensor are stored;

a capture mechanism configured to capture at least two images of the scene with different capture parameters and to store the images in the memory;

a processor;

a program stored in the memory and executable by the processor to modify blur in at least a part of one of the captured images of the scene, said program comprising:

code for causing the capture system to capture at least two images of the scene with different camera parameters (820,840) to produce a different amount of blur in each of the captured images;

code for selecting a corresponding image patch (642,652) in each of the captured images, each of the selected image patches having an initial amount of blur;

code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches;

code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and

code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

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15. A computer readable storage medium having a program recorded thereon, the program being executable by a processor to modify blur in at least a part of an image of a scene, said program comprising:

code for receiving at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images;

code for selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur;

code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches;

code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power (1050), thereby forming an amplified set of frequency domain pixel values; and

code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

Dated this 3rd day of December 2012

CANON KABUSHIKI KAISHA

Patent Attorneys for the Applicant

Spruson&Ferguson

2012258467 03 Dec 2012

ABSTRACT

BOKEH AMPLIFICATION

Disclosed is a method (700; 1200) of modifying the blur in at least a part of an image of a scene. The method captures or receives (710; 1210) at least two images (600,610) of the scene, the images being captured with different camera parameters (820,840) to produce a different amount of blur in each of the captured images. The method selects (720; 1240) a corresponding image patch (642,652) in each of the captured images, each of the selected image patches having an initial amount of blur and calculates (1010-1040) a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches. Each of the pixel values in the set of frequency domain pixel values are raised to a predetermined power (1050), thereby forming an amplified set of frequency domain pixel values. The method then combines the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch (1085) with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

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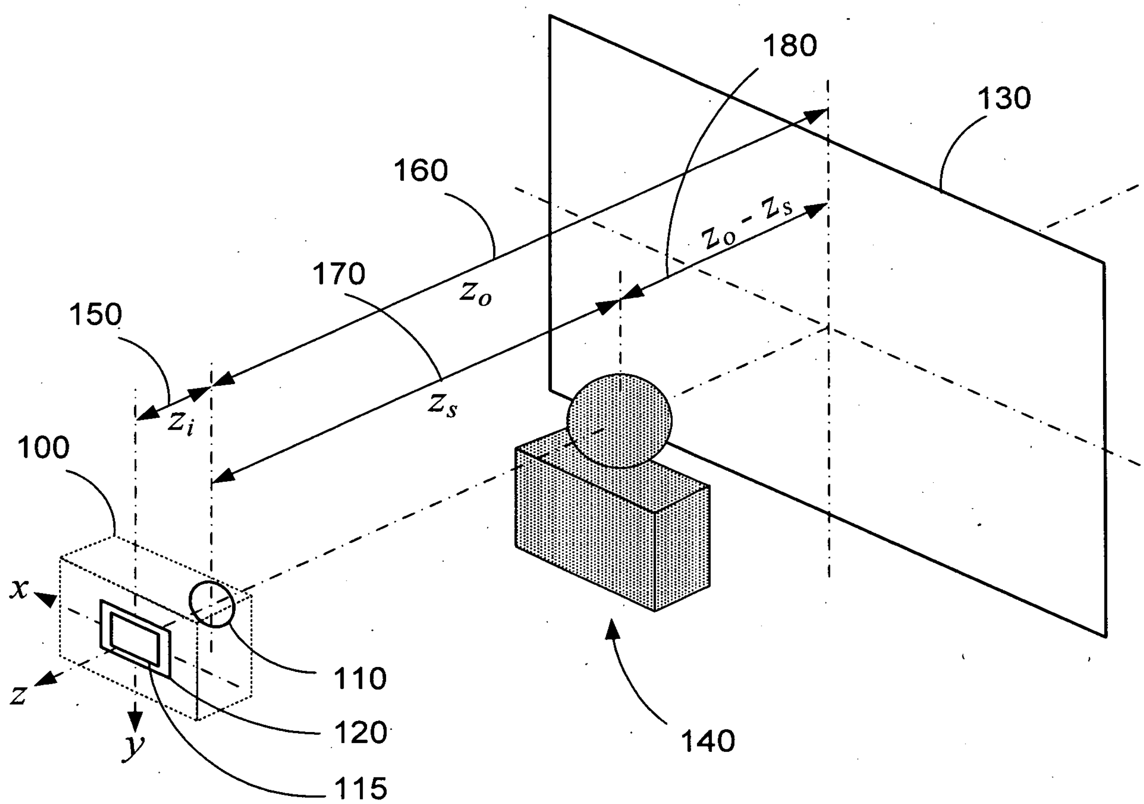

Fig. 1

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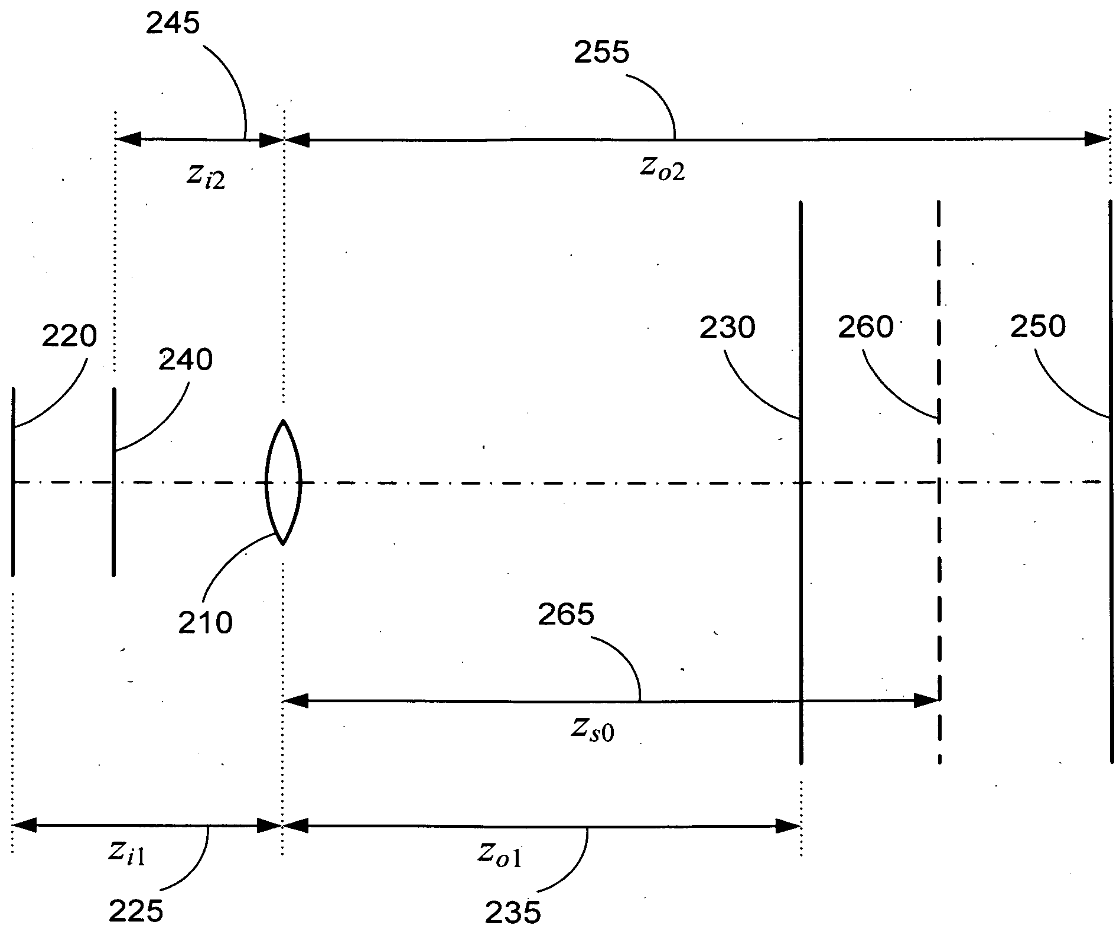

Fig. 2

2012258467 03 Dec 2012

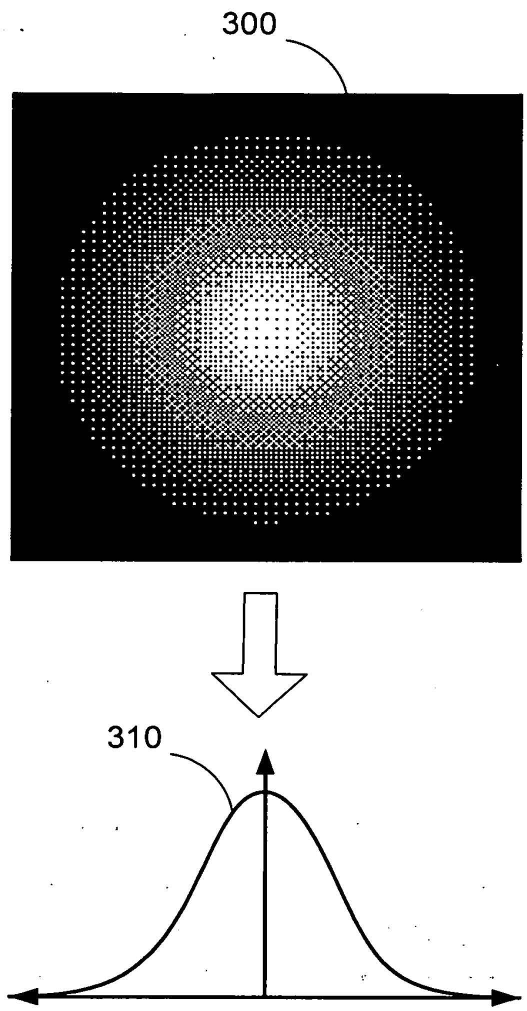

Fig. 3A

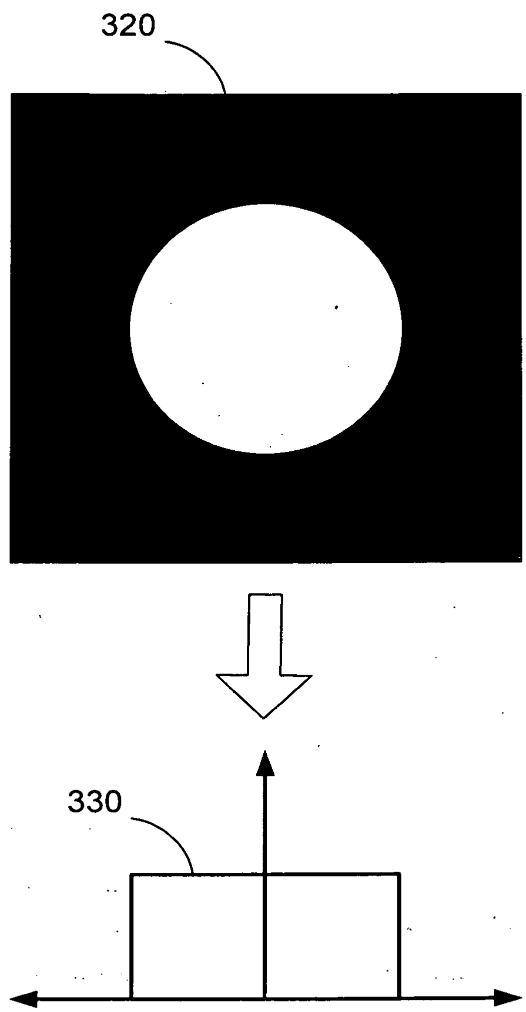

Fig. 3B

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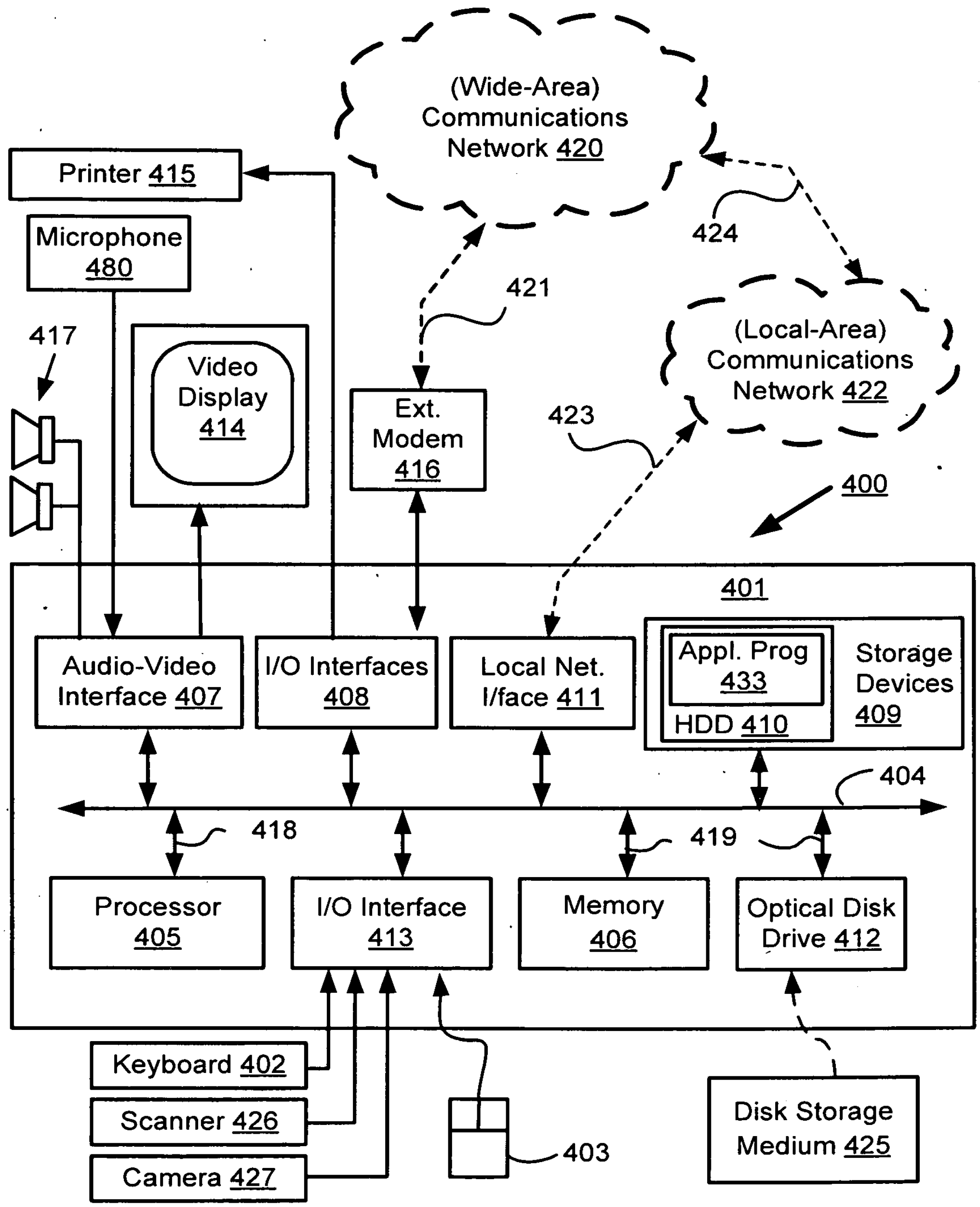

Fig. 4A

20122258467 03 Dec 2012

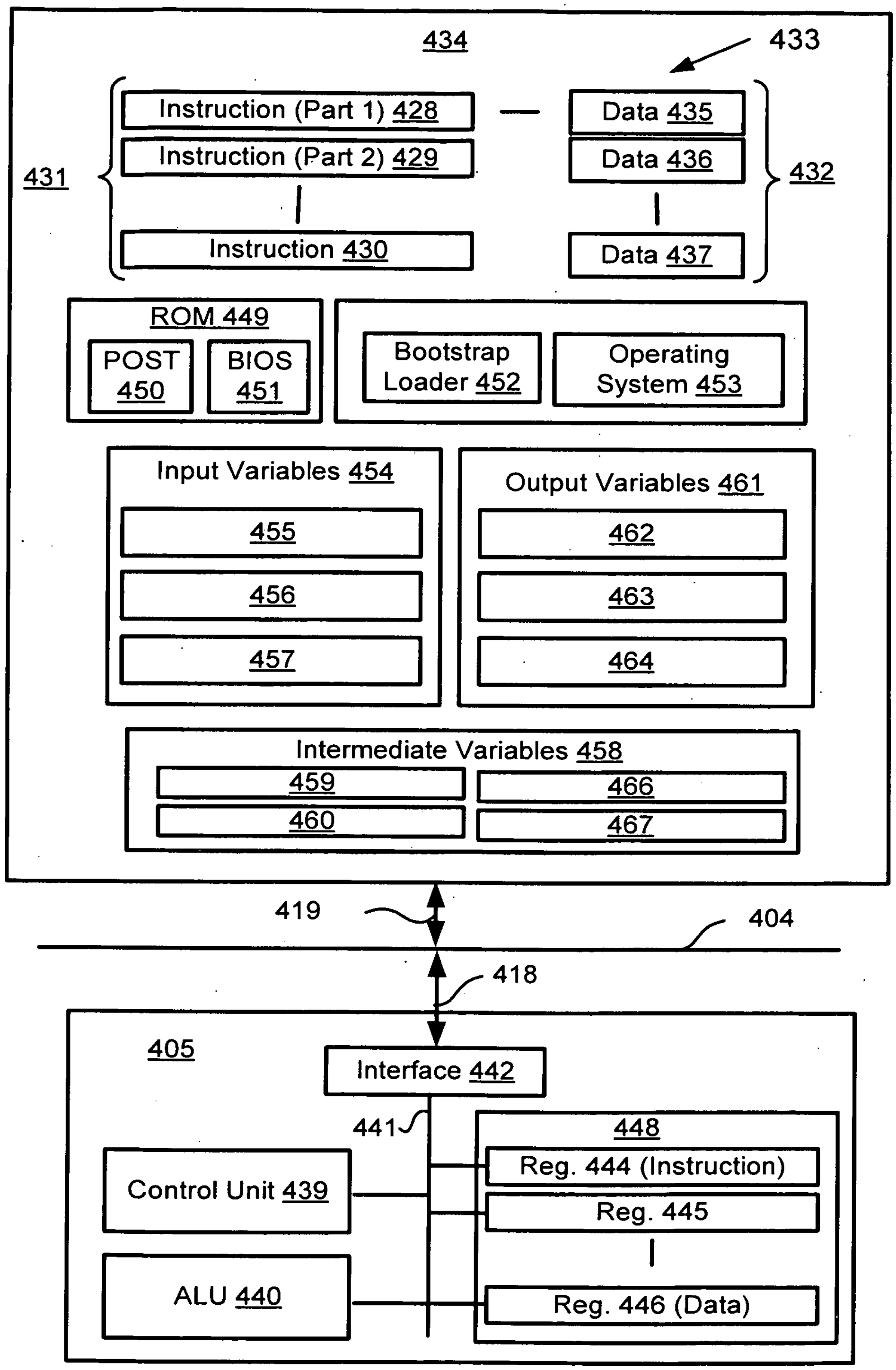

Fig. 4B

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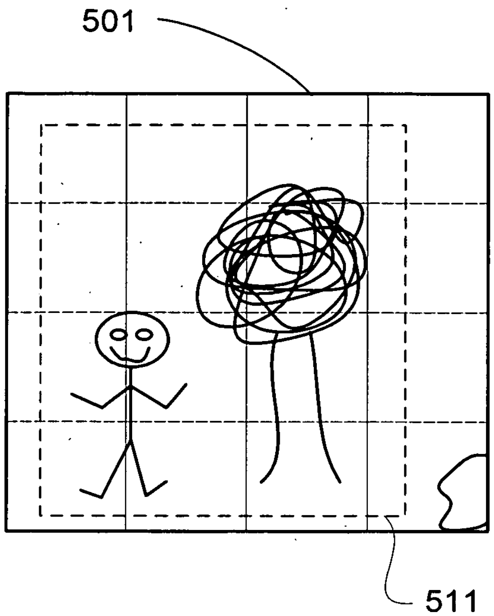


Fig. 5A

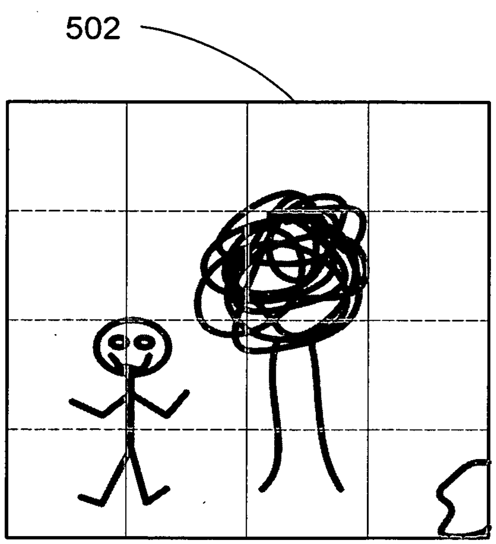


Fig. 5B

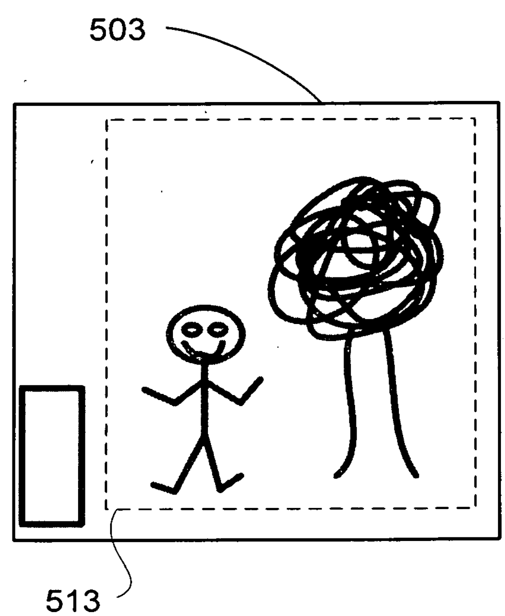


Fig. 5C

2012258467 03 Dec 2012

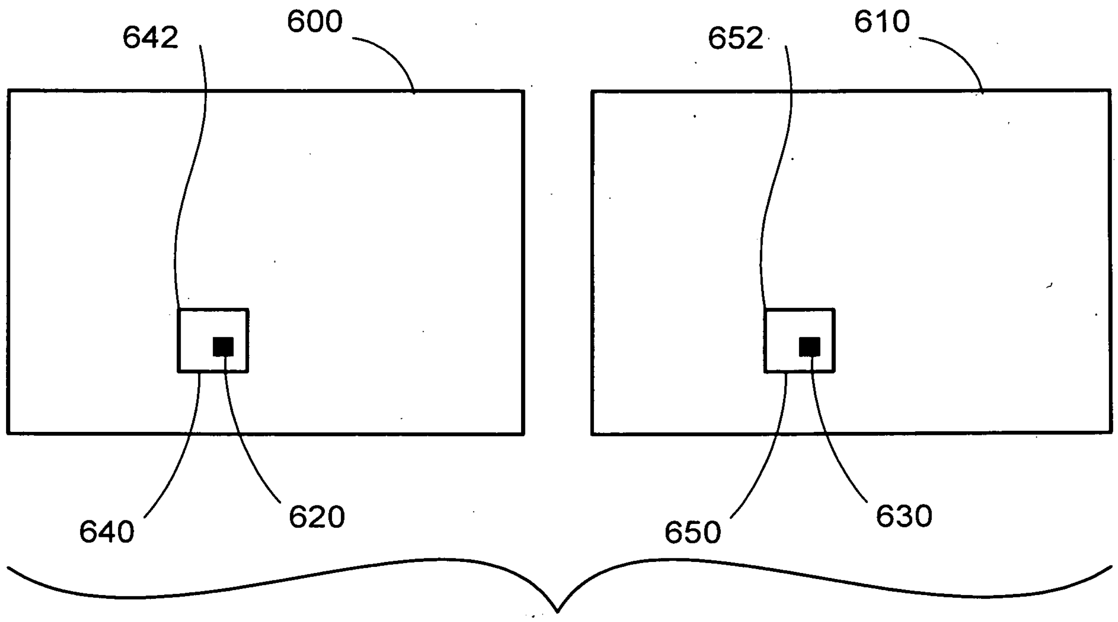
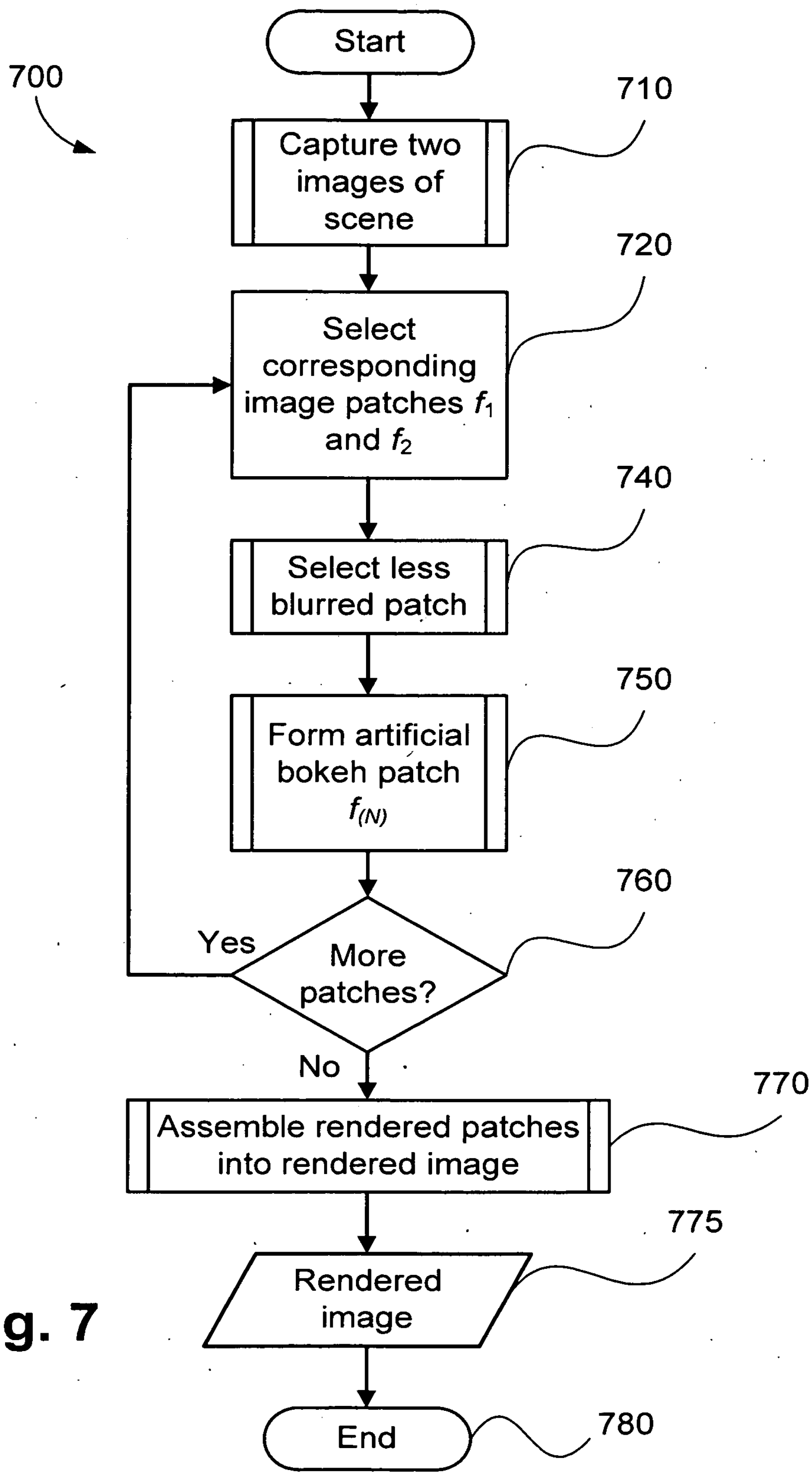


Fig. 6



700
Start
Capture two images of scene
710
Select corresponding image patches f_1 and f_2
720
Select less blurred patch
740
Form artificial bokeh patch $f_{(N)}$
750
More patches?
760
Yes
No
Assemble rendered patches into rendered image
770
Rendered image
775
End
780

Fig. 7

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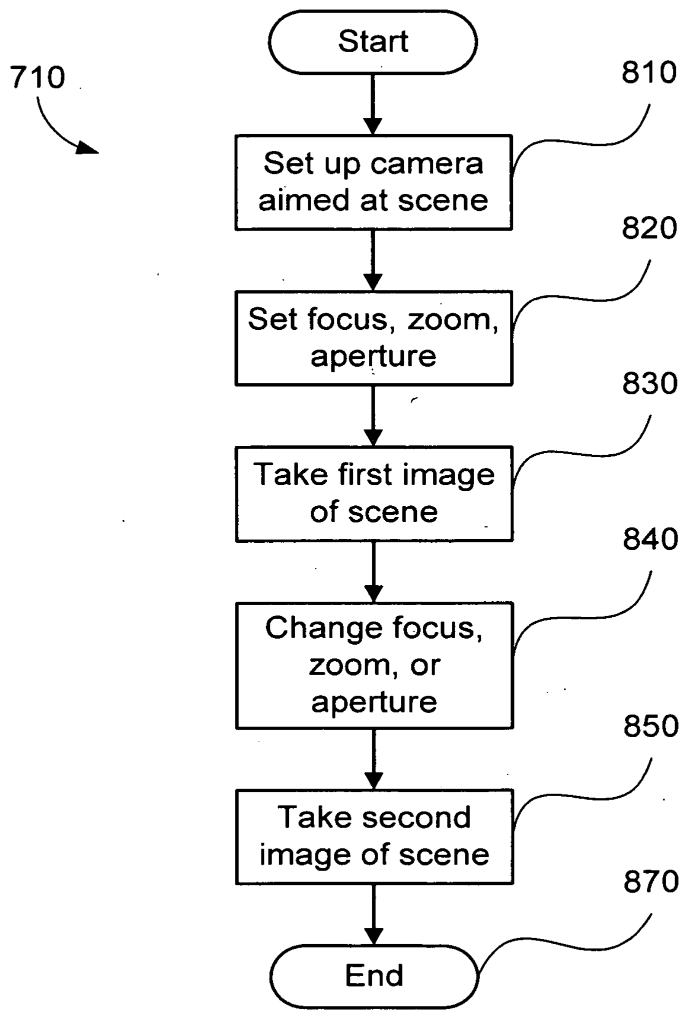

Fig. 8

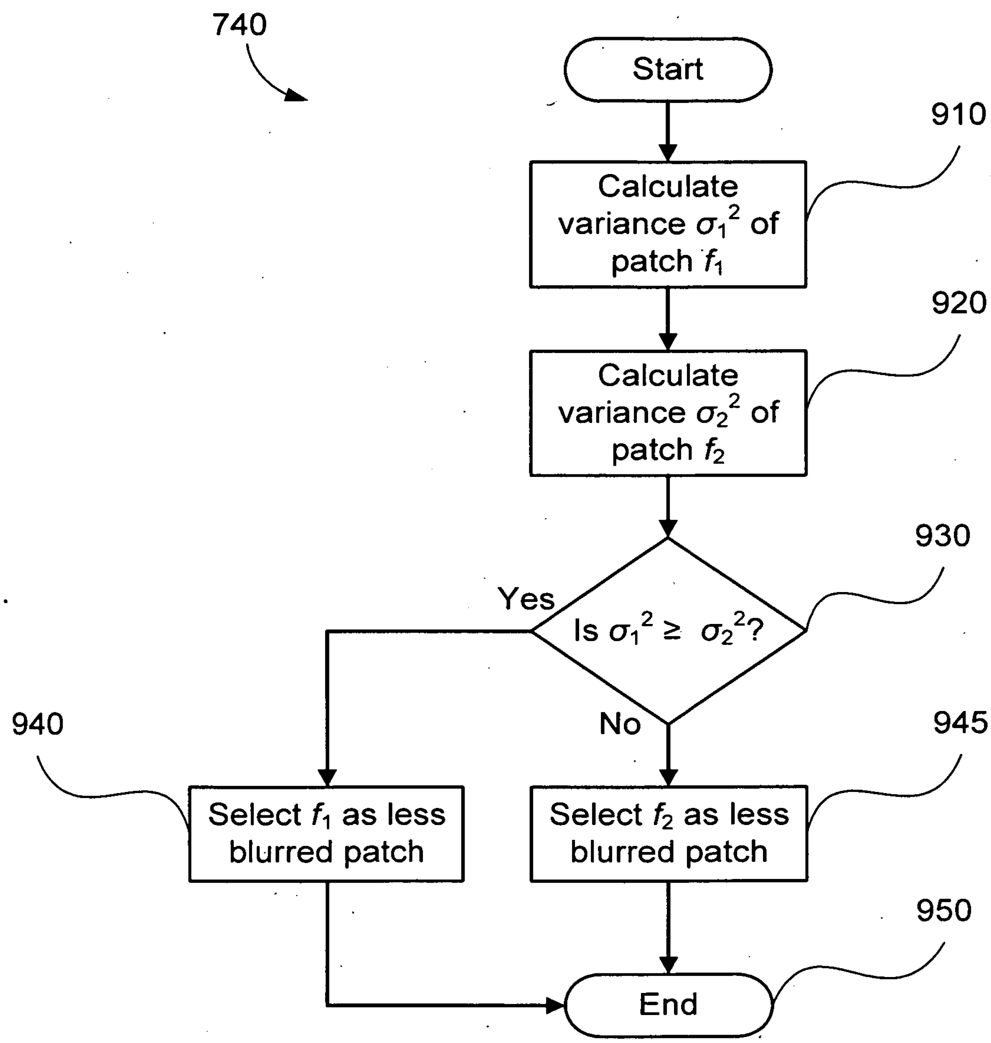
740
Start
910
Calculate variance σ_1^2 of patch f_1
920
Calculate variance σ_2^2 of patch f_2
930
Yes
Is $\sigma_1^2 \geq \sigma_2^2$?
No
940
Select f_1 as less blurred patch
945
Select f_2 as less blurred patch
950
End

Fig. 9

2012258467 03 Dec 2012

11/13

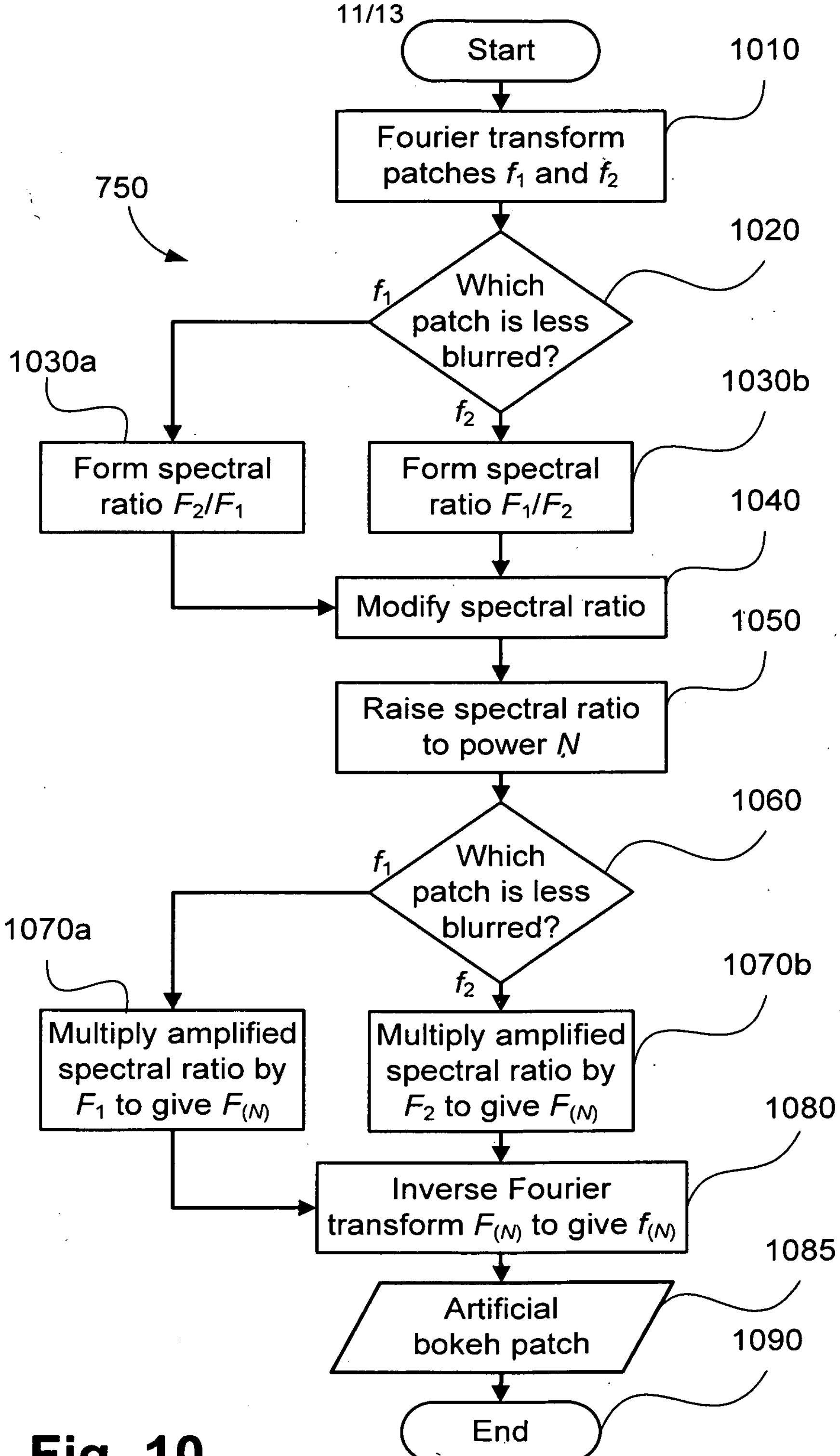

Fig. 10

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2012258467 03 Dec 2012

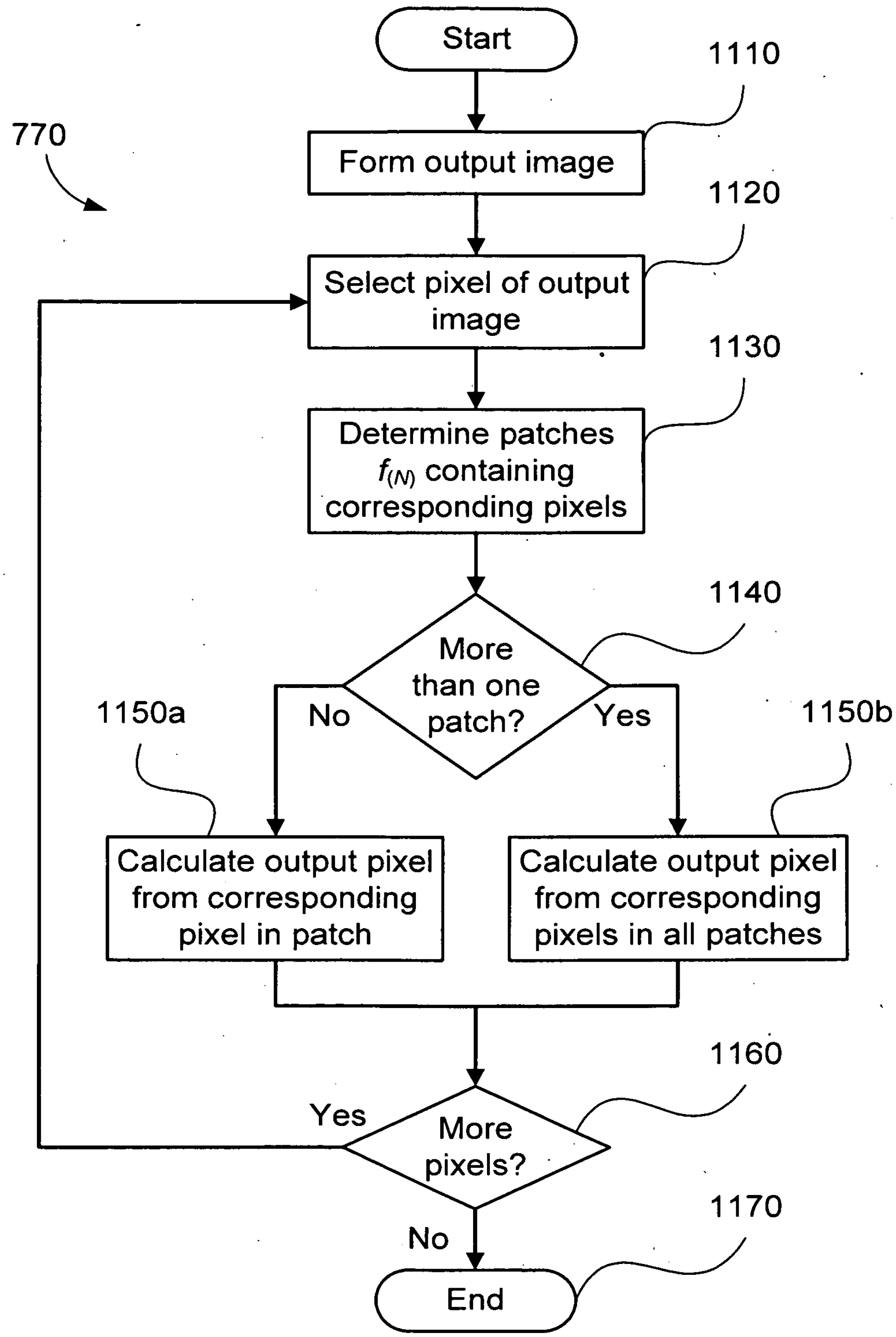

Fig. 11

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APPLE INC. v. COREPHOTONICS LTD.

2012258467 03 Dec 2012

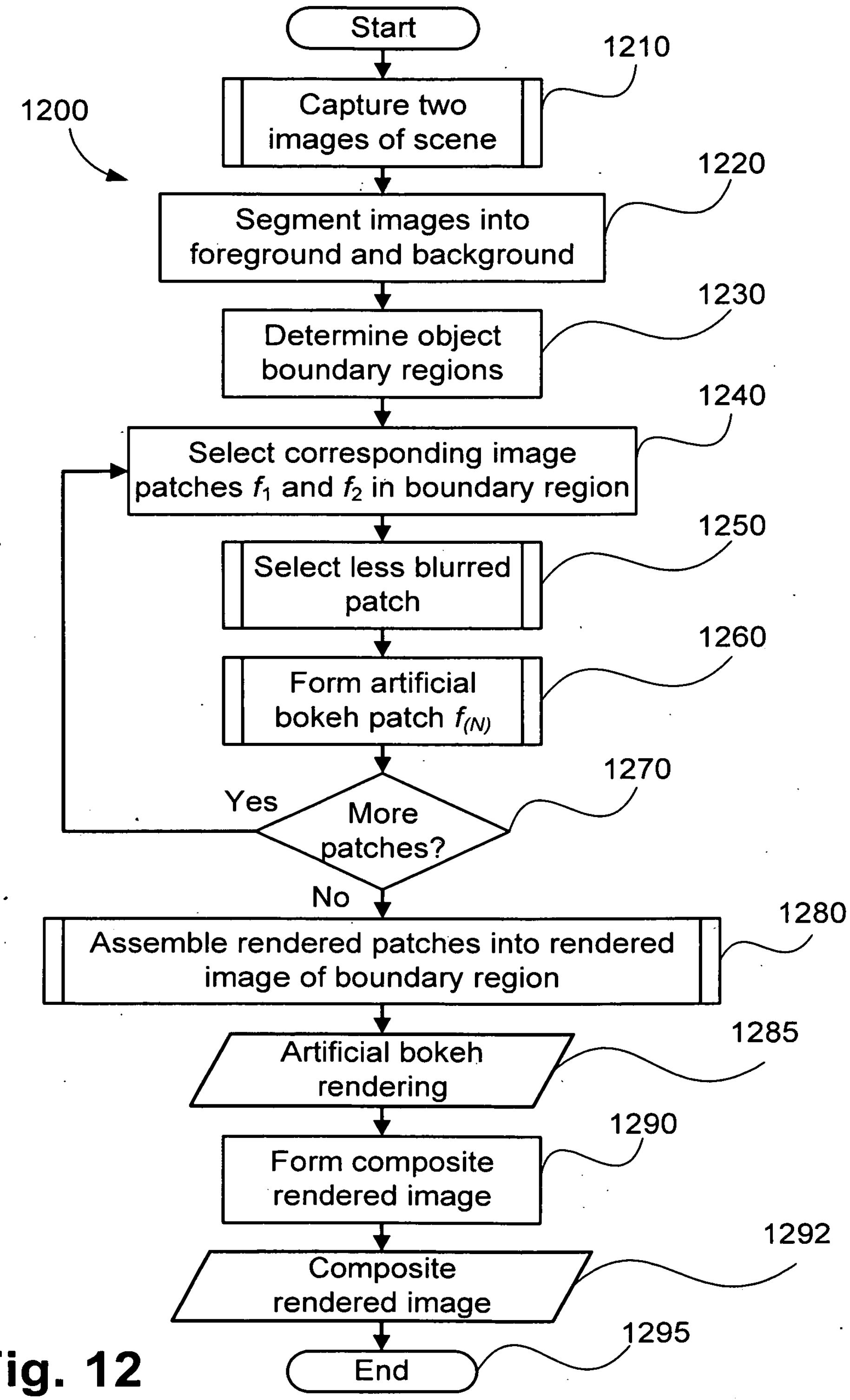

Fig. 12

APPL-1008 / Page 108 of 242
APPLE INC. v. COREPHOTONICS LTD.

Doc Code: TRAN.LET
Document Description: Transmittal Letter

OPAP MAR 20 2014 PATENT & TRADEMARK OFFICE

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TRANSMITTAL FORM	Application Number	14/079,481
	Filing Date	November 13, 2013
	First Named Inventor	David Peter MORGAN-MAR
	Art Unit	2664
(to be used for all correspondence after initial filing)	Examiner Name	Lin YE
Total Number of Pages in This Submission: 1	Attorney Docket Number	2200-15777-CINC

ENCLOSURES *(Check all that apply)*

- [ ] Fee Transmittal Form
  - [ ] Fee Attached
- [ ] Amendment/Reply
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  - [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
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- [x] Certified Copy of Priority Document(s)
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Remarks

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SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	Canon U.S.A. Inc., IP Division		
Signature	/Jiaxiao Zhang/		
Printed name	Jiaxiao ZHANG		
Date	February 27, 2014	Reg. No.	63,235

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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
14/079,481	11/13/2013	2852	2020	2200-15777-CINC	15	4

CONFIRMATION NO. 8099

34904
CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

FILING RECEIPT

OC000000065187040

Date Mailed: 11/29/2013

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Inventor(s)

David Peter MORGAN-MAR, Wollstonecraft, AUSTRALIA;
Kieran Gerard LARKIN, Putney, AUSTRALIA;
Matthew Raphael ARNISON, Umina Beach, AUSTRALIA;

Applicant(s)

CANON KABUSHIKI KAISHA, Tokyo, JAPAN

Assignment For Published Patent Application

CANON KABUSHIKI KAISHA, Tokyo, JAPAN

Power of Attorney: The patent practitioners associated with Customer Number 34904

Domestic Applications for which benefit is claimed - None.
A proper domestic benefit claim must be provided in an Application Data Sheet in order to constitute a claim for domestic benefit. See 37 CFR 1.76 and 1.78.

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)
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Projected Publication Date: 06/05/2014

Non-Publication Request: No

Early Publication Request: No
Title

BOKEH AMPLIFICATION

Preliminary Class

396

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

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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 14/079,481

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			N/A	280
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	600
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	720
TOTAL CLAIMS (37 CFR 1.16(i))	15 minus 20 =	*			OR	x 80 =	0.00
INDEPENDENT CLAIMS (37 CFR 1.16(h))	4 minus 3 =	* 1				x 420 =	420
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			TOTAL	2020

* 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	

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
14/079,481	11/13/2013	David Peter MORGAN-MAR	2200-15777-CINC

CONFIRMATION NO. 8099

34904
CANON U.S.A. INC. INTELLECTUAL PROPERTY DIVISION
15975 ALTON PARKWAY
IRVINE, CA 92618-3731

POA ACCEPTANCE LETTER

OC000000065187090

Date Mailed: 11/29/2013

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PTO/SB/08a (01-10)
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	Application Number	
	Filing Date	
	First Named Inventor	David Peter MORGAN-MAR
	Art Unit	
	Examiner Name	
	Attorney Docket Number	2200-15777-CINC

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Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	7065256	B2	2006-06-20	Alex ALON et al.	

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	1	20090141163	A1	2009-06-04	Ziv ATTAR et al.	

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	1	2008/149363	WO	A2	2008-12-11	DBLUR TECHNOLOGIES LTD.		☐

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	
	Filing Date	
	First Named Inventor	David Peter MORGAN-MAR
	Art Unit	
	Examiner Name	
	Attorney Docket Number	2200-15777-CINC

	1	Bae, Soonmin, and Durand, Frédo. "Defocus Magnification." Computer Graphics Forum: Proceedings of Eurographics 2007, Prague, 3-7 September 2007. Ed. Cohen-Or, D and Slavik, P. Oxford, UK: Blackwell Publishing, 2007. 26.3: 571-579.	☐
	2	Kubota, Akira, and Aizawa, Kiyoharu. "Reconstructing Arbitrarily Focused Images From Two Differently Focused Images Using Linear Filters." IEEE Transactions on Image Processing 14.11 (2005): 1848-1859.	☐

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99)**	Application Number		
	Filing Date		
	First Named Inventor	David Peter MORGAN-MAR	
	Art Unit		
	Examiner Name		
	Attorney Docket Number	2200-15777-CINC	

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	/Jiaxiao Zhang/	Date (YYYY-MM-DD)	2013-11-12
Name/Print	Jiaxiao ZHANG	Registration Number	63235

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Application Number	TBD
Filing Date	Hereon
First Named Inventor	David Peter MORGAN-MAR
Title	BOKEH AMPLIFICATION
Art Unit	TBD
Examiner Name	TBD
Attorney Docket Number	2200-15777-CINC

SIGNATURE of Applicant or Patent Practitioner

Signature	/Jiaxiao Zhang/	Date	November 12, 2013
Name	Jiaxiao ZHANG	Telephone	(949) 932-3157
Registration Number	63,235		

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

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I hereby revoke all previous powers of attorney given in the application identified in the attached transmittal letter.

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☐ I hereby appoint Practitioner(s) named below as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter (form PTO/AIA/82A or equivalent):

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I am the Applicant:

☐ Inventor or Joint Inventor

☐ Legal Representative of a Deceased or Legally Incapacitated Inventor

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SIGNATURE of Applicant for Patent

Signature	[signature]	Date	September 14, 2012
Name	Kenichi Nagasawa	Telephone	+81-3-3757-6945
Title and Company	Director, Group Executive, Corporate Intellectual Property and Legal Headquarters, Canon Kabushiki Kaisha		

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Application Number:	
Filing Date:	
Title of Invention:	BOKEH AMPLIFICATION
First Named Inventor/Applicant Name:	David Peter MORGAN-MAR
Filer:	Jiaxiao Zhang
Attorney Docket Number:	2200-15777-CINC

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
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Utility Search Fee	1111	1	600	600
Utility Examination Fee	1311	1	720	720
Pages:				
Claims:				
Independent claims in excess of 3	1201	1	420	420
Miscellaneous-Filing:				
Petition:				

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Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**2020**

Electronic Acknowledgement Receipt

EFS ID:	17389667
Application Number:	14079481
International Application Number:	
Confirmation Number:	8099
Title of Invention:	BOKEH AMPLIFICATION
First Named Inventor/Applicant Name:	David Peter MORGAN-MAR
Customer Number:	34904
Filer:	Jiaxiao Zhang/Jocelyn Lin
Filer Authorized By:	Jiaxiao Zhang
Attorney Docket Number:	2200-15777-CINC
Receipt Date:	13-NOV-2013
Filing Date:	
Time Stamp:	19:03:35
Application Type:	Utility under 35 USC 111(a)

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Submitted with Payment	yes
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Warnings:					
Information:					
2	Oath or Declaration filed	10130047US01_Decs.pdf	208942 e711bd19cf70e66c4c2ed55fa5fec6f4e1bb44bf	no	3
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Claims	45	48
Abstract	49	49

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
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4	Non Patent Literature	_P053198_Bae_et_al_Defocus_Magnification_.pdf	3052532 a6bdc67806b6afa56dcdd344d55577a7168c6043	no	9
Warnings:					
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6	Drawings-only black and white line drawings	_P053198US_drawings_.pdf	756616 b185290141590fca9640d8e32f4b6da4dae94fed	no	13
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7	Application Data Sheet	10130047US01_ADS.pdf	1503194 241fd9c84f3fc1946da897fa56f2de481697dae0	no	7
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Warnings:					
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9	Power of Attorney	10130047US01_POA.pdf	231907 922c1c1967c8c86f693897cbc0b0fb15b9322f9f	no	2
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10	Fee Worksheet (SB06)	fee-info.pdf	36487 efc9281d256a94fe777f9fbc09e21668becf9328	no	2
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EFS ID:	17389667
Application Number:	14079481
International Application Number:	
Confirmation Number:	8099
Title of Invention:	BOKEH AMPLIFICATION
First Named Inventor/Applicant Name:	David Peter MORGAN-MAR
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Filer Authorized By:	Jiaxiao Zhang
Attorney Docket Number:	2200-15777-CINC
Receipt Date:	13-NOV-2013
Filing Date:	
Time Stamp:	19:03:35
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$2020
RAM confirmation Number	6286
Deposit Account	502456
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File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Foreign Reference	_WO2008149363_pub.pdf	5985311 1573bbceac2c7de2c1134c3bee575123451d533b	no	41
Warnings:					
Information:					
2	Oath or Declaration filed	10130047US01_Decs.pdf	208942 e711bd19cf70e66c4c2ed55fa5fec6f4e1bb44bf	no	3
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3		_10130047US01_Specification.pdf	20447832 4734bd2f52f0ccced90e091672fc63a0dcb93dad	yes	49

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Document Description	Start	End
Specification	1	44
Claims	45	48
Abstract	49	49

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
Warnings:					
Information:					
4	Non Patent Literature	_P053198_Bae_et_al_Defocus_Magnification_.pdf	3052532 a6bdc67806b6afa56dcdd344d55577a7168c6043	no	9
Warnings:					
Information:					
5	Non Patent Literature	_P053198_Kubota_et_al_ReconstructingArbitarilyFocusedImages_.pdf	6804449 38dcb255eb58cad1edb2572dc662473526b4f483	no	12
Warnings:					
Information:					
6	Drawings-only black and white line drawings	_P053198US_drawings_.pdf	756616 b185290141590fca9640d8e32f4b6da4dae94fed	no	13
Warnings:					

Information:					
7	Application Data Sheet	10130047US01_ADS.pdf	1503194 241fd9c84f3fc1946da897fa56f2de481697dae0	no	7
Warnings:					
Information:					
8	Information Disclosure Statement (IDS) Form (SB08)	10130047US01_IDS.pdf	612396 675c4b024b710c77d77d35cafb6ff03282976a6f	no	4
Warnings:					
Information:					
9	Power of Attorney	10130047US01_POA.pdf	231907 922c1c1967c8c86f693897cbc0b0fb15b9322f9f	no	2
Warnings:					
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10	Fee Worksheet (SB06)	fee-info.pdf	36487 efc9281d256a94fe777f9fbc09e21668becf9328	no	2
Warnings:					
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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 December 2008 (11.12.2008)

PCT

(10) International Publication Number
WO 2008/149363 A2

(51) International Patent Classification:
G06T 7/20 (2006.01)

(21) International Application Number: PCT/IL2008/000769

(22) International Filing Date: 5 June 2008 (05.06.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/933,446 5 June 2007 (05.06.2007) US
61/072,132 26 March 2008 (26.03.2008) US

(71) Applicant *(for all designated States except US)*: **DBLUR TECHNOLOGIES LTD.** [IL/IL]; 8 Abba Even Boulevard, 46725 Herzliya Pituach (IL).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **KINROT, Uri** [IL/IL]; 25 Hadror Street, 45268 Hod Hasharon (IL). **LITVINOV, Anatoly** [IL/IL]; 43a Hacharzit Street, 30500 Binyamina (IL). **LAVI, Yoav** [IL/IL]; 11 Kazan Street, 43611 Ra'anana (IL). **ALON, Irina** [IL/IL]; 11G Sheshet Hayamim Street, 30500 Binyamina (IL). **ALON, Alex** [IL/IL]; 11G Sheshet Hayamim Street, 30500 Binyamin (IL).

(74) Agents: SANFORD T. COLB & CO. et al.; P.O. Box 2273, 76122 Rehovot (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, BR, BW, BY, BZ, CA, CH, 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, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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Published:
— *without international search report and to be republished upon receipt of that report*

(54) Title: NON-LINEAR TRANSFORMATIONS FOR ENHANCEMENT OF IMAGES

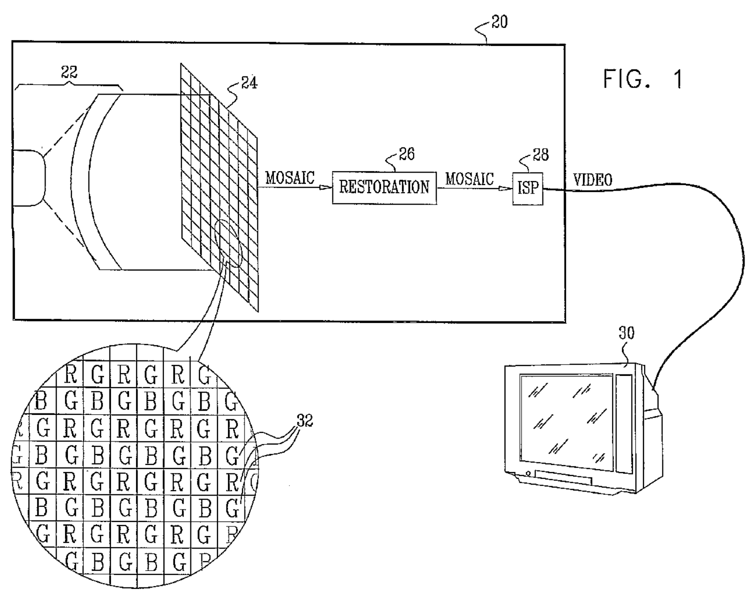

FIG. 1

(57) Abstract: Imaging apparatus (26) is provided for use with an image sensor (24). The apparatus includes a non-linear mapping circuit (42), which is configured to receive a raw stream of input pixel values generated by the image sensor and to perform a non-linear mapping of the input pixel values. to generate a mapped stream of mapped pixel values, and a linear convolution filter (44), which is arranged to filter the mapped stream of mapped pixel values to generate a filtered stream of filtered pixel values. Other embodiments are also described.

WO 2008/149363 A2

NON-LINEAR TRANSFORMATIONS FOR ENHANCEMENT OF IMAGES

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of the following US provisional applications, both of which are assigned to the assignee of the present application and are incorporated herein by reference:

- US Provisional Application 60/933,446, filed June 5, 2007; and
- US Provisional Application 61/072,132, filed March 26, 2008.

FIELD OF THE INVENTION

The present invention relates generally to digital image processing, and specifically to methods and devices for enhancing image quality in digital cameras.

BACKGROUND OF THE INVENTION

The objective optics used in digital cameras are typically designed so as to minimize the optical point spread function (PSF) and maximize the modulation transfer function (MTF), subject to the limitations of size, cost, aperture size, and other factors imposed by the camera manufacturer. The PSF of the resulting optical system may still vary from the ideal due to focal variations and aberrations..

A number of methods are known in the art for compensating for such PSF deviations by digital image processing. For example, U.S. Patent 6,154,574, whose disclosure is incorporated herein by reference, describes a method for digitally focusing an out-of-focus image in an image processing system. A mean step response is obtained by dividing a defocused image into sub-images, and calculating step responses with respect to the edge direction in each sub-image. The mean step response is used in calculating PSF coefficients, which are applied in turn to determine an image restoration transfer function. An in-focus image is obtained by multiplying this function by the out-of-focus image in the frequency domain.

U.S. Patent 7,077,810 to Alon et al., which is assigned to the assignee of the present application and is incorporated herein by reference, describes a method and system for processing a distorted digital image B that is a convolution of an undistorted image F and a point spread function. Noise is removed from the image B so as to produce an image B' of reduced noise. The image F is then obtained based upon a calculation involving the image B'.

US Patent Application Publication 2007/0236573 to Alon et al., which is incorporated herein by reference, describes a method for designing a camera, which includes objective optics for forming an image on an electronic image sensor and a digital filter for filtering an output of the image sensor. The method includes estimating an enhancement of the image that can be accomplished using the digital filter. A target optical specification for the camera is processed responsively to the estimated enhancement so as to determine a modified optical specification, and the objective optics are designed responsively to the modified optical specification.

PCT International Publication WO 2004/063989, whose disclosure is incorporated herein by reference, describes an electronic imaging camera, comprising an image sensing array and an image processor, which applies a deblurring function – typically in the form of a deconvolution filter (DCF) – to the signal output by the array in order to generate an output image with reduced blur. This blur reduction makes it possible to design and use camera optics with a poor inherent PSF, while restoring the electronic image generated by the sensing array to give an acceptable output image.

Low-cost color video cameras typically use a single solid-state image sensor with a multi-colored mosaic filter overlay. A mosaic filter is a mask of miniature color filter elements in which a filter element is positioned in front of each detector element of the image sensor. The filter elements in the mosaic filter generally alternate between the primary RGB colors, or between the complementary colors cyan, magenta and yellow. One common type of color mosaic filter is called a "Bayer sensor" or "Bayer mosaic," which is described in U.S. Patent 3,971,065, whose disclosure is incorporated herein by reference.

Processing the image produced by a mosaic image sensor typically involves reconstructing the full color image by extracting three color signals (red, green and blue) from the sensor output. An image signal processor (ISP) processes the image sensor output in order to compute luminance (Y) and chrominance (C) values for each pixel of the output image. The ISP then outputs these values (or the corresponding R, G and B color values) in a standard video format.

PCT International Publication WO 2007/054931, which is assigned to the assignee of the present patent application and whose disclosure is incorporated herein by reference, describes methods and devices for image enhancement in the mosaic domain. A mosaic image sensor outputs a stream of pixel values belonging to a plurality of input sub-images, each of which is due to light of a different, respective color that is incident on the sensor. An image restoration circuit filters the pixel values in each of the input sub-images so as to generate corresponding output sub-images with enhanced quality, such as with reduced blur. An image signal processor (ISP) then combines the output sub-images so as to generate a color video output image.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide methods and devices for processing and enhancement of electronic images. An image sensor outputs a stream of input pixels values which suffer from an input blur. An image restoration circuit performs a non-linear mapping of the input pixel values to generate a mapped stream of output pixel values, and performs linear convolution filtering of the mapped stream of output pixel values to generate a filtered pixel stream with enhanced quality, such as with reduced blur. Typically, the images are produced using objective optics characterized by a point spread function (PSF) that causes the input blur, and the image restoration circuit includes a deconvolution filter (DCF), having a filter kernel determined according to the PSF.

The non-linear mapping typically spreads a portion of the input pixels with relatively low values over a larger range of output values, and contracts a portion of the input pixels with relatively high-amplitude values to a narrower range of output values. The mapping thus minimizes artifacts in the output pixel stream near low-illumination pixels. In some embodiments, the image restoration circuit performs a second non-linear mapping, generally inverse to the initial non-linear mapping, on the filtered pixel stream, in order to cancel a distortion of the input pixels caused by the initial non-linear mapping.

In some embodiments of the present invention, the image restoration circuit performs the non-linear mapping using a piecewise linear function. Alternatively or additionally, the image restoration circuit uses one or more look-up tables to approximate a continuous non-linear function, in order to mitigate any distortion in the output pixel stream that might otherwise be caused by sharp angles between segments of the piecewise linear function.

In some embodiments of the present invention, the image sensor comprises a mosaic image sensor, which outputs a stream of pixel values belonging to a plurality of input sub-images, each of which is due to light of a different, respective color that is incident on the mosaic image sensor. Following the non-linear mapping and linear convolution filtering, which generate corresponding output sub-images with enhanced quality, such as with reduced blur, an image signal processor (ISP) combines the output sub-images so as to generate a color video output image.

There is therefore provided, in accordance with an embodiment of the present invention, imaging apparatus for use with an image sensor, the apparatus including:

a non-linear mapping circuit, which is configured to receive a raw stream of input pixel values generated by the image sensor and to perform a non-linear mapping of the input pixel values to generate a mapped stream of mapped pixel values; and

a linear convolution filter, which is arranged to filter the mapped stream of mapped pixel values to generate a filtered stream of filtered pixel values.

In disclosed embodiments, the image sensor generates the raw stream of input pixel values responsively to light that is incident on the sensor via objective optics that are characterized by a point spread function (PSF), which gives rise to an input blur, and the linear convolution filter includes a deconvolution filter which has a filter kernel determined according to the PSF. Typically, the non-linear mapping circuit is configured to perform the non-linear mapping on each of the input pixel values individually, irrespective of any neighboring input pixel values. Additionally or alternatively, the raw stream typically includes at least 100,000 of the input pixel values, and the non-linear mapping circuit is configured to perform the non-linear mapping such that at least 10% of the mapped pixel values are different from the corresponding input pixel values.

In some embodiments, the non-linear mapping circuit includes a first non-linear mapping circuit, wherein the non-linear mapping includes a first non-linear mapping, and the apparatus includes a second non-linear mapping circuit, which is arranged to perform a second non-linear mapping of the filtered pixel values. Typically, the first non-linear mapping has a first functional characteristic, and the second non-linear mapping has a second functional characteristic that is inverse to the first functional characteristic over at least a portion of a range of allowable filtered pixel values.

In a disclosed embodiment, the raw stream of input pixel values includes an input subset of relatively low-amplitude pixel values characterized by an input range of amplitude values, and the non-linear mapping circuit is configured to perform the non-linear mapping of the low-amplitude pixel values to a mapped subset of the mapped pixel values characterized by a mapped range of amplitude values that is greater than the input range of amplitude values. Additionally or alternatively, the non-linear mapping includes a power law transformation, and the non-linear mapping circuit is configured to perform the power law transformation.

Further additionally or alternatively, the non-linear mapping uses a piecewise linear function, and the non-linear mapping circuit is configured to implement the piecewise linear function. In one embodiment, the non-linear mapping circuit is configured to use curve approximation to smooth knees in the piecewise linear function. Additionally or alternatively,

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the piecewise linear function includes a plurality of segments, and the non-linear mapping circuit includes a sparse lookup table having respective entries that specify the segments.

In a disclosed embodiment, the image sensor is a mosaic image sensor, and wherein the raw stream of input pixel values belongs to a plurality of interleaved input sub-images, each sub-image responsive to light of a different, respective color that is incident on the mosaic image sensor, and the non-linear mapping circuit is configured to generate a plurality of interleaved output sub-images respectively, and the apparatus includes an image signal processor (ISP), which is coupled to receive and combine the plurality of the output sub-images in order to generate a color video output image.

In one embodiment, the non-linear mapping circuit is configured to dynamically alter the non-linear mapping responsively to one or more characteristics of the input pixel values.

There is also provided, in accordance with an embodiment of the present invention, a method for imaging, including:

receiving a raw stream of input pixel values generated by an image sensor;

digitally performing a non-linear mapping of the input pixel values to generate a mapped stream of mapped pixel values; and

applying a linear convolution filter to the mapped stream of mapped pixel values to generate a filtered stream of filtered pixel values.

The present invention will be more fully understood from the following detailed description of the embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram that schematically illustrates an electronic imaging camera, in accordance with an embodiment of the present invention;

Fig. 2 is a block diagram that schematically shows functional components of an image restoration circuit, in accordance with an embodiment of the present invention;

Fig. 3 is a graphical illustration of a piecewise linear function that implements a non-linear mapping, in accordance with an embodiment of the present invention;

Fig. 4 is a schematic illustration of a digital hardware circuit that implements the piecewise linear function depicted in Fig. 3, in accordance with an embodiment of the present invention;

Fig. 5 is a graphical illustration of a piecewise linear function that implements a non-linear mapping that is generally inverse to the non-linear mapping depicted in Fig. 3, in accordance with an embodiment of the present invention;

Fig. 6 is a schematic illustration of a digital hardware circuit that implements the piecewise linear function depicted in Fig. 5, in accordance with an embodiment of the present invention;

Fig. 7 is a graphical illustration of a piecewise linear function that implements another non-linear mapping, in accordance with an embodiment of the present invention;

Fig. 8 is a graphical illustration of a piecewise linear function that implements a non-linear mapping that is generally inverse to the non-linear mapping depicted in Fig. 7, in accordance with an embodiment of the present invention;

Fig. 9 is a schematic illustration of a digital hardware circuit that implements the piecewise linear function depicted in Fig. 8, in accordance with an embodiment of the present invention;

Fig. 10 is a graphical illustration of a non-linear mapping that uses a spline to smooth a knee in a piecewise linear transformation, in accordance with an embodiment of the present invention;

Fig, 11 is a schematic illustration of a digital hardware circuit that implements a non-linear mapping that uses splines to smooth knees in a piecewise linear transformation, in accordance with an embodiment of the present invention;

Fig. 12 is a graphical illustration of a piecewise linear transformation that uses varying segment lengths to approximate a smoothly curved non-linear mapping, in accordance with an embodiment of the present invention;

Fig. 13 is a graphical illustration of another piecewise linear transformation that uses varying segment lengths to approximate a smoothly curved non-linear mapping, in accordance with an embodiment of the present invention;

Fig. 14 is a schematic illustration of a digital hardware circuit that implements a piecewise linear transformation that approximates a smooth curve by using a sparse lookup table to obtain varying segment lengths, in accordance with an embodiment of the present invention;

Fig. 15 is a graphical illustration of non-linear mapping functions, in accordance with an embodiment of the present invention;

Fig. 16 is a schematic illustration of an exemplary non-linear mapping, in accordance with an embodiment of the present invention; and

Fig. 17 is an exemplary graph including a curve representing the exemplary non-linear mapping depicted in Fig. 16, in accordance with an embodiment of the present invention.

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DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 is a block diagram that schematically illustrates an electronic imaging camera 20, in accordance with an embodiment of the present invention. This specific, simplified camera design is shown here by way of example, in order to clarify and concretize the principles of the present invention. These principles, however, are not limited to this design, but may rather be applied in reducing the blur in images in imaging systems of other types, for example, in which a sensor produces multiple sub-images of different colors, which are then combined to produce an enhanced color output image.

In an embodiment of the present invention, in camera 20, objective optics 22 focus light from a scene onto a mosaic image sensor 24. Objective optics 22 is characterized by a point spread function (PSF) that gives rise to an input blur in the received image. Any suitable type of image sensor, such as a CCD or CMOS image sensor, may be used in the camera. In this example, as well as in the description that follows, the sensor is assumed to have a mosaic filter, e.g., a Bayer-type mosaic filter, so that each pixel 32 in the image signal output by the sensor is responsive to either red, green or blue light. Thus, the mosaic sensor output can be seen as comprising red, green and blue sub-images, made up of the pixel values of the corresponding sensor element.

The stream of pixel values output by image sensor 24 is received and processed by a digital restoration circuit 26. This circuit is described in detail with reference to the figures that follow. The pixel values are digitized prior to processing by circuit 26 by an analog/digital converter (not shown in the figures), which may be integrated with either sensor 24 or circuit 26 or may be a separate component. In any case, circuit 26 processes the red, green and blue input sub-images that are produced by sensor 24 in order to reduce the image blur, as described hereinbelow. Circuit 26 then outputs red, green and blue sub-images with reduced blur.

Typically, circuit 26 outputs the sub-images in the same format in which it received the sub-images from sensor 24. For example, circuit 26 may interleave the pixel values in the output sub-images to generate a single output stream, in which the pixel values have the same interleaving as the input pixel values from sensor 24. Alternatively, circuit 26 may be configured to demultiplex and output each sub-image as a separate data block or data stream.

An image signal processor (ISP) 28 receives the deblurred red, green and blue output sub-images from restoration circuit 26 and processes the sub-images together to generate a color video output image (or image sequence) in a standard video format. This output image

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may be displayed on a video screen 30, as well as transmitted over a communication link and/or stored in a memory. In embodiments in which circuit 26 outputs the sub-images in the same format in which it received the sub-images from sensor 24, ISP 28 may be used interchangeably to process either the output of circuit 26 or to process the output of sensor 24 directly.

Further details pertaining to the components described in Fig. 1 are found in the above-mentioned PCT International Publication WO 2007/054931.

Typically, restoration circuit 26 and ISP 28 are embodied in one or more integrated circuit chips, which may comprise either custom or semi-custom components. Although restoration circuit 26 and ISP 28 are shown as separate functional blocks in Fig. 1, the functions of the restoration circuit and the ISP may be implemented in a single integrated circuit component. Optionally, image sensor 24 may be combined with circuit 26 and possibly also ISP 28 on the same semiconductor substrate in a system-on-chip (SoC) or camera-on-chip design. Alternatively, some or all of the functions of restoration circuit 26 and ISP 28 may be implemented in software on a programmable processor, such as a digital signal processor. This software may be downloaded to the processor in electronic form, or it may alternatively be provided on tangible media, such as optical, magnetic or electronic memory media.

Fig. 2 is a block diagram that schematically shows functional components of restoration circuit 26, in accordance with an embodiment of the present invention. Typically, these functional components are embodied together in a single custom or semi-custom integrated circuit device. In this example, as well as in the description that follows, the functional components are assumed to be implemented using digital hardware components. Alternatively, the functions shown in Fig. 2 may be divided among a number of components, which may carry out the functions in hardware or software.

In the exemplary embodiment shown in Fig. 2, circuit 26 performs image restoration by linear convolution filtering, e.g., deconvolution filtering, to reduce blur of the sub-images before they are processed by ISP 28 to generate a color output image, typically in RGB or Y-Cr-Cb format. Prior to the linear convolution filtering, circuit 26 performs a non-linear mapping of the raw stream of pixel values of each of the sub-images output by image sensor 24 to generate respective mapped streams of pixel values for each of the sub-images. The non-linear mapping deterministically maps each allowable input value to exactly one respective output value (although a plurality of input values may be mapped to a single output value). Circuit 26 typically performs the non-linear mapping on each pixel in isolation, irrespective of the values of other pixels in the pixel stream, such as neighboring pixels. Typically, circuit 26 implements a non-decreasing non-linear mapping. Typically, circuit 26 alters the value of at least 10% of the pixels in the raw pixel stream, such as at least 20% or at least 30% of the pixels in the raw pixel stream. For some applications, as described hereinbelow with reference to Figs. 3-6, circuit 26 may use a piecewise linear function to perform the non-linear mapping. Alternatively or additionally, the circuit may use one or more look-up tables to perform the non-linear mapping. Other techniques for performing the non-linear mapping will be apparent to those skilled in the art who have read the present application, and are within the scope of the present invention. Typically, the raw stream includes at least 100,000 input pixels, such as at least one million input pixels. For some applications, circuit 26 performs an additional non-linear mapping of the pixel stream output from the linear convolution filter, such as described hereinbelow with reference to Figs. 5 and 8.

A buffering and pre-processing unit 41 performs various functions on the input pixels, in addition to buffering the input pixels while circuit 26 is operating on them. Typically, pre-processing unit 41 performs image restoration functions on the sub-images, such as spike removal, noise filtering, edge detection, and frame widening. Alternatively or additionally, pre-processing unit 41 may be configured to carry out only one or two of these restoration functions, or to carry out additional digital filtering functions in the space of the mosaic sub-images. For example, pre-processing unit 41 may implement techniques described in the above-mentioned PCT International Publication WO 2007/054931. Although some of these steps, such as spike removal, may involve non-linear operations, they do not constitute non-linear mapping in the sense that is defined hereinabove.

A pre-filter non-linear mapping unit 42 performs a non-linear mapping of the input pixels. For some applications, the non-linear mapping unit uses digital hardware to implement the non-linear mapping, as described hereinbelow with reference to Fig. 4. Typically, non-linear mapping unit 42 uses a piecewise linear function to implement the non-linear mapping, as described hereinbelow with reference to Fig. 3. For some applications, in order to avoid image artifacts caused by knees in the piecewise linear function, non-linear mapping unit 42 uses curve approximation to smooth the knees, as described hereinbelow with reference to Fig. 10. For other applications, non-linear mapping unit 42 uses a sparse look-up table to implement the non-linear mapping, as described hereinbelow with reference to Figs. 12-13.

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In an embodiment of the present invention, non-linear mapping unit 42 implements several different non-linear mappings, and decides which to perform on the pixels output by image sensor 24. For some applications, non-linear mapping unit 42 decides based on a static configuration, for example, a configuration register of circuit 26. For other applications, non-linear mapping unit 42 decides which mapping to use dynamically, responsively to one or more characteristics of the input pixel stream.

In an embodiment of the present invention, non-linear mapping unit 42 performs different non-linear mappings on each of the sub-images received from sensor 24. For instance, the non-linear mapping unit may use different non-linear mappings corresponding to different deconvolution kernels that are applied to the different sub-images, as described hereinbelow. As one example, the non-linear mapping unit may apply a more aggressive mapping (with a steeper slope at low pixel values, as illustrated in the figures that follow) to the sub-images that have a more aggressive filter kernel (with a stronger high-pass filtering effect).

A linear convolution filter, such as a deconvolution filter (DCF) 44, performs a deblurring operation on the pixel stream output by non-linear mapping unit 42, typically for each of the sub-images individually. Filter 44 typically uses one or more kernels that are roughly inverse to the point spread function (PSF) of optics 22, in order to "undo" the effects of the aberrations of the optics. Methods for computing deconvolution kernels of this sort are described, for example, in the above-mentioned PCT International Publication WO 2004/063989, as well as in the above-mentioned U.S. Patent Application Publication 2007/0236573. Alternatively, other sorts of filter kernels may be applied by filter 44, whether for deblurring or for other image processing functions that are known in the art. The kernels are typically masked so that each of the sub-images is filtered independently of the other sub-images, notwithstanding the interleaving of the sub-images in the input pixel stream. Techniques of masking the kernels are explained, for example, in the above-mentioned PCT International Publication WO 2007/054931.

In many cameras, the PSF of the optics is not uniform over the entire field of view of the camera. Thus, in camera 20, for example, different areas of image sensor 24 may be subject to different PSF profiles. Therefore, for optimal deblurring, filter 44 may use different filter kernels for pixels in different parts of the image. Techniques of this sort are also explained, for example, in PCT International Publication WO 2007/054931.

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Additionally or alternatively, filter 44 may change the set of filter kernels on the fly, depending on the characteristics of the image captured by camera 20 (and hence of the input sub-images). Buffering and pre-processing block 41 supplies convolution parameters 50 to filter 44, such as image illumination level, type of image content, or other image information, which parameters filter 44 may use to choose among the different filter kernels. For some applications, the kernels may be varied depending on both the location of the current pixel in the image plane and on other factors, such as the image distance. The optics and DCF kernels may be chosen to provide specific image enhancement functions, such as increasing the effective depth of field of camera 20. Alternatively, the arrangement of filter 44, with different filtering operations applied in alternation to sub-images of different colors, may be used to carry out a wide variety of other image enhancement functions in the mosaic color space.

In an embodiment of the present invention, circuit 26 comprises a post-filter non-linear mapping unit 46, which performs a post-filter non-linear mapping of pixels output from filter 44. Post-filter non-linear mapping unit 46 uses a non-linear mapping function different from the mapping function used by pre-filter non-linear mapping unit 42, described above. For some applications, the post-filter unit uses digital hardware to implement the non-linear mapping, as described hereinbelow with reference to Figs. 6 and 9. Typically, the post-filter non-linear mapping is generally the inverse of the non-linear mapping performed by pre-filter unit 42, at least for a portion of the pixel values, as described hereinbelow with reference to Figs. 5 and 8, so as to reverse the effect of the pre-filter mapping and to prevent distortion in the sub-images output to ISP 28. Optionally, post-filter mapping unit 46 may implement a plurality of non-linear mappings and decide which mapping to use based on either a static configuration or in real-time, responsively to input from buffering and pre-processing block 41.

A post-processing unit 48 performs further processing operations on the sub-images, before outputting the deblurred sub-images to ISP 28. Examples of post-processing operations are described in, for example, the above-mentioned US Provisional Application 60/933,446.

For some applications, circuit 26 does not perform the post-filter non-linear mapping, and instead directly provides the output from filter 44 as input to post-processing unit 48.

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Mode 1 – Piecewise linear estimation without smoothing

Fig. 3 is a graphical illustration of a piecewise linear function NT_1, which implements a non-linear mapping, in accordance with an embodiment of the present invention. Function NT_1 uses four line segments to implement the mapping, which transforms input pixels p_{in} to output pixels p_{out}. The function is expressed mathematically by Equation 1 below. Additional piecewise linear functions that implement non-linear mappings will be evident to those skilled in the art who have read the present application, and are within the scope of the present invention. Functions NT_1 and NT_3 (described hereinbelow with reference to Fig. 7) are typically non-decreasing (although they may be decreasing at some points due to undesirable rounding errors). In the description of Fig. 3 that follows, certain numerical values are given, by way of example, for the parameters of the function, such as range limits, slopes and intercepts, but these values are given solely by way of example and not limitation. These parameters are, for the most part, configurable and may be varied depending on application requirements and image features.

The function uses a first line segment 59 to transform input pixels having input values in a first range S_1 to the value 0, or to another low value near 0. Range S_1 extends from 0 to a parameter BL, which represents the "black level" of the function, i.e., the value of the pixels below which no meaningful information is expected from the sensor. Typically, parameter BL is a low number, and may be zero.

The function uses a second line segment 60, having a slope M_1 greater than 1, such as a positive integer power of 2, for example 2 or 4, and an x-intercept equal to parameter BL, to transform input pixels having input values in a second range S_2. The low end of range S_2 equals BL, and the high end of S_2 is typically set to a value between 5% and 25% of the maximum allowable input value. For example, for implementations in which the allowable input value range is 0 to 1023, the high end of S_2 is typically 128, but any other suitable value may be used. For some applications, the high end of S_2 may even be the highest allowable input value..

The function uses a third line segment 62, having a slope of 1, for example, and a y-intercept equal to a parameter P1, having a typical value of between 0 and 512, such as 100, to transform input pixels having input values in a third range S_3. Range S_3 extends from the high end of range S_2 to an upper limit that is typically between 50% and 90% of the maximum

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allowable input value, but is, again, adjustable and may extend up to the highest allowable input value.

The function uses a fourth line segment 64, having a slope M_2 less than 1, such as a negative integer power of 2, for example 0.5 or 0.25, and a y-intercept equal to a parameter P2, to transform input pixels having input values in a fourth range S_4. On the ten-bit scale mentioned above, P2 typically has a value of between 512 and 1023, such as 768. Range S_4 extends from the high end of range S_3 to the maximum allowable input value.

Fig. 3 shows the straight line $p_{out} = p_{in}$ as a line segment 66 for reference. As noted earlier, the bounds of ranges S_1, S_2, S_3 and/or S_4 may be adjustable parameters, which may be configured by setting appropriate values in one or more configuration registers.

$$p_{out} = \begin{cases} 0 , p_{in} \in S_1; \\ M_1(p_{in} - BL), p_{in} \in S_2 ; \\ p_{in} + P1 , p_{in} \in S_3 ; \\ M_2 p_{in} + P2 , p_{in} \in S_4 ; \end{cases} \qquad \text{(Equation 1)}$$

Fig. 4 is a schematic illustration of a digital hardware circuit 80 that implements piecewise linear function NT_1, in accordance with an embodiment of the present invention. Additional circuits for implementing function NT_1 will be evident to those skilled in the art who have read the present application, and are within the scope of the present invention. When a range of values is given for parameters in this figure, as well as in the figures that follow, circuit 26 may comprise digital hardware that implements a specific function for several different values in the range. For some applications, circuit 26 uses a control input or a static configuration bit to choose from among the values. Additionally or alternatively, circuit 26 may choose from among the values on the fly, for example, according to parameters of the sub-images. Circuit 80 transforms an input pixel value p_{in}, comprising, for example, 8 or 10 bits, to an output pixel value p_{out}, comprising, for example, 8 or 10 bits in accordance with the function given in Equation 1 above. A first multiplier element 82 multiplies input value p_{in} by slope M_2. For applications in which circuit 80 sets slope M_2 to either 0.5 or 0.25, as described

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hereinabove, circuit 80 implements multiplier 82 using two bit-shifting elements, which shift input value p_{in} to the right by one or two bits, respectively, and a multiplexer to choose between the two bit-shifted values. Alternatively, circuit 80 shifts input value p_{in} to the right by an appropriate number of bits for values of slope M_2 equal to any negative integer power of 2. Further alternatively, circuit 80 allows any value less than 1 for slope M_2.

A first adder element 84 adds parameter P2 to the output of multiplier 82. A second adder element 86 adds parameter P1 to input value p_{in}. A subtractor element 88 subtracts parameter BL from input value p_{in}. A clamp-to-zero element 90 outputs 0 if the output of subtractor 88 is less than or equal to 0 (i.e., if the value of input pixel p_{in} is less than or equal to parameter BL), and passes through the output of subtractor 88 if the output is greater than 0. Input pixels with values less than BL thus generate a value of 0 at the output of clamp-to-zero element 90, in accordance with function NT_1. A second multiplier element 92 multiplies the output of clamp-to-zero element 90 by slope M_1. For applications in which circuit 80 sets slope M_2 to either 2 or 4, as described hereinabove, circuit 80 implements multiplier 92 using two bit-shifting elements, which shift the output of clamp-to-zero element 90 to the left by one or two bits, respectively, and a multiplexer to choose between the two bit-shifted values. Alternatively, circuit 80 shifts the output of clamp-to-zero element 90 to the left by an appropriate number of bits for values of slope M_1 equal to any positive integer power of 2. Further alternatively, circuit 80 allows any value greater than 1 for slope M_1.

The outputs of adder 84, adder 86, and multiplier 92 enter into a select-minimum block 94, which chooses the minimum values from among its inputs. Since the slopes of the line segments that comprise the function NT_1 are positive and decrease as p_{in} moves from BL towards infinity, the output of select-minimum block 94 provides the correct p_{out} for all values of p_{in}. For some applications, circuit 80 implements select-minimum block 94 using two comparators and two multiplexers.

Fig. 5 is a graphical illustration of a piecewise linear function NT_2, expressed in Equation 2 below, which implements a non-linear mapping that is generally inverse to the non-linear mapping implemented in function NT_1, in accordance with an embodiment of the present invention. Typically, function NT_1, described hereinabove with reference to Figs. 3 and 4, has a first functional characteristic, and function NT_2 has a second functional

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characteristic that is inverse to the first functional characteristic over at least a portion of the range of pixel values. For example, the first functional characteristic may be a coefficient or a slope applicable to a portion of the pixel values, such as to a segment of the function, and the second functional characteristic may be the inverse, e.g., the reciprocal of the coefficient or the slope. For cases in which function NT_1 includes a vertical segment (such as in range S_1 in Fig. 3), NT_2 typically does not use this segment. In the exemplary function shown in Fig. 5, for input values of $p_{in} = 0$, the output of NT_2 is equal to the parameter BL (which may be equal to zero), but the output for $p_{in} = 0$ may alternatively be set to another value. Similarly, as in Fig. 3, values of the parameters of NT_2 are given here by way of example, and any other suitable values may be used.

Function NT_2 uses three line segments to implement the mapping, which transforms input pixels p_{in} to output pixels p_{out}. The function maps the point ($p_{in} = 0$) to the point ($p_{out} = BL$). The function uses a first line segment 160, having a slope ($1/M_1$) and a y-intercept equal to parameter BL, to transform input pixels having input values in a range T_1. The function uses a second line segment 162, which in this example has a slope of 1, and a y-intercept equal to the additive inverse of parameter P1, to transform input pixels in range a T_2. The function uses a third line segment 164, having a slope ($1/M_2$) and a y-intercept equal to the additive inverse of parameter P2, to transform input pixels having input values in a range T_3. Fig. 5 shows the straight line $p_{out} = p_{in}$ as a line segment 166 for reference. Typically, ranges T_1, T_2, and T_3 correspond to the ranges of values to which function NT_1 maps input pixels having input values in range S_2, S_3, and S_4, respectively. For some applications, the bounds of ranges T_1, T_2, and/or T_3 may be adjustable parameters, which may be configured by setting appropriate values in one or more configuration registers.

$$p_{out} = \begin{cases} BL \; , p_{in}=0 \; ; \\ \dfrac{p_{in}}{M_1}+BL \; , \; p_{in} \in T_1 \; ; \\ p_{in}-P1 \; , p_{in} \in T_2 \; ; \\ \dfrac{(p_{in}-P2)}{M_2} \; , p_{in} \in T_3 \; ; \end{cases} \qquad \text{(Equation 2)}$$

Fig. 6 is a schematic illustration of a digital hardware circuit 180 that implements piecewise linear function NT_2, in accordance with an embodiment of the present invention. Additional circuits for implementing function NT_2 will be evident to those skilled in the art who have read the present application, and are within the scope of the present invention. Circuit 180 transforms an input pixel value p_{in}, comprising, for example, 8 or 10 bits, to an output pixel value p_{out}, comprising, for example, 8 or 10 bits, in accordance with the function given above in Equation 2. A first subtractor element 182 subtracts parameter P2 from input value p_{in}. For applications in which circuit 180 sets parameter P2 as a negative number, subtractor element 182 may subtract parameter P2 from input value p_{in} by adding the absolute value of parameter P2 to input value p_{in}. A first multiplier element 184 multiplies the output of subtractor 182 by the inverse of slope M_2. For applications in which circuit 80 sets slope M_2 equal to either 2 or 4, as described hereinabove, circuit 180 may implement multiplier 184 using two bit-shifting elements, which shift the output of subtractor 182 to the right by one or two bits, respectively, and a multiplexer to choose between the two bit-shifted values. A second subtractor element 186 subtracts parameter P1 from input value p_{in}. A second multiplier element 188 multiplies the input value p_{in} by the inverse of slope M_1. For applications in which circuit 80 sets slope M_1 equal to either 0.5 or 0.25, as described hereinabove, circuit 180 may implement multiplier 188 using two bit-shifting elements, which shift input value p_{in} to the left by one or two bits, respectively, and a multiplexer to choose between the two bit-shifted values. An adder element 192 adds parameter BL to the output of multiplier 188. The outputs of adder 192, multiplier 184, and subtractor 186 enter into a select-maximum block 194, which chooses the maximum values from among its inputs. Since the slopes of the line segments that comprise the function NT_2 are positive and increase as p_{in} moves from 0 towards infinity, the output of select-maximum block 194 provides the correct p_{out} for all values of p_{in}. For some applications, circuit 180 implements select-maximum block 194 using two comparators and two multiplexers

Fig. 7 is a graphical illustration of a piecewise linear function NT_3, which implements another non-linear mapping, in accordance with an embodiment of the present invention. Function NT_3 is similar to function NT_1, described hereinabove with reference to Fig. 3, except that function NT_3 is smoother, since the slopes of the component line segments change more gradually than in function NT_1. Thus, at a knee point 270 in Fig. 7, for example, the slope of function NT_3 is still discontinuous, but the change is not so abrupt as at the knees of NT_1. As in the preceding embodiments, the parameters of function NT_3 may be adjusted to any suitable values, and specific values and ranges are given below solely by way of example. Fig. 7 shows the straight line $p_{out} = p_{in}$ as a line segment 266 for reference.

Function NT_3 uses four line segments to implement the mapping, which transforms input pixels p_{in} to output pixels p_{out}. The function uses a first line segment 259 to map input pixels having input values in a first range U_1, which extends from 0 to parameter BL, to the value 0, or another low value near 0. Alternatively, BL may be set to zero, in which case segment 259 is omitted.

The function uses a second line segment 260, having a slope of typically between 2 and 16, for example, 4, and an x-intercept equal to parameter BL, to map input pixels having input values in a second range U_2. The low end of range U_2 equals BL, and the high end of U_2 may extend to up to 50% of the maximum allowable input value. For example, for implementations in which the allowable input value range is 0 to 1023, the high end of U_2 may be between 80 and 120, such as 100.

The function uses a third line segment 262, having a slope lower than the slope of line segment 260, such as between 1.5 and 4, for example, 2, and an x-intercept equal to a parameter Q1, typically having a value of between 200 and 500, to map input pixels having input values in a third range U_3. Range U_3 extends from the high end of range U_2 to, typically, between 50% and 90% of the maximum allowable input value. For some applications, function NT_3 uses only three line segments to implement the mapping, and omits line segment 260.

The function uses a fourth line segment 264, which has a slope of exactly 1 in this example, and which intersects the origin, to map input pixels having input values in a fourth range U_4. Range U_4 extends from the high end of range U_3 to the maximum allowable input value. As noted earlier, the parameters that define ranges U_1, U_2, U_3, and/or U_4 may be configured by setting appropriate values in one or more configuration registers.

An implementation of function NT_3 in digital hardware may be similar to the implementation of function NT_1 described hereinabove with reference to Fig. 4. Specifically, a circuit that implements function NT_3 may remove from circuit 80 multiplier 82 and adder 84, and replace adder 86 by a subtractor unit, which subtracts parameter Q1 from input value p_{in}, followed by a multiplier unit that multiplies the output of the subtractor by 2.

Fig. 8 is a graphical illustration of a piecewise linear function NT_4, which implements a non-linear mapping that is generally inverse to the non-linear mapping implemented in function NT_3, in accordance with an embodiment of the present invention. The function maps the point ($p_{in} = 0$) to the point ($p_{out} = BL$). The function uses a first line segment 272, having a slope that is the multiplicative inverse of the slope of line segment 260, for example, 0.25, and an x-intercept equal to a parameter R1 (where R1 = -4*BL in this example), to map input pixels having input values in a range V_1. The function uses a second line segment 274, having a slope that is the multiplicative inverse of the slope of line segment 262, for example, 0.5, and an x-intercept equal to a parameter R2, to map input pixels having input values in range V_2. The function uses a third line segment 276, which overlaps with the line $p_{out} = p_{in}$, to map input pixels in range V_3. Typically, ranges V_1, V_2, and V_3 correspond to the ranges of values to which function NT_3 maps input pixels having input values in range U_2, U_3, and U_4, respectively (and thus the unity slope of segment 276 in range V_3 corresponds to the unity slope of segment 264 in range U_4). For some applications, the parameters that define ranges V_1, V_2, and/or V_3 may be configured by setting appropriate values in one or more configuration registers.

Fig. 9 is a schematic illustration of a digital hardware circuit 280 that implements piecewise linear function NT_4, in accordance with an embodiment of the present invention.

Additional circuits for implementing function NT_4 will be evident to those skilled in the art who have read the present application, and are within the scope of the present invention. A first subtractor unit 284 subtracts parameter R2 from input pixel value p_{in}. (Assuming R2 to be negative, as shown in Fig. 8, this subtraction operation is equivalent to adding the absolute value of R2 to p_{in}.) A divide-by-2 unit 286 divides the output of subtractor 284 by 2. For some applications, circuit 280 may implement divide-by-2 unit 286 using a bit shifting element that shifts the output of subtractor 284 to the right by one bit. A second subtractor unit 294 subtracts parameter R1 from input pixel p_{in}. A divide-by-4 unit 296 divides the output of subtractor 294 by 4. For some applications, circuit 280 may implement divide-by-4 unit 296 using a bit shifting element that shifts the output of subtractor 294 to the right by two bits. Input pixel value p_{in} and the outputs of divide-by-2 unit 286 and divide-by-4 unit 296 enter into a select maximum block 298, which outputs the correct value for output pixel value p_{out}.

Mode 2 – Piecewise linear estimation with curve approximation

Fig. 10 is a graphical illustration of a non-linear mapping 299 that uses a spline to smooth knee 270, in accordance with an embodiment of the present invention. Knee 270 (as shown in Fig. 7, for example) is caused by a transition between line segments of differing slopes in a piecewise linear transformation. Knees of this sort sometimes cause undesirable effects in the output pixel stream from circuit 26, which may lead to artifacts in the image produced by ISP 28. Circuit 26 reduces or eliminates these undesirable effects by replacing the line segments in a neighborhood 300 (represented by the shaded area in Fig. 10) of knee 270 with a smoother curve, such as a spline. While the description that follows describes the use of a spline to smooth knee 270, other methods for smoothing knees in curves may be used, as will be readily apparent to one skilled in the art.

Non-linear mapping 299 comprises three sets of points: A first set of points lies on a line segment 301 (only a point 303 in this set is shown in the figure). A second set of points, comprising points 304, 305, and 306, is in neighborhood 300 of knee 270 and lies on the spline. A third set of points, of which points 308, 310, and 312 are shown in the figure, lies on a line segment 302. Substitution of the portions of line segments 301 and 302 in neighborhood 300 of knee 270 by spline points 304, 305, and 306 causes mapping 299 to be smoother and to better approximate a curve..

Fig. 11 is a schematic illustration of a digital hardware circuit 320 that implements a non-linear mapping that uses splines to smooth knees in a piecewise linear transformation, in

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accordance with an embodiment of the present invention. While circuit 320 may smooth any number of knees present in the piecewise linear transformation, in this example, and in the description that follows, circuit 320 is designed to smooth two knees using spline insertion. Additional circuits for implementing non-linear mappings that use splines to smooth knees will be evident to those skilled in the art who have read the present application, and are within the scope of the present invention.

A piecewise linear function unit 330 performs a piecewise linear transformation whose graph has two knees, for example, the transformation NT_1, which is described hereinabove with reference to Figs. 3 and 4. A first spline lookup table 326 constructs a smooth curve in a neighborhood of a first knee by associating some or all values of p_{in} with respective output pixel values. A second spline lookup table 328 constructs a smooth curve in a neighborhood of a second knee. Typically, spline lookup tables 326 and 328 specify output pixel values only for input pixels in the neighborhood of the first knee or the second knee, respectively, and not for all input values of p_{in}. In an embodiment of the present invention, spline lookup tables 326 and 328 use the value of the input pixel as an index. Alternatively, the spline lookup tables use as the index a difference between the value of the lowest-amplitude pixel in the neighborhood of the first or second knee, respectively, and the value of input pixel p_{in}. Alternatively or additionally, spline lookup tables 326 and 328 associate some or all input pixel values with respective offset values, and circuit 320 adds the outputs of tables 326 and 328 to constant base pixel values, respectively, thus allowing circuit 320 to implement tables 326 and 328 with a memory element having fewer output bits than the width in bits of input pixel value p_{in}.

A first knee neighborhood detector 322 detects whether input pixel value p_{in} is in the neighborhood of the first knee. For some applications, circuit 320 defines a knee range that includes values of input pixels that are in the neighborhood of the first knee, and detector 322 compares the input pixel with the lower and upper ends of the knee range to decide whether the input pixel value is in the vicinity of the knee. For example, circuit 320 may use two digital comparators, one for the upper end and one for the lower end of the knee range, and one logical gate, to implement detector 322. A second knee neighborhood detector 324 works similarly to first knee neighborhood detector 322, but with comparator values corresponding to the second knee.

If first knee neighborhood detector 322 indicates that the input pixel is in the neighborhood of the first knee, a multiplexer (mux) 334 chooses the output of first spline lookup table 326. If second knee neighborhood detector 324 indicates that the input pixel is in the neighborhood of the second knee, mux 334 chooses the output of second spline lookup table 328. If, on the other hand, knee neighborhood detectors 322 and 324 indicate that the input pixel is not in the neighborhood of either the first or the second knee, respectively, mux 334 chooses the output of piecewise linear function unit 330. Circuit 320 may implement selector logic for mux 334, for example, using a NAND gate 332 on the output of knee neighborhood detectors 322 and 324.

Mode 3 – Piecewise linear estimation using sparse look-up table

Fig. 12 is a graphical illustration of a piecewise linear transformation 340 that uses multiple segments of varying segment lengths to approximate a smoothly curved non-linear mapping 341, in accordance with an embodiment of the present invention. Transformation 340 approximates non-linear mapping 341 using shorter line segments in a low-amplitude range of pixel values 342, and longer line segments in a high-amplitude range of pixel values 344.

Fig. 13 is a graphical illustration of a piecewise linear transformation 350 that approximates smoothly curved non-linear mapping 341 using a different set of segments, in accordance with another embodiment of the present invention. Transformation 350, in contrast to transformation 340 (Fig. 12), approximates non-linear mapping 341 using longer line segments in a low-amplitude range of pixel values 352, and shorter line segments in a relatively high-amplitude range of pixel values 354. In some cases, transformation 350 approximates non-linear mapping 341 with greater accuracy than does transformation 340.

Fig. 14 is a schematic illustration of a digital hardware circuit 360 that implements a piecewise linear transformation of the sort shown in Figs. 12 and 13, in accordance with an embodiment of the present invention. Circuit 360 approximates a smooth curve using a sparse lookup table 362, with entries corresponding to varying segment lengths. Additional circuits for implementing piecewise linear transformations that approximate smooth curves by using sparse lookup tables will be evident to those skilled in the art who have read the present application, and are within the scope of the present invention.

Sparse lookup table 362 contains a number of table entries equal to the number of line segments that make up the piecewise linear transformation. Thus, the difference in value between each two neighboring table entries establishes the number of input pixel values that the transformation maps via a specific line segment. In relatively sharply-curved areas of the transformation, sparse lookup table 362 contains many table entries that are closely spaced. In

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relatively gradually-curved areas of the transformation, on the other hand, sparse lookup table 362 contains fewer table entries that are spaced further apart.

A subtractor element 361 subtracts parameter BL from input pixel values p_{in} so that input pixel values below BL are mapped to zero. (Alternatively, an equivalent effect may be obtained by appropriate choice of lookup table parameters.) The output of subtractor 361 serves as the key to sparse lookup table 362, which associates each input pixel value with a chosen table entry 363, typically by choosing a table entry having a key value that is closest to, but not greater than, the input pixel value. Sparse lookup table 362 maps each table entry to a segment intercept 364 and a segment slope 366. Therefore, each table entry uniquely defines a line segment by its slope and its intercept. A mask logic unit 368 subtracts chosen table entry 363 from the value of the input pixel and, a multiplier unit 370 then multiplies the output of mask logic unit 368 by segment slope 366. An adder unit 372 adds the output of multiplier unit 370 to segment intercept 364 to obtain the output pixel value p_{out}.

In an embodiment of the present invention, in which both input pixel value p_{in} and output pixel value p_{out} are 12 bit values, circuit 360 uses sparse lookup table 362 with 19 table entries. Table 1 is an example of such a table, for 12-bit input pixels, which uses longer line segments for relatively high-amplitude pixels and shorter line segments for relatively high-amplitude pixels, as described hereinabove with reference to Fig. 12. (Alternatively, the same table may be used for 10-bit input pixel values simply by truncating the two least significant bits in each table entry.) Each entry provides a slope and intercept for the corresponding segment, wherein the slopes typically decrease while the intercepts increase with increasing entry number.

TABLE 1

Entry Number	Table Entry
19	11xx xxxx xxxx
18	10xx xxxx xxxx
17	011x xxxx xxxx
16	010x xxxx xxxx
15	0011 xxxx xxxx
14	0010 xxxx xxxx
13	0001 1xxx xxxx

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12	0001 0xxx xxxx
11	0000 11xx xxxx
10	0000 10xx xxxx
9	0000 011x xxxx
8	0000 010x xxxx
7	0000 0011 xxxx
6	0000 0010 xxxx
5	0000 0001 1xxx
4	0000 0001 0xxx
3	0000 0000 11xx
2	0000 0000 10xx
1	0000 0000 0000

An "x" in Table 1 indicates a "do not care" bit value, meaning that the value of the bit in question in the input pixel does not affect the functioning of the table.

For applications in which circuit 360 uses table 362 as shown in Table 1, table 362 locates table entry 363 for any given input pixel value p_{in} by observing only the leftmost asserted ("1") bit in the binary representation of the input pixel and a neighboring bit immediately to the right of the leftmost "1" bit. Table 362 chooses for input pixel value p_{in} the table entry whose leftmost "1" bit and neighbor bit are equal to those of the input pixel value. For example, for the input pixel value 0001 0011 1101, table 362 finds that the bits "10" in positions fourth and fifth from left, respectively, which are the leftmost asserted bit of the input pixel value and its right-hand neighbor bit, correspond to table entry number 12. For applications in which circuit 360 uses sparse lookup table 362 in this manner, mask logic unit 368 typically obtains the difference between chosen table entry 363 and the value of the input pixel by masking (i.e., setting to zero) the leftmost "1" bit in the binary representation of the input pixel and the bit immediately to the right of the leftmost "1" bit. Multiplier unit 370 then multiplies the result of this masking operation by the appropriate segment slope 366.

Although Table 1 illustrates sparse lookup table 362 for bit vectors of width 12, it will be readily appreciated by one skilled in the art that lookup table 362 may be adapted for any width of bit vector.

In another embodiment of the present invention, in which both input pixel value p_{in} and output pixel value p_{out} are 10 bit values, sparse lookup table 362 may have 10 table entries. The following is an example of such a table, which uses longer line segments for relatively low-amplitude pixels and shorter line segments for relatively high-amplitude pixels, as described hereinabove with reference to Fig. 13:

TABLE 2

Entry Number	Table Entry
10	11 1xxx xxxx
9	11 0xxx xxxx
8	10 1xxx xxxx
7	10 0xxx xxxx
6	01 10xx xxxx
5	01 00xx xxxx
4	00 11xx xxxx
3	00 10xx xxxx
2	00 01xx xxxx
1	00 0xxx xxxx

In this exemplary table, sparse lookup table 362 uses a subset of the bits of input pixel value p_{in}, for example, the most significant "1" and one or two neighboring bits, to associate table entry 363 with input pixel value p_{in}.

Fig. 15 is a graphical illustration of a mapping function 380 and a mapping function 382 that is generally inverse to function 380, in accordance with an embodiment of the present invention. Functions 380 and 382 may be approximated by piecewise linear functions, using one or more of the techniques described above. Function 382 is a reflection of function 380 across a line $p_{out} = p_{in}$ 384. In an embodiment of the present invention, a digital hardware circuit that implements inverse function 382 with a sparse lookup table uses the same basic architecture as circuit 360, described hereinabove with reference to Fig. 14. The circuit replaces sparse lookup table 362 with a new sparse lookup table that produces inverse function 382. For some applications, the new sparse lookup table uses the same entries as table 362, replacing only the values of segment slopes 364 and segment intercepts 366 for the entries. In addition, to generate function 382, subtractor 361 is removed, and an additional adder element adds parameter BL to the output of adder 372. (Alternatively, the value BL may simply be added to segment intercept 364.)

Fig. 16 is a schematic illustration of an exemplary non-linear mapping 400, in accordance with an embodiment of the present invention. A function domain 402 includes a spectrum of allowed input values for a non-linear mapping function, for example, the values from 0 to 255 for an 8-bit input domain. A function range 404 contains a spectrum of allowed output values for the non-linear mapping function, likewise from 0 to 255 in the present example. Subsets of domain 402 and range 404 are characterized by sub-domain and sub-range lengths, respectively, which are defined as the difference between the highest and lowest values of members of the subsets of the domain and the range, respectively. A low-amplitude sub-domain 406 comprises a non-empty subset of domain 402 that contains values from domain 402 having relatively low amplitudes, for example, between 20 and 40. A low-amplitude sub-range 408 comprises a non-empty subset of range 404 that contains values from range 404 having relatively low amplitudes, for example, between 60 and 120. The non-linear mapping function performs low-amplitude expansion by mapping members of low-amplitude sub-domain 406 to low-amplitude sub-range 408, whose length is greater than the length of sub-domain 406. Similarly, a high-amplitude sub-domain 410 comprises a non-empty subset of domain 402 that contains values from domain 402 having high relative amplitudes, for example, between 150 and 220. For some applications, the non-linear mapping function performs high-amplitude compression by mapping members of sub-domain 402 to a high-amplitude sub-range 412, whose length is less than the length of sub-domain 410.

Fig. 17 is an exemplary graph 418 including a curve 420 representing non-linear mapping 400 of Fig. 16, in accordance with an embodiment of the present invention. The x- and y-axes of graph 418 represent input and output values, respectively, of the non-linear mapping function. As can be seen in the figure, the mapping function performs a low-amplitude expansion of sub-domain 406 to sub-range 408, and a high-amplitude compression of sub-domain 410 to sub-range 412.

In an embodiment of the present invention, graph 418 implements curve 420 using a power law function, for example, of the form given in Equation 3 below.

$$p_{out} = M^{(1-x)} * p_{in}{}^{x} \quad \text{(Equation 3)}$$

In this exemplary function, M is the minimum value of input pixel value p_{in}, and $x < 1$. The function applies a gain that is greatest for the lowest pixel values and is normalized to be 1 for

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the maximum pixel value. The function keeps the same dynamic range of output pixel values as input pixel values, but redistributes the pixel values so that the low range of input values is mapped to a wider range of output values, while the high range of input values is compressed into a narrower range of output values. The mapping of Equation 3 may be approximated by a piecewise linear function, as described above.

Alternatively, graph 418 may use another power law function, for example, of the form $y = (a * (x - b) ^\wedge n) + c$, where $n < 1$, $a > 0$.

It will thus be appreciated that the embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art.

In all of the figures described hereinabove no reference is made to widths of signals or buses, and it will be readily appreciated by one skilled in the art that the circuits described may be implemented for any width of signals, parameters, registers, and configuration values. Similarly, various implementation details of digital logic components such as adders, multipliers, and multiplexers, will be apparent to one skilled in the art, including but not limited to use of fixed point or floating point arithmetic, and synchronous and combinational design. It will likewise be appreciated by one skilled in the art that the components may be implemented using various techniques known in the art, including software-based implementations on programmable components, such as microprocessors or field-programmable logic devices.

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CLAIMS

1. Imaging apparatus for use with an image sensor, the apparatus comprising:

a non-linear mapping circuit, which is configured to receive a raw stream of input pixel values generated by the image sensor and to perform a non-linear mapping of the input pixel values to generate a mapped stream of mapped pixel values; and

a linear convolution filter, which is arranged to filter the mapped stream of mapped pixel values to generate a filtered stream of filtered pixel values.

2. The apparatus according to claim 1, wherein the image sensor generates the raw stream of input pixel values responsively to light that is incident on the sensor via objective optics that are characterized by a point spread function (PSF), which gives rise to an input blur, and wherein the linear convolution filter comprises a deconvolution filter which has a filter kernel determined according to the PSF.

3. The apparatus according to claim 1, wherein the non-linear mapping circuit is configured to perform the non-linear mapping on each of the input pixel values individually, irrespective of any neighboring input pixel values.

4. The apparatus according to claim 1, wherein the raw stream includes at least 100,000 of the input pixel values, and wherein the non-linear mapping circuit is configured to perform the non-linear mapping such that at least 10% of the mapped pixel values are different from the corresponding input pixel values.

5. The apparatus according to claim 1, wherein the non-linear mapping circuit comprises a first non-linear mapping circuit, wherein the non-linear mapping includes a first non-linear mapping, and comprising a second non-linear mapping circuit, which is arranged to perform a second non-linear mapping of the filtered pixel values.

6. The apparatus according to claim 5, wherein the first non-linear mapping has a first functional characteristic, and the second non-linear mapping has a second functional characteristic that is inverse to the first functional characteristic over at least a portion of a range of allowable filtered pixel values.

7. The apparatus according to any of claims 1-6, wherein the raw stream of input pixel values includes an input subset of relatively low-amplitude pixel values characterized by an input range of amplitude values, and wherein the non-linear mapping circuit is configured to perform the non-linear mapping of the low-amplitude pixel values to a mapped subset of the

mapped pixel values characterized by a mapped range of amplitude values that is greater than the input range of amplitude values.

8. The apparatus according to any of claims 1-6, wherein the non-linear mapping includes a power law transformation, and wherein the non-linear mapping circuit is configured to perform the power law transformation.

9. The apparatus according to any of claims 1-6, wherein the non-linear mapping uses a piecewise linear function, and wherein the non-linear mapping circuit is configured to implement the piecewise linear function.

10. The apparatus according to claim 9, wherein the non-linear mapping circuit is configured to use curve approximation to smooth knees in the piecewise linear function.

11. The apparatus according to claim 9, wherein the piecewise linear function includes a plurality of segments, and wherein the non-linear mapping circuit comprises a sparse lookup table having respective entries that specify the segments.

12. The apparatus according to any of claims 1-6, wherein the image sensor is a mosaic image sensor, and wherein the raw stream of input pixel values belongs to a plurality of interleaved input sub-images, each sub-image responsive to light of a different, respective color that is incident on the mosaic image sensor, and wherein the non-linear mapping circuit is configured to generate a plurality of interleaved output sub-images respectively, and wherein the apparatus comprises an image signal processor (ISP), which is coupled to receive and combine the plurality of the output sub-images in order to generate a color video output image.

13. The apparatus according to any of claims 1-6, wherein the non-linear mapping circuit is configured to dynamically alter the non-linear mapping responsively to one or more characteristics of the input pixel values.

14. A method for imaging, comprising:

receiving a raw stream of input pixel values generated by an image sensor;

digitally performing a non-linear mapping of the input pixel values to generate a mapped stream of mapped pixel values; and

applying a linear convolution filter to the mapped stream of mapped pixel values to generate a filtered stream of filtered pixel values.

15. The method according to claim 14, wherein the raw stream of input pixel values is generated by the image sensor responsively to light that is incident on the sensor via objective optics that are characterized by a point spread function (PSF), which gives rise to an input blur, and wherein applying the linear convolution filter comprises applying a deconvolution filter which has a filter kernel determined according to the PSF.

16. The method according to claim 14, wherein performing the non-linear mapping comprises performing the non-linear mapping on each of the input pixel values individually, irrespective of any neighboring input pixel values.

17. The method according to claim 14, wherein the raw stream includes at least 100,000 of the input pixel values, and wherein performing the non-linear mapping comprises performing the non-linear mapping such that at least 10% of the mapped pixel values are different from the corresponding input pixel values.

18. The method according to claim 14, wherein performing the non-linear mapping comprises performing a first non-linear mapping, and comprising performing a second non-linear mapping of the filtered pixel values.

19. The method according to claim 18, wherein the first non-linear mapping has a first functional characteristic, and the second non-linear mapping has a second functional characteristic that is inverse to the first functional characteristic over at least a portion of a range of allowable filtered pixel values.

20. The method according to any of claims 14-19, wherein the raw stream of input pixel values includes an input subset of relatively low-amplitude pixel values characterized by an input range of amplitude values, and wherein performing the non-linear mapping comprises performing the non-linear mapping of the low-amplitude pixel values to a mapped subset of the mapped pixel values characterized by a mapped range of amplitude values that is greater than the input range of amplitude values.

21. The method according to any of claims 14-19, wherein performing the non-linear mapping comprises performing a power law transformation.

22. The method according to any of claims 14-19, wherein performing the non-linear mapping comprises implementing a piecewise linear function.

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23. The method according to claim 22, wherein implementing the piecewise linear function comprises using curve approximation to smooth knees in the piecewise linear function.

24. The method according to claim 22, wherein the piecewise linear function includes a plurality of segments, and wherein implementing the piecewise linear function comprises using a sparse lookup table having respective entries that specify the segments.

25. The method according to any of claims 14-19, wherein the image sensor is a mosaic image sensor, wherein the raw stream of input pixel values belongs to a plurality of interleaved input sub-images, each sub-image responsive to light of a different, respective color that is incident on the mosaic image sensor, wherein performing the non-linear mapping comprises generating a plurality of interleaved output sub-images respectively, and wherein the method comprises receiving and combining the plurality of the output sub-images in order to generate a color video output image.

26. The method according to any of claims 14-19, wherein performing the non-linear mapping comprises dynamically altering the non-linear mapping responsively to one or more characteristics of the input pixel values.

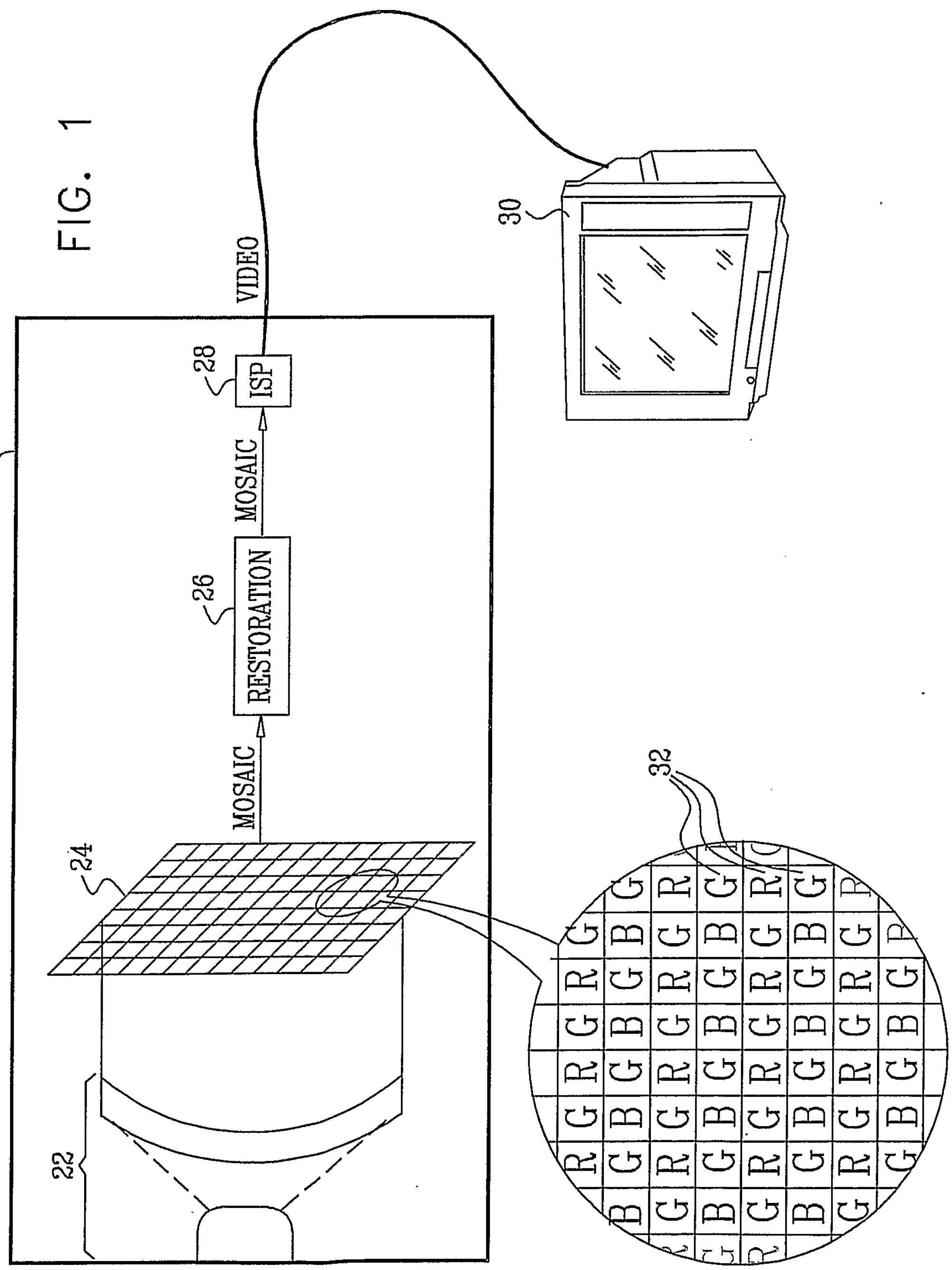


FIG. 1

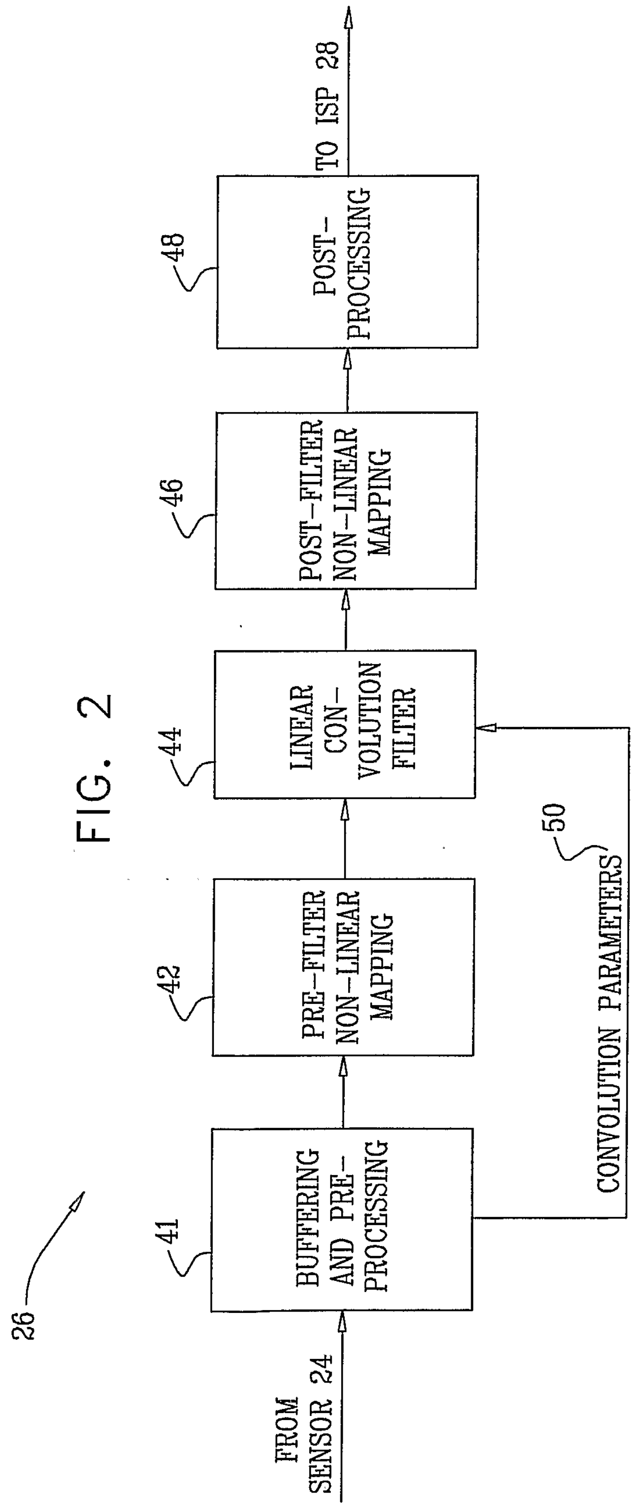

26
FROM SENSOR 24
41
BUFFERING AND PRE-PROCESSING
42
PRE-FILTER NON-LINEAR MAPPING
44
LINEAR CON-VOLUTION FILTER
46
POST-FILTER NON-LINEAR MAPPING
48
POST-PROCESSING
TO ISP 28
50
CONVOLUTION PARAMETERS

FIG. 2

FIG. 3

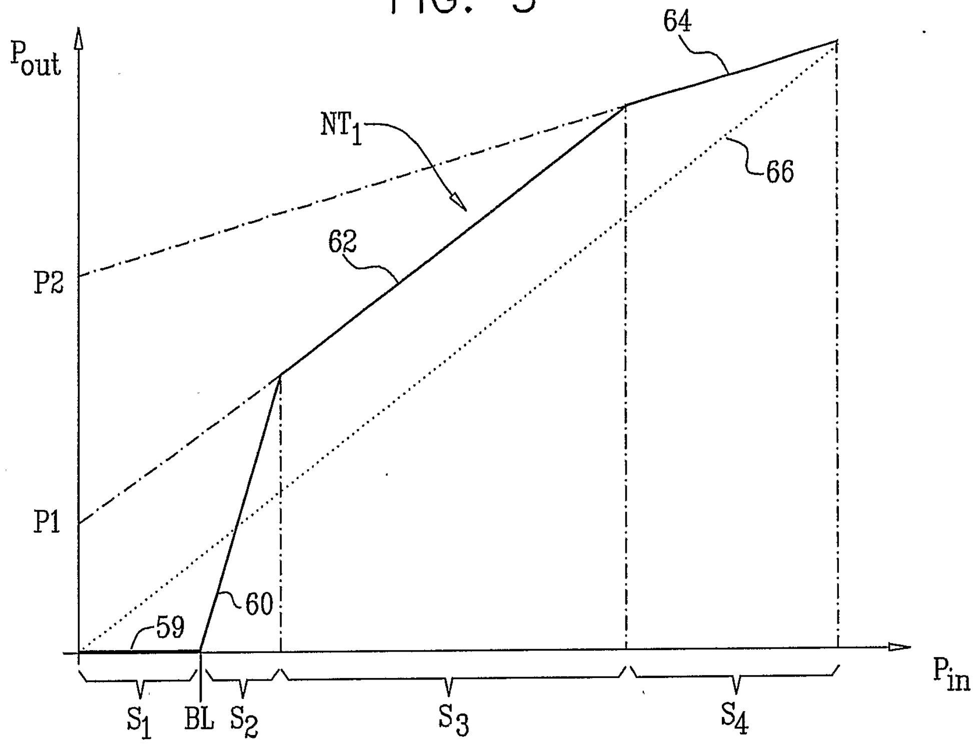

Pout
64
NT1
66
62
P2
P1
60
59
Pin
S1
BL
S2
S3
S4

FIG. 4

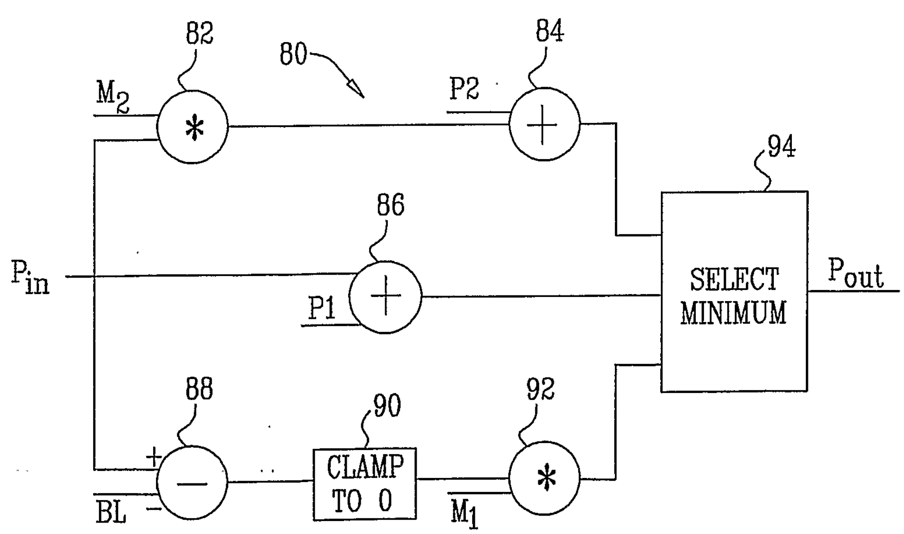
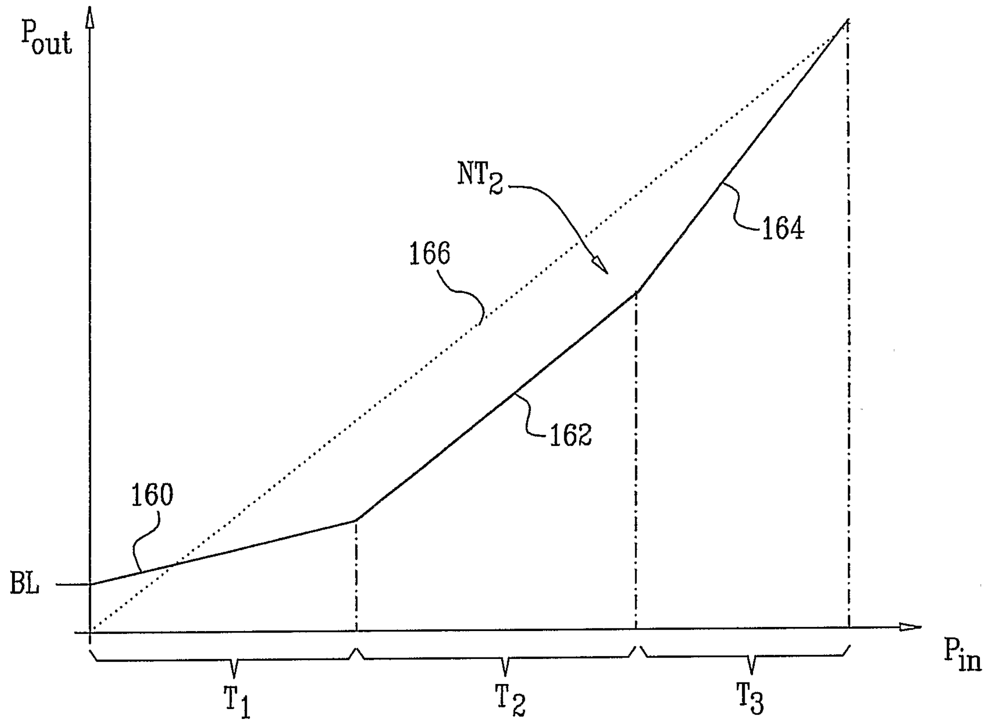
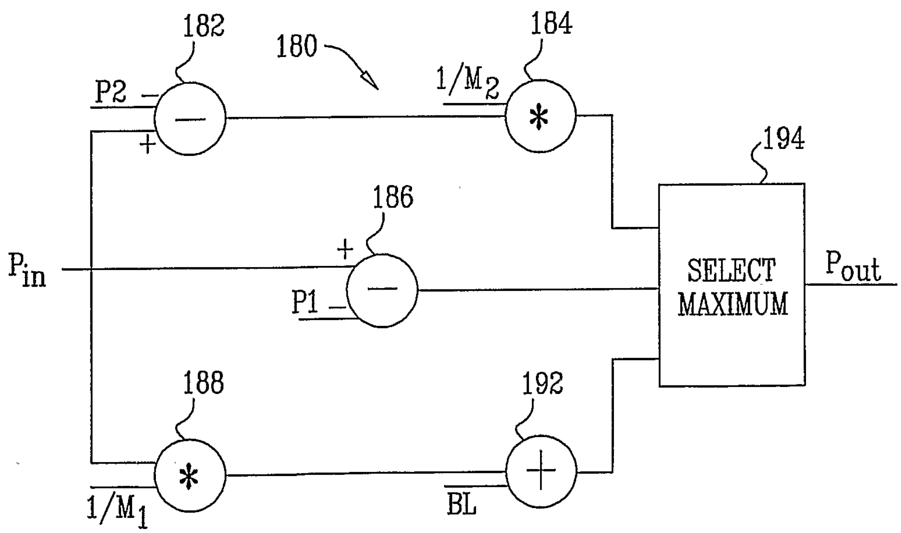

82
80
84
M2
P2
94
86
Pin
SELECT MINIMUM
Pout
P1
88
90
92
CLAMP TO 0
BL
M1

FIG. 5



P_{out}
NT_2
164
166
162
160
BL
P_{in}
T_1
T_2
T_3

FIG. 6



182
180
184
P2
$1/M_2$
194
186
P_{in}
SELECT MAXIMUM
P_{out}
P1
188
192
$1/M_1$
BL

FIG. 7

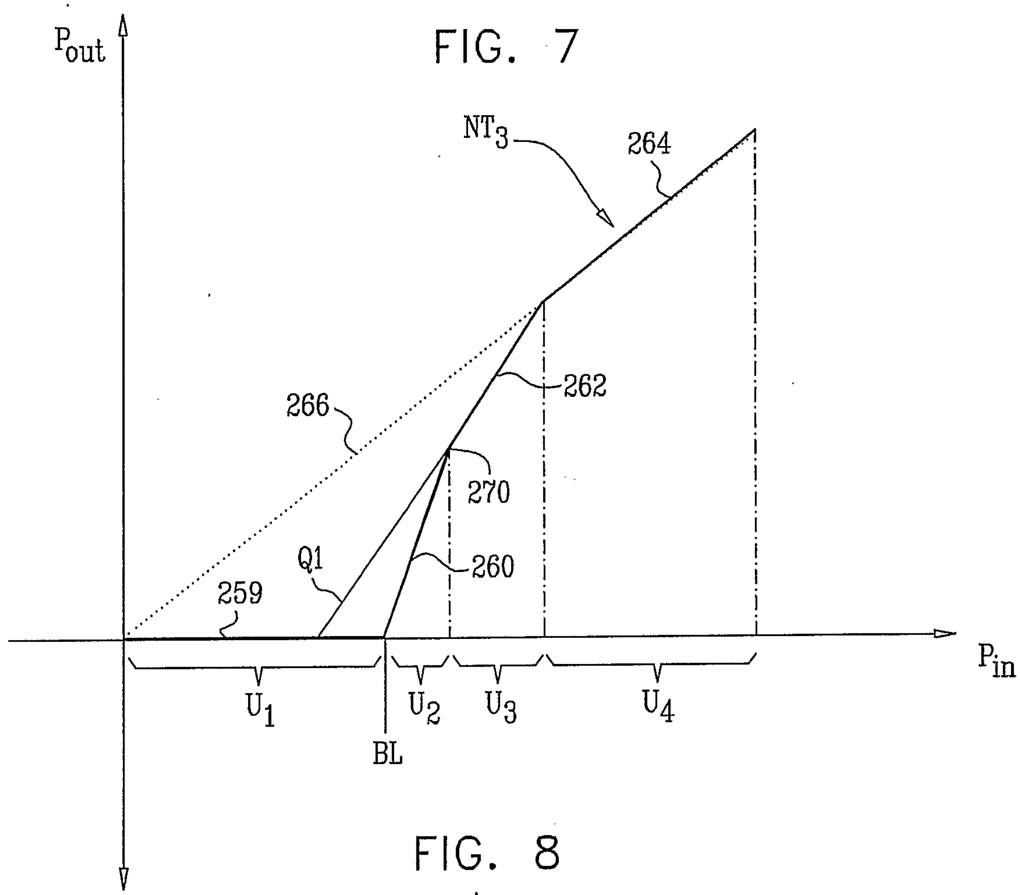

Pout
NT3
264
262
266
270
Q1
260
259
Pin
U1
U2
U3
U4
BL

FIG. 8

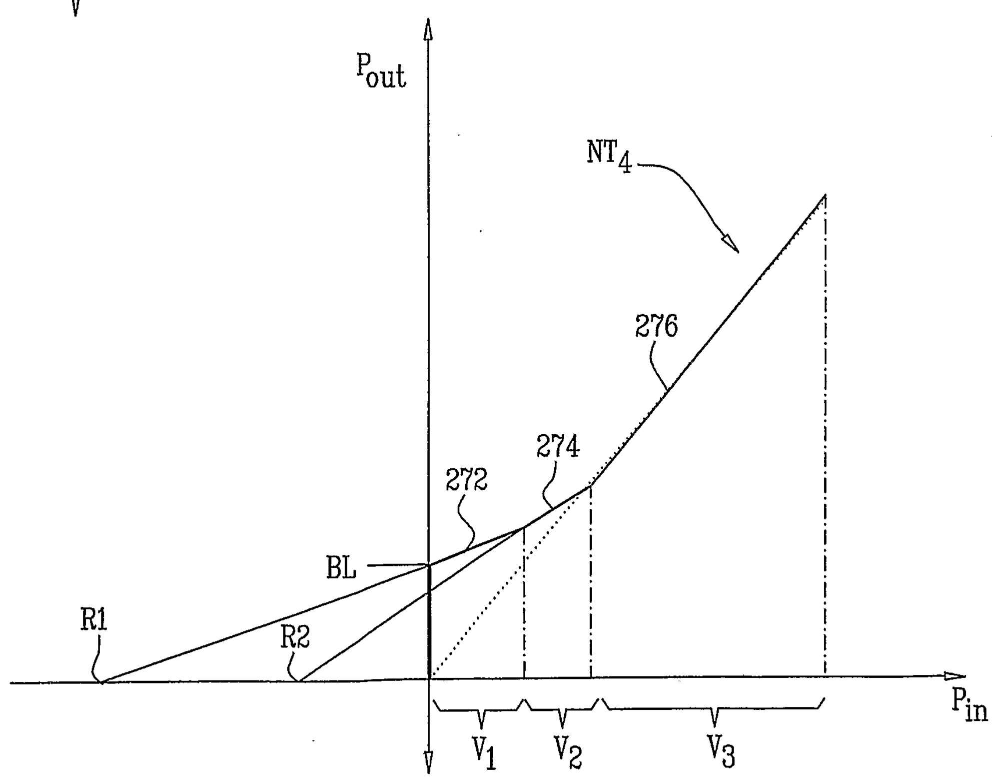

Pout
NT4
276
274
272
BL
R1
R2
Pin
V1
V2
V3

FIG. 9

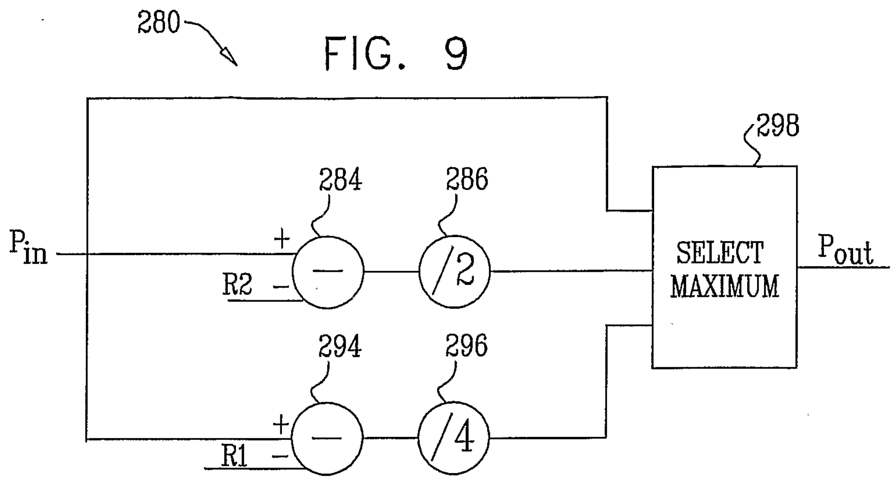

280
298
284
286
P_{in}
+
R2 −
SELECT
MAXIMUM
P_{out}
294
296
+
R1 −
/2
/4

FIG. 10

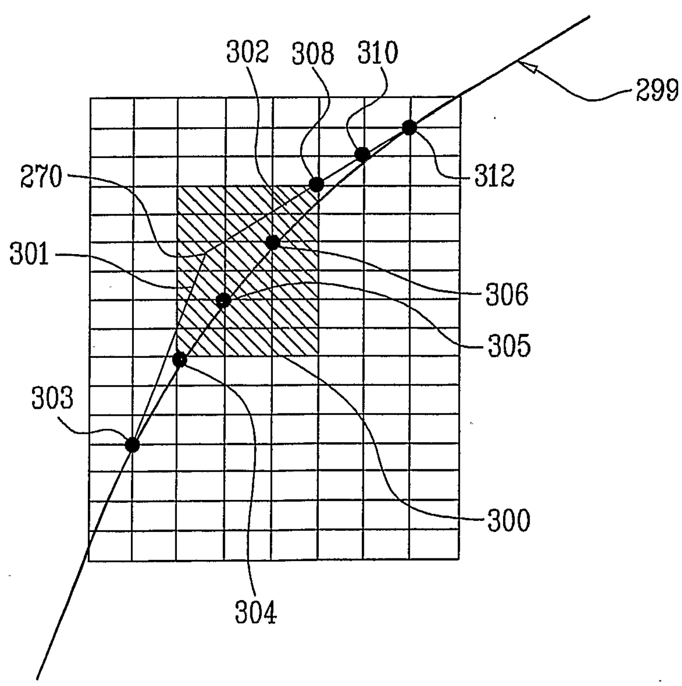
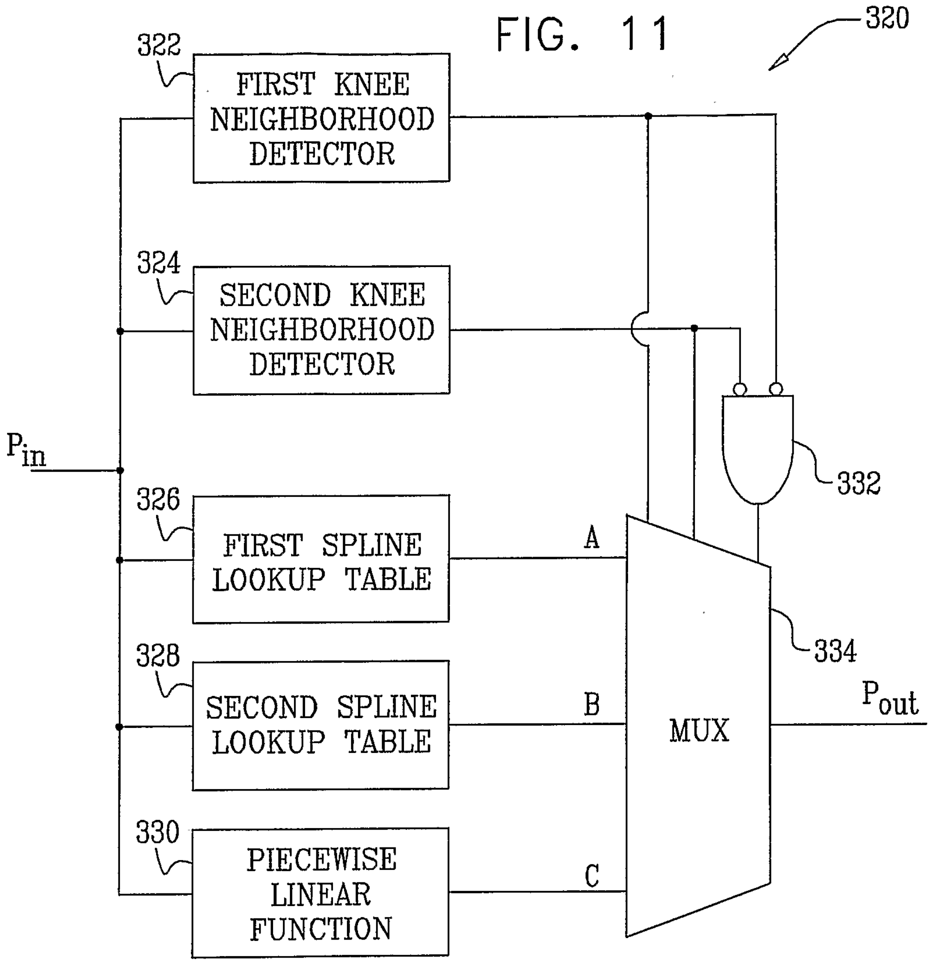
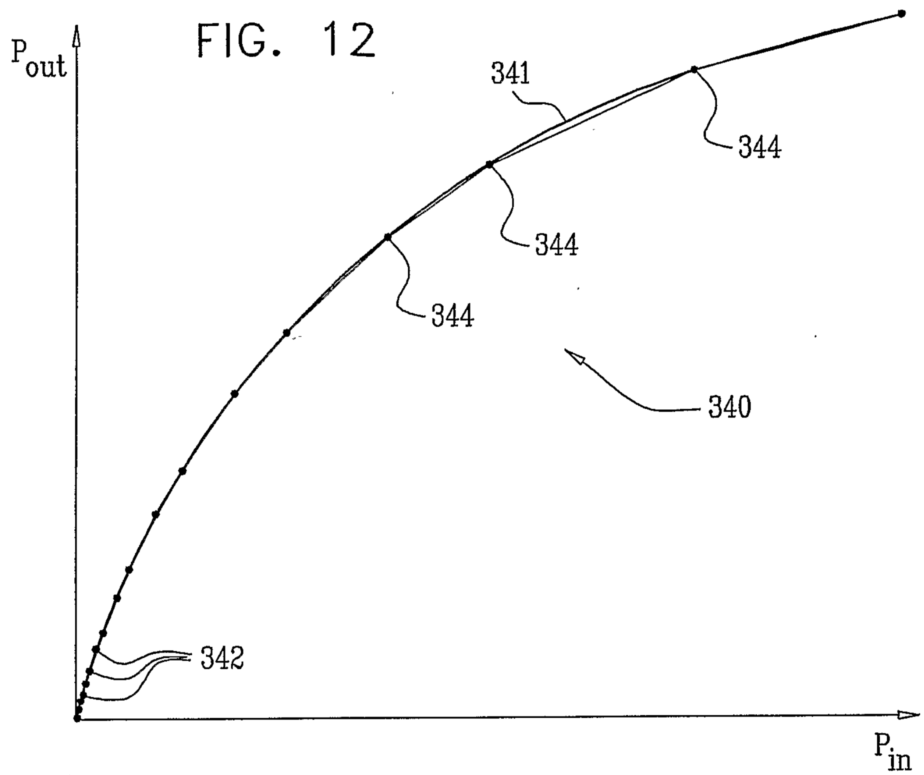

302 308 310
299
270
312
301
306
305
303
300
304

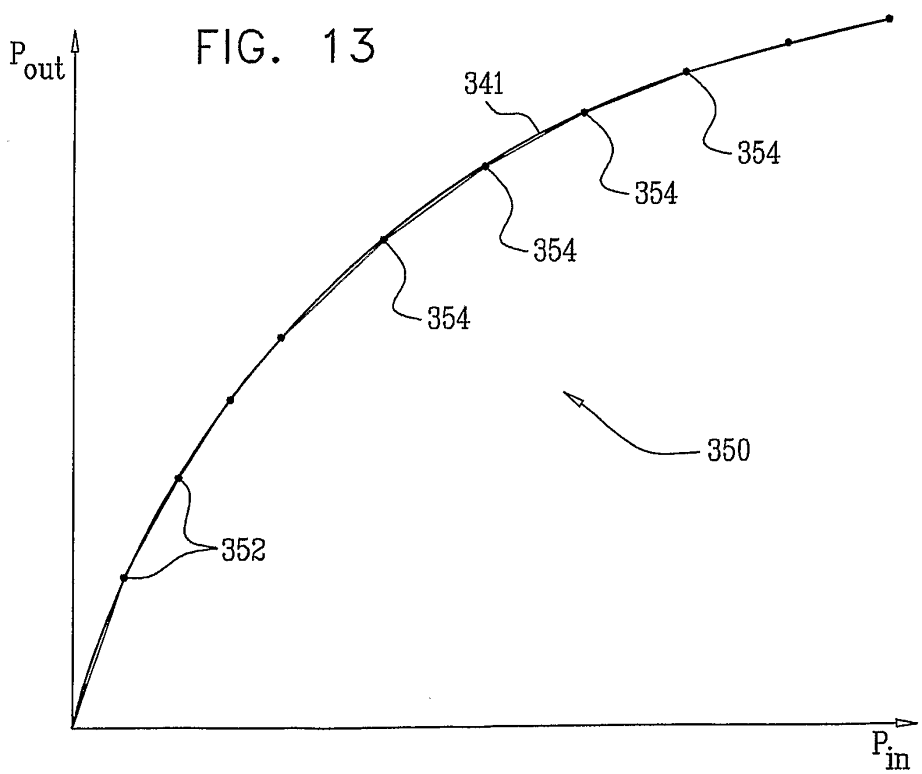
FIG. 11


320
322
FIRST KNEE NEIGHBORHOOD DETECTOR
324
SECOND KNEE NEIGHBORHOOD DETECTOR
P_{in}
326
FIRST SPLINE LOOKUP TABLE
328
SECOND SPLINE LOOKUP TABLE
330
PIECEWISE LINEAR FUNCTION
A
B
C
332
334
MUX
P_{out}



P_{out}
341
344
344
344
340
342
P_{in}

FIG. 12



P_{out}
341
354
354
354
354
350
352
P_{in}

FIG. 13

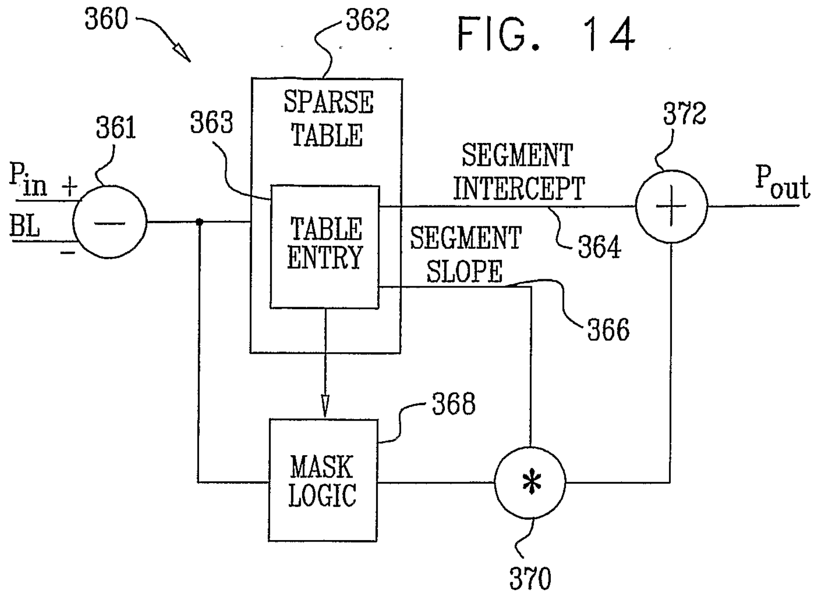

360
362
SPARSE TABLE
361
363
P in +
BL
−
TABLE ENTRY
SEGMENT INTERCEPT
364
SEGMENT SLOPE
366
372
P out
368
MASK LOGIC
*
370

FIG. 14

FIG. 15

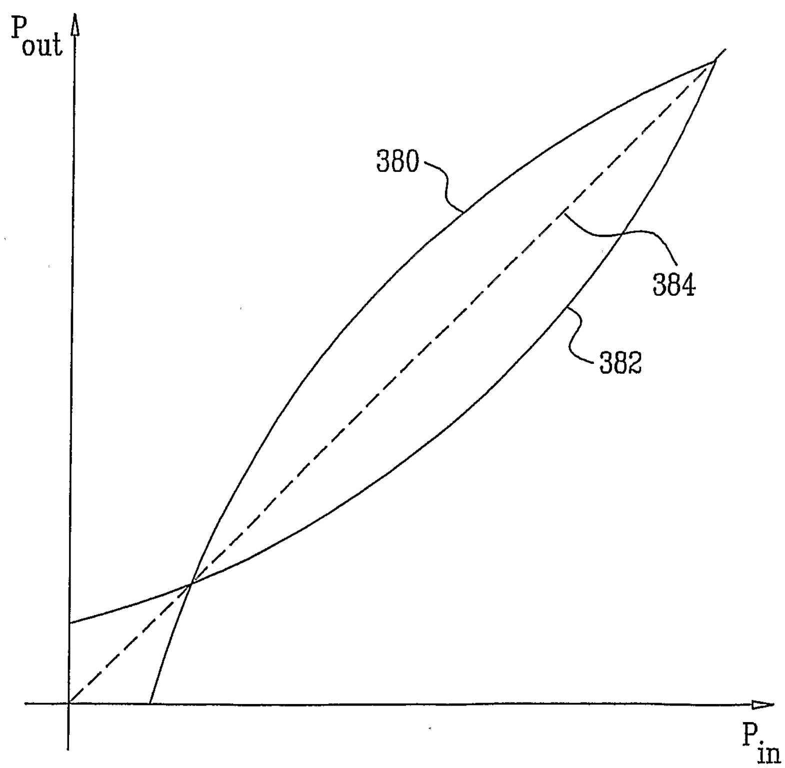

P out
380
384
382
P in

FIG. 16

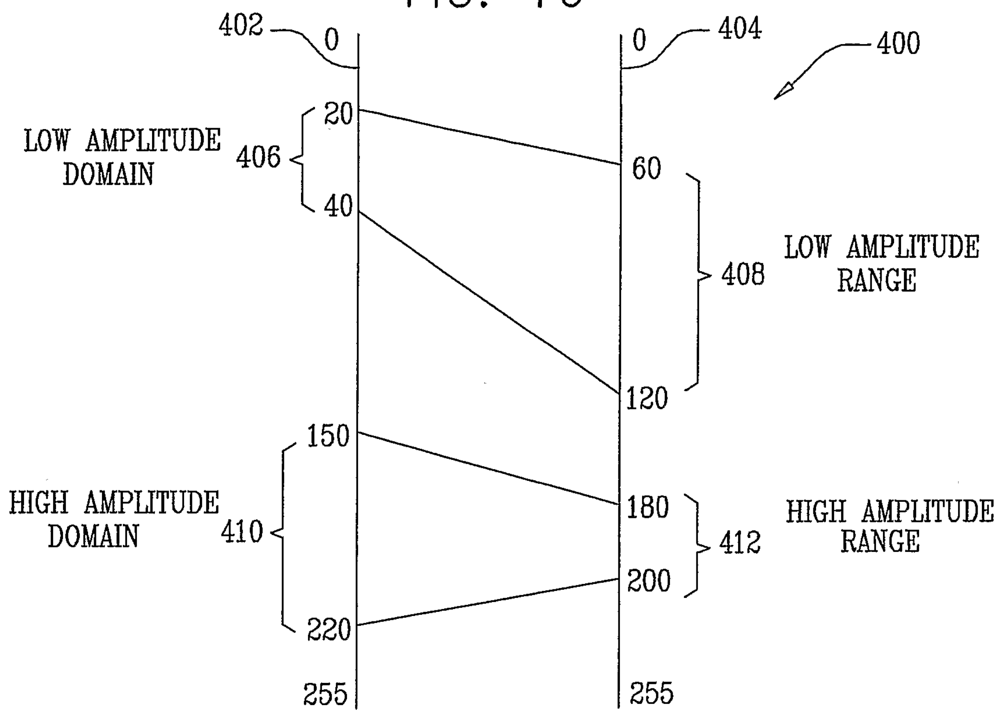
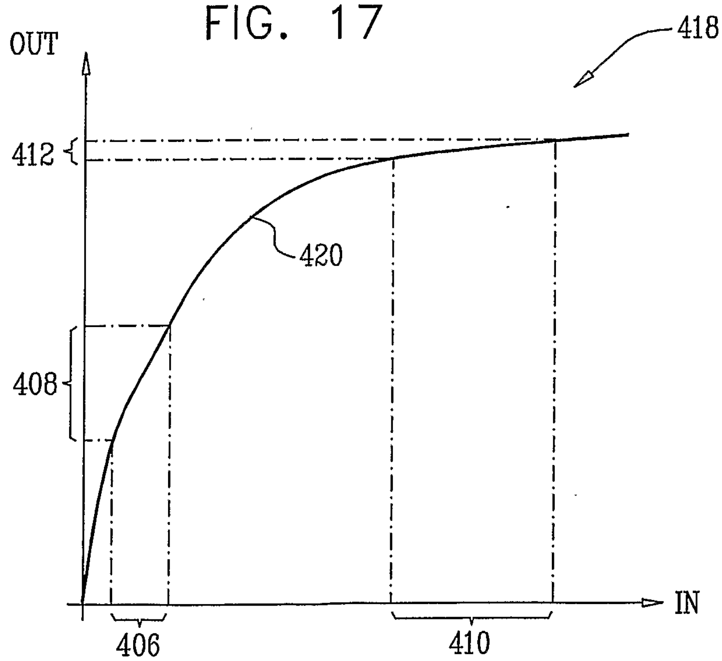

402
0
404
0
400
LOW AMPLITUDE DOMAIN
406
20
40
60
408
LOW AMPLITUDE RANGE
120
150
HIGH AMPLITUDE DOMAIN
410
180
412
HIGH AMPLITUDE RANGE
200
220
255
255

FIG. 17


418
OUT
412
420
408
IN
406
410

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

Title of Invention	Bokeh amplification

As the below named inventor, I hereby declare that:

This declaration is directed to:

☒ The attached application, or

☐ United States application or PCT international application number ____________ filed on ____________.

The above-identified application was made or authorized to be made by me.
I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.
I have reviewed and understand the contents of the above-identified application, including the claims.
I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in 37 CFR § 1.56.
I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five(5) years, or both.

WARNING:

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

LEGAL NAME OF INVENTOR

Inventor: DAVID PETER MORGAN-MAR **Date:** 23 (day) of October (month) 2013 (year)

Signature: David M

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

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

Title of Invention	Bokeh amplification

As the below named inventor, I hereby declare that:

This declaration is directed to:

☒ The attached application, or

☐ United States application or PCT international application number ______________ filed on ______________.

The above-identified application was made or authorized to be made by me.
I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.
I have reviewed and understand the contents of the above-identified application, including the claims.
I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in 37 CFR § 1.56.
I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five(5) years, or both.

WARNING:

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

LEGAL NAME OF INVENTOR

Inventor: MATTHEW RAPHAEL ARNISON **Date:** 24 (day) of October (month) 2013 (year)

Signature: ______________________

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

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

Title of Invention	Bokeh amplification

As the below named inventor, I hereby declare that:

This declaration is directed to:

☒ The attached application, or

☐ United States application or PCT international application number ____________ filed on ____________.

The above-identified application was made or authorized to be made by me.
I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.
I have reviewed and understand the contents of the above-identified application, including the claims.
I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in 37 CFR § 1.56.
I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five(5) years, or both.

WARNING:

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

LEGAL NAME OF INVENTOR

Inventor: KIERAN GERARD LARKIN **Date:** 23 (day) of October (month) 2013 (year)

Signature: [signature]

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

BOKEH AMPLIFICATION

REFERENCE TO RELATED PATENT APPLICATION(S)

[0001] This application claims the benefit under 35 U.S.C. §119 of the filing date of Australian Patent Application No. 2012258467, filed December 03, 2012, hereby incorporated by reference in its entirety as if fully set forth herein.

TECHNICAL FIELD

[0002] The current invention relates to digital image processing and, in particular, to rendering a photographic image with modified blur characteristics.

BACKGROUND

[0003] Single-lens reflex (SLR) and digital single-lens reflex (DSLR) cameras have large aperture optics which can produce a narrow depth of field. Depth of field measures the distance from the nearest object to the camera which is in focus, to the farthest object from the camera which is in focus. (D)SLR cameras typically have a depth of filed of order significantly less than 1 metre for a typical portrait scenario of a subject a few metres from the camera. This allows the foreground subject of a photo to be rendered in sharp focus, while the background is blurred by defocus. The result is visually pleasing as it provides a separation between the subject and any distracting elements in the background. The aesthetic quality of background blur (encompassing both the quantity and "look" of the blur) is known as *bokeh*. Bokeh is especially important for photos of people, or portraits.

[0004] Compact digital cameras are more popular than DSLRs with consumers because of their smaller size, lighter weight, and lower cost. However, the smaller optics on a compact camera produce a large depth of field, of order greater than approximately 1 metre for the same typical portrait scenario, which renders the background in typical portrait shots as sharp and distracting.

[0005] Depth of field varies significantly depending on the geometry of the photographic scene. The following examples are for taking a photo of a person about 3 metres from the camera:

(i) the depth of field for a full frame SLR camera at 50mm focal length and aperture *f*/2.8 is about 0.5 metres. For a portrait scenario, a photographer would typically want to use a depth of field this size, or even smaller, maybe 0.2 metres or even 0.1 metres. An SLR camera can also be configured with a smaller aperture to achieve very large depth of field, though this is not usually done for portraits.

(ii) the depth of field for a small compact camera (e.g. Canon™ IXUS™ model) at 50mm full-frame equivalent focal length and aperture f/2.8, is 6 metres.

(iii) a large compact camera (e.g. Canon™ G12) at 50mm full-frame equivalent focal length and aperture f/4 is 1.6 metres. (This camera cannot achieve f/2.8 aperture – if it could, its depth of field would be 1.2 metres.) It is practically impossible for a camera with a compact form factor to achieve a depth of field under about 1 metre, for a subject at 3 metres distance. Technically, such is possible, but would require very large and expensive lenses. Depth of field for compact cameras under normal conditions can easily be tens of metres or even infinity, meaning that everything from the subject to the far distance is in focus.

[0006] If the person is closer to the camera than 3 metres, all the depth of field distances discussed above will be smaller, and if the person is further away, they will all be larger. Importantly, an SLR camera will always be able to achieve a significantly smaller depth of field than a compact camera. The depth of field is largely dictated by the size of the camera sensor.

[0007] A method of producing *artificial bokeh* with a compact camera, mimicking the amount and quality of background blur produced by an SLR camera, would provide a major improvement in image quality for compact camera users.

[0008] Camera manufacturers and professional photographers have recognised the depth of field limitations of small format cameras for decades. With the advent of digital camera technology, it has become feasible to process camera images after capture to modify the appearance of the photo. The generation of SLR-like bokeh from compact camera images has been an early target for research in the field of digital camera image processing. However, no solution providing results of high (i.e. visually acceptable) aesthetic quality has been demonstrated.

[0009] To accurately mimic small depth of field given a large depth of field photo, objects in the image must be blurred by an amount that varies with distance from the camera. The most common prior approach tackles this problem in two steps:

(1a). Estimate the distance of regions in the image from the camera to produce a *depth map*.

(1b). Apply a blurring operation using a blur kernel size that varies with the estimated distance.

[0010] Step (1a) is a difficult problem in itself, and the subject of active research by many groups. The three main methods of depth map estimation from camera images (i.e. excluding active illumination methods) are:

(i) Stereo: taking photos from different camera positions and extracting depth from parallax. A major disadvantage of this approach is the requirement to take photos from multiple viewpoints, making it impractical for compact cameras.

(ii) Depth from focus (DFF): taking a series of many images focused at different distances and measuring in patches which photo corresponds to a best focus at that patch, usually using maximal contrast as the best focus criterion. A major disadvantage of this approach is that many exposures are required, necessitating a long elapsed time. During the exposures the camera or subject may inadvertently move, potentially blurring the subject and introducing additional problems caused by image misalignment.

(iii) Depth from defocus (DFD): quantifying the difference in amount of blur between two images taken with different focus and equating the blur difference to a distance. This is the most suitable approach for implementation in a compact camera, as it does not require stereo camera hardware and can be performed with as few as two photos. However, it has the disadvantages that accuracy is typically relatively low, particularly around the boundaries of objects in the scene, and that consistency is adversely affected by differing object textures in the scene. Some DFD methods show better accuracy around object edges, at the cost of using computationally expensive algorithms unsuited to implementation in camera hardware.

[0011] Step (1b) is computationally expensive for optically realistic blur kernel shapes. A fallback is to use a Gaussian blur kernel, which produces a blur that looks optically unrealistic, making the resulting image aesthetically unpleasing.

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[0012] To more easily approach artificial bokeh, many prior methods use a simplified version of the above two-step method, being:

(2a). Segment the image into a foreground region and a background region.

(2b). Apply a constant blurring operation to the background region only.

[0013] Assuming step (2a) is done correctly, step (2b) is straightforward. However, step (2a) is still difficult and has not been achieved satisfactorily within the constraints of a compact camera. In particular, the accuracy of segmentation around the edges of objects at different depths in the scene is poor. Even if this simplified method can be achieved without error, the resulting images can look artificial, since intermediate levels of blur between the foreground and background will be absent.

[0014] An alternative approach to artificial bokeh is to:

(3a). Estimate the amount of blur at different places in an image, compared to a blur-free representation of the subject scene.

(3b). Apply a blurring operation using a blur kernel size that varies with the estimated blur amount.

[0015] A compact camera does not have an infinite depth of field, so the background will show a small amount of blurring relative to an in-focus foreground object. If such blurred regions can be identified accurately, they can be blurred more, producing increased blur in the background.

[0016] Step (3a) can be performed with a single image, or by using multiple images of the scene captured with different camera parameters. Estimating blur from a single image is under-constrained and can only be achieved under certain assumptions. For example, one assumption is that edges detected in the image are step function edges in the scene, blurred by the camera optics, and that regions away from edges may be accurately infilled from the edge blur estimates. These assumptions are often false, resulting in poor blur estimates. Estimating blur from multiple images is akin to DFF or DFD, because blur amount is directly related to depth, and shares the same problems.

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SUMMARY

[0017] According to the present disclosure there is provided a method of modifying the blur in at least a part of an image of a scene, sa d method comprising: capturing at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

[0018] Preferably, the set of frequency domain pixel values are modified before being raised to the predetermined power. Generally the modification includes a median filtering operation. Alternatively the modification may include a smoothing filtering operation. The modification may include a normalisation operation and/or a weighting operation. The weights for the weighting operation are determined by the phases of the set of frequency domain pixel values.

[0019] Typically the at least two images of the scene are divided into a plurality of corresponding image patches in each of the captured images; and the output image patches are combined to produce an output image. Desirably the plurality of corresponding image patches in each of the captured images form a tiling substantially covering the area of the captured images, and the output image is formed by tiling the output image patches. Generally the plurality of corresponding image patches in each of the captured images overlap, and the output image is formed by combining the pixel values of the output image patches.

[0020] In a specific implementation the plurality of corresponding image patches in each of the captured images cover part of the area of the captured images; and the output image patches are combined with the area of at least one of the captured images not covered by the plurality of corresponding image patches to produce an output image. Desirably at least part of the area of the at least one of the captured images not covered by the plurality of corresponding image patches is blurred by convolution with a blur kernel.

[0021] According to another aspect, disclosed is a camera comprising an image capture system coupled to memory in which captured images are stored, a processor, and a program executable by the processor to modify the blur in at least a part of an image of a scene, said program comprising: code for causing the capture system to capture at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; code for selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

[0022] Another aspect is a camera system comprising: a lens formed of optics producing a relatively large depth of field; a sensor configured capture an image of a scene focussed through the lens; a memory in which images captured by the sensor are stored; a capture mechanism configured to capture at least two images of the scene with different capture parameters and to store the images in the memory; a processor; a program stored in the memory and executable by the processor to modify blur in at least a part of one of the captured images of the scene, said program comprising: code for causing the capture system to capture at least two images of the scene with different camera parameters to produce a different amount of blur in each of the captured images; code for selecting a corresponding image patch in each of the captured images, each of the selected image

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patches having an initial amount of blur; code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

[0023] In another aspect disclosed is a computer readable storage medium having a program recorded thereon, the program being executable by a processor to modify blur in at least a part of an image of a scene, the program comprising: code for receiving at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images; code for selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur; code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches; code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

[0024] Other aspects are disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] At least one embodiment of the invention will now be described with reference to the following drawings, in which:

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[0026] Fig. 1 is a schematic diagram of a scene and an image capture device positioned to capture an image of the scene;

[0027] Fig. 2 is a schematic diagram illustrating the geometry of a lens forming two different images at two different focal planes;

[0028] Figs. 3A and 3B illustrate a two-dimensional Gaussian function and a two-dimensional pillbox function, and one-dimensional cross-sections thereof;

[0029] Figs. 4A and 4B collectively form a schematic block diagram of a general purpose computer on which various implementations may be practised;

[0030] Figs. 5A, 5B, and 5C illustrate example images upon which artificial bokeh processing according to the present disclosure may be performed;

[0031] Fig. 6 is a diagram illustrating the correspondence between pixels and image patches within a first image and a second image of a scene;

[0032] Fig. 7 is a schematic flow diagram illustrating an exemplary method of determining an artificial bokeh image from two images of a scene, according to the present disclosure;

[0033] Fig. 8 is a schematic flow diagram illustrating one example of a method of capturing two images as used in the method of Fig. 7;

[0034] Fig. 9 is a schematic flow diagram illustrating one example of a method of asymmetrical patch selection as used in the method of Fig. 7;

[0035] Fig. 10 is a schematic flow diagram illustrating one example of a method of determining an artificial bokeh image patch from two corresponding patches of two images of a scene as used in the method of Fig. 7;

[0036] Fig. 11 is a schematic flow diagram illustrating one example of a method of assembling artificial bokeh patches into an artificial bokeh image as used in the method of Fig. 7; and

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[0037] Fig. 12 is a schematic flow diagram illustrating a second exemplary method of determining an artificial bokeh image from two images of a scene, according to the present disclosure.

DETAILED DESCRIPTION INCLUDING BEST MODE

Introduction

[0038] The present disclosure is directed to providing methods of rendering a photographic image taken with large depth of field so as to mimic a photo taken with a smaller depth of field by modifying blur already present in the image taken with a large depth of field. The methods seek to offer one or more of improved accuracy, improved tolerance to imaging noise, improved tolerance to differences of object texture in the image, and improved aesthetic appearance of the final image, all of these particularly in regions at and near the boundaries of objects in the scene.

Context

Thin lens equation, basic geometry

[0039] The technical details of accurately rendering artificial bokeh rely on key aspects of the geometry and optics of imaging devices. Most scenes that are captured using an imaging device, such as a camera, contain multiple objects, which are located at various distances from the lens of the device. Commonly, the imaging device is focused on an object of interest in the scene. The object of interest shall be referred to as the ***subject*** of the scene. Otherwise, objects in the scene, which may include the subject, shall simply be referred to as ***objects***.

[0040] Fig. 1 is a schematic diagram showing the geometrical relationships between key parts of an imaging device and objects in a scene to be captured. Fig. 1 shows an imaging device or system (e.g. a camera) 100 which includes a lens 110, and a sensor 115. For the purposes of this description, the camera 100 is typically a compact digital camera and the lens 110 has relatively small optics producing a large depth of field, particularly in comparison to an SLR camera. Fig. 1 also shows an in-focus plane 130 and a general object 140 formed by sphere positioned upon a rectangular prism, forming part of the

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scene but not necessarily the subject of the scene to be captured. The image plane 120 of the imaging device 100, also referred to as the focal plane, is defined to be at the location of the sensor 115. When projected through the lens 110, the image plane 120 forms the *in-focus plane* 130, which can be considered to be a virtual plane in the geometrical region of the object 140. A distance 150 from the lens 110 to the image plane 120 is related to a distance 160 from the lens 110 to the in-focus plane 130, by the thin lens law according to the equation

$$\frac{1}{z_i}+\frac{1}{z_o}=\frac{1}{f} \qquad (1)$$

where f is the focal length of the lens 110, z_i is the lens-to-sensor distance 150, and z_o is the distance 160 from the lens 110 to the in-focus plane 130. The general scene object 140 is located at a distance 170 from the lens 110 and at a distance 180 from the in-focus plane 130. This distance 170 is referred to as z_s. The distance 180 from the object 140 to the in-focus plane 130 is given by z_s - z_o and may be positive, zero, or negative. If the object 140 is focused onto the image plane 120, then $z_s = z_o$ and the object 140 is located in the in-focus plane 130. If z_s is less than or greater than z_o, then the object 140 is located behind or in front of the in-focus plane 130 respectively, and the image of the object 140 will appear blurred on the image plane 120.

[0041] Fig. 1 illustrates a relatively simple geometrical optics model of imaging. This model relies on approximations including the thin lens approximation, paraxial imaging rays, and a lens free of aberrations. These approximations ignore some aspects of the optics that are inherent in actual imaging systems, but are sufficient for general understanding of imaging behaviour, as is understood by those skilled in the art.

[0042] Focusing is carried out either manually by the user or by using an autofocus mechanism that is built into the imaging device 100. Focusing typically manipulates the lens-to-sensor distance 150 in order to place the in-focus plane 130 such that the distance z_o 160 is equal to the distance z_s 170 to a specific object of interest, *i.e.* to place the subject in the in-focus plane 130. Other objects in the scene that have a distance z_s from the lens 110 that is different from that of the subject are located either behind or in front of the in-focus plane 130. These other objects will appear blurred to some degree on the image

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plane 120 and thus in the image captured on the sensor 115. This blur is referred to as *defocus blur*.

Defocus blur

[0043] The amount of defocus blurring of an imaged object 140 increases with the distance 180 of the object 140 from the in-focus plane 130. The amount of defocus blur present in a given patch or portion of a captured 2D image can be characterised by the point spread function (PSF). The PSF is the response of the imaging system to a point source, defined such that the integral of the PSF over the image plane is equal to unity. The PSF of an optical system is generally a spatially restricted two-dimensional function of spatial coordinates (x, y) that approaches zero beyond a certain radial distance from the origin. The amount of blur can be characterised by measures of the shape of the PSF. Typical measures of the amount of blur are the full-width-at-half-maximum (FWHM) of the PSF, or the standard deviation of the PSF.

[0044] A basic understanding of the principles behind image blurring may be gained by assuming a mathematically simple model for the PSF of a camera lens 110. To achieve this simplicity, prior art analyses often model the PSF as a two-dimensional Gaussian function. This assumption is followed in the present description for explanatory purposes only, noting that the PSFs of physical optical systems are typically not well approximated by Gaussian functions. Under this assumption, the standard deviation σ of the Gaussian can be regarded as a *blur radius*, providing a convenient quantitative measure of the concept of "amount of blur". It can be shown that the relationship of the Gaussian blur radius σ, object distance z_s, and the camera image capture parameters of focal length f and lens aperture A_V is given by

$$z_s = \frac{f z_i}{z_i - f - 2\sigma A_V} \qquad (2)$$

where A_V is the relative aperture (also known as the f-number) of the lens 110. If the blur radius σ of a point located at pixel coordinates (x_i, y_i) in a captured image of a scene can be measured, the distance z_s to an object at the corresponding point in the scene can be determined using equation (2), provided the remaining quantities in equation (2) are known. Through this relationship, knowledge of the blur radius is effectively equivalent to knowledge of the object depth, since the remaining quantities in equation (2) are usually known.

[0045] However, determining the blur radius σ from a single image of a scene without detailed prior knowledge of the scene to be imaged is known to be an unsolvable problem. This is because determining the blur radius σ is not possible from a single image unless details of the unblurred scene image are known. For example, an image feature resembling a blurred disc may be caused by a disc of some indeterminate smaller size that has been blurred by some unknown amount, or by an object in the scene that resembles a blurred disc, rendered in sharp focus. Given this ambiguity, it is impossible to determine the blur radius σ. Thus, in terms of equation (2), even if the parameters z_i, f, and A_V are known, it is not possible to determine depth from a single image of an unconstrained scene.

[0046] In the majority of circumstances, scenes are imaged without detailed knowledge of the structure of the objects in the scene. It is a general requirement for many imaging applications to work with unconstrained scenes, and even under carefully controlled imaging environments, such as portrait studios, it is very difficult to estimate the required information needed to obtain a depth map from a single image. However, referring to equation (2), it is theoretically possible to extract information about the blur radius (or equivalently the depth) using two captured images of the same scene, provided that the value of at least one of the parameters, in addition to blur radius σ, differs between the two captured images. This is the basic principle that underpins depth from defocus (DFD) methods, which rely on calculating the relative defocus blur between two images of a scene.

Practical considerations

[0047] In practice, images of a scene are captured with some amount of imaging noise. This affects the accuracy of any measurements made by processing the image data. The simple optical models, such as Gaussian PSFs, used to derive the principles of many prior art artificial bokeh methods are not realistic. Real lenses contain aberrations other than defocus, objects are imaged with large field angles, and diffraction effects can be important. There are also considerations of the amount of visual texture in the scene

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objects. For example, if an area of an object is uniform in colour and reflectivity, then it is impossible to distinguish any amount of blurring within this area. Further, the combination of different visual textures with varying amounts of imaging noise produces widely varying responses for many artificial bokeh methods. Particularly problematical is when different visual textures at the same depth produce different estimates of the amount of blur.

[0048] For combinations of these reasons, artificial bokeh methods in practice have shown limited success at rendering enhanced background blur in realistic photographic scenes. Much of the reported success of artificial bokeh methods has been restricted to highly constrained test scenes.

Overview

[0049] The arrangements presently described improve on the prior art by utilising more realistic theoretical modelling of the behaviour of lens optics in real world conditions, and by providing a more robust means of rendering enhanced background blur in a scene independent manner and in the presence of imaging noise particularly in regions at and near the boundaries of objects in the scene.

[0050] Figs. 3A and 3B illustrate two simple two-dimensional functions that are commonly assumed as approximations to lens PSFs. Fig. 3A shows a two-dimensional Gaussian function 300, whose one-dimensional cross section is a one-dimensional Gaussian function 310. The two-dimensional Gaussian function 300 is illustrated schematically in a dithered fashion, to assist with photocopy reproduction of this patent specification. Fig. 3B shows a circular pillbox function 320, whose one-dimensional cross section is a square function 330.

[0051] Prior art modelling of the lens behaviour in the context of artificial bokeh commonly assumes that the PSF of defocus blur is well modelled by a two-dimensional Gaussian function 300. In general this is not true. The defocus blur PSF of a photographic camera lens often more closely resembles a circular pillbox 320, with relatively sharp edges compared to the gradual fall-off of a Gaussian function. In reality, the shape of the defocus blur PSF is more complex than either of these approximations, and varies

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significantly from lens to lens and with different camera parameters for a single lens. The PSF also varies with field angle such that the PSF in one region of the image plane 120 may be different to the PSF in some other region of the image plane 120.

[0052] Also in particular, prior art modelling of the lens behaviour in the context of artificial bokeh assumes that consideration of the modulation transfer function (MTF), which is the modulus of the optical transfer function (OTF), is adequate to determine accurate blur estimates from a comparison of two images. This assumption neglects the important contribution of the phase of the OTF, effectively disregarding half of the available data. By fully utilising the phase information, the arrangements presently disclosed can achieve significantly more accurate results than the prior art.

[0053] The presently disclosed arrangements facilitate artificial bokeh rendering from a pair of images taken of the same scene with different camera parameters: (a) without making any assumption about the shape of the defocus blur PSF, (b) without discarding the information present in the phases of the image spectrum and OTF, and (c) using an improved method of characterising the relative blur between two image patches which is less sensitive to imaging noise than prior methods. These features will be explained in detail in the following sections.

Theory

Spectral ratio and relative point spread function

[0054] A method of rendering enhanced blur from two images of the same scene can be developed by considering the theory of image formation. Consider a patch f_0 of the scene to be imaged, the patch being small enough such that any variation in object depth or PSF of the imaging system within the patch is small and thus can be ignored. The two-dimensional intensity distribution of the corresponding patch of an image f_1 of the intensity distribution of the patch f_0 can be modelled using a fully general point spread function (PSF) by a spatial convolution operation as follows:

$$f_1(x,y) = f_0(x,y) \otimes PSF_1(x,y) \quad (3)$$

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where PSF_1 is the defocus blur PSF of the scene patch f_0 when it is projected on to the image patch f_1. Taking the Fourier transform of both sides of equation (3) gives

$$F_1(u,v) = F_0(u,v)OTF_1(u,v) \quad (4)$$

where (u, v) are spatial frequency coordinates, F_1 is the Fourier transform of f_1, F_0 is the Fourier transform of f_0, and OTF_1 is the Fourier transform of PSF_1. By the Fourier convolution theorem the spatial convolution operation has become a product. The function OTF_1 is known as the optical transfer function (OTF). The OTF is a complex-valued function, with modulus and phase components.

[0055] Assume we have two images of the same scene taken with different camera parameters, but without moving the camera or any objects in the scene so that the images are in alignment with one another. Then the second image patch f_2 of the same scene patch f_0 may be modelled in the same way as equation (3), replacing the 1 subscripts with 2 subscripts. Taking the ratio of the Fourier transforms of corresponding patches in the two images gives

$$\frac{F_1(u,v)}{F_2(u,v)} = \frac{OTF_1(u,v)}{OTF_2(u,v)} \quad (5)$$

where the Fourier transform $F_0(u, v)$ of the scene is common to the numerator and denominator of the right hand side and has been cancelled from the ratio. This ratio may be called the *spectral ratio*. When no noise is present, the spectral ratio is scene independent because all contributions of the scene have been cancelled out. In the presence of imaging or quantisation noise, the cancellation may not be perfect, and the spectral ratio may be biased by the noise.

[0056] The spectral ratio can be formed with an arbitrary assignment of the image patches as f_1 and f_2. However, as explained further below, it is advantageous to use asymmetric patch selection, based on which of the two image patches f_1 and f_2 is less blurred than the other image patch. Such a determination can be made by, for example, calculating the variance of the pixel intensities or brightness in each image patch, with the patch with the higher variance deemed to be less blurred, and thus the most focussed representation of the

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scene. Other methods of determining which patch is less blurred may be used, for example if the images are taken at different apertures and diffraction can be ignored, the patch captured with the narrower aperture may be deemed to be less blurred.

[0057] Once determination has been made of which patch is less blurred, the less blurred patch may be assigned as patch f_2, with the patch deemed to be more blurred assigned as f_1. This assignment allows an interpretation in which it is possible to consider f_1 as a more blurred version of f_2, related by a relative optical transfer function OTF_r given by the spectral ratio:

$$\begin{aligned} F_1(u,v) &= F_2(u,v)\frac{OTF_1(u,v)}{OTF_2(u,v)} \\ &= F_2(u,v)OTF_r(u,v) \end{aligned} \tag{6}$$

Taking the inverse Fourier transform of equation (6) gives the following relationship

$$f_1(x,y) = f_2(x,y) \otimes PSF_r(x,y) \tag{7}$$

where PSF_r is defined to be the *relative point spread function* (relative PSF) which when convolved with the image patch f_2 produces the image patch f_1. The relative point spread function PSF_r is not simply related to PSF_1 and PSF_2, but is the result of a non-linear combination of the two. The relative point spread function PSF_r varies with parameters of the imaging system such as focus and aperture, with the depth of the object imaged in patch f_0, and with field angle across the image plane 120.

Application to artificial bokeh

[0058] The space-varying relative point spread function PSF_r is the inverse Fourier transform of (OTF_1/OTF_2). PSF_r operates on the image patch f_2 to increase the amount of blur in the image, but in a very specific way:

(a) where an object is in focus in both images (for example, the subject of the photo, usually in the foreground), there is very little blur difference, so the relative PSF is close to a delta function; and

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(b) where an object is more in focus in f_2 than in f_1, the relative PSF produces the necessary amount of relative blurring in f_1. For objects at distances similar to the subject, this is a small amount of blur, while for objects at distances very different to the subject (e.g. the distant background) this is a larger amount of blur.

[0059] The goal of rendering artificial bokeh simulating a shallower depth of field from such a pair of images can be expressed as:

(i) where an object is in focus in both images (e.g. the subject of the photo), do not blur; and

(ii) where an object is more in focus in f_2 than in f_1, apply a variable amount of blurring. For objects at distances similar to the subject, apply a relatively small amount of blur, while for objects at distances very different to the subject (e.g. the distant background) apply a larger amount of blur.

[0060] The present inventors observe the similarity in the two sets of points above, and deduce it is possible to achieve the goal of rendering a shallower depth of field image $f_{(N)}$ by applying the relative PSF to the image patch f_2 multiple times, in other words by convolving f_2 with the relative PSF N times:

$$f_{(N)} = f_2 \otimes \overbrace{PSF_r \otimes PSF_r \otimes \cdots \otimes PSF_r}^{N} \qquad (8)$$

Expressed in the Fourier domain, this becomes:

$$F_{(N)} = \left(\frac{OTF_1}{OTF_2} \right)^N F_2 \qquad (9)$$

[0061] The amount of additional blurring of background regions can be controlled by adjusting the amplification factor N. In the Fourier domain, N is not constrained to being an integer. As long as $N > 1$, the blurring of the background is increased. If $N < 1$, the blurring of the background is reduced; in other words the background is sharpened, mimicking the effect of a greater depth of field than the original images. Equation (9) must be implemented using complex arithmetic to preserve the phase information that is crucial to the reconstruction of an image.

[0062] The present inventors have thus determined it is possible to produce a shallow depth of field or artificial bokeh image by dividing the input images into patches f_1 and f_2, and then, for each patch:

(i) calculate the spectral ratio F_1/F_2;

(ii) raise the spectral ratio to some power $N > 1$ and multiply by the patch Fourier transform F_2 to obtain the Fourier domain patch $F_{(N)}$; and

(iii) inverse Fourier transform the Fourier domain patch $F_{(N)}$ to obtain the output image patch $f_{(N)}$.

[0063] The resulting patches may then be reassembled to give the final image, which will appear to be a shallow depth of field image of the scene, with objects away from the focal plane blurred more than in the input images.

[0064] Advantageously, the resulting patches produce an image in which objects near the focal plane are not blurred, while objects far from the focal plane are blurred in proportion to their distance from the focal plane. This tends to hold even when a single patch covers objects or parts of objects at multiple distances. The frequency domain information from discrete objects or parts of objects at different distances from the camera, visible in the same patch, tend to separate out into discrete spatial frequencies. Each of the spatial frequencies is amplified independently by an amount required to produce the appropriate amount of blur for an object at the corresponding distance. For spatial frequencies present in multiple discrete objects, the amplification is intermediate, and the combination of other amplified frequencies and the original phase information from patch F_2 tends to construct the desired differential blurring appropriately. The result is that a single pair of input patches f_1 and f_2 covering objects at different distances will produce an output image patch $f_{(N)}$ containing an additional amount of blur that varies across the patch, the variation in additional blur being appropriate for the differing distances of the various objects within the patch.

Normalisation

[0065] A complication arises if the mean intensity levels of the two image patches f_1 and f_2 are not the same as each other. In most cases the mean intensity levels of the two patches will be similar, since the two images will preferentially have been captured with a short

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time interval between the exposures (for example, typically less than 1 second), and with similar photographic exposures. However due to variations in illumination intensity, motion of objects in the scene, or the effects of imaging noise, the mean intensity levels of the two image patches f_1 and f_2 are unlikely to be identical. By properties of the Fourier transform, the pixels of the Fourier transforms F_1 and F_2 corresponding to zero spatial frequency in the Fourier domain (known as the DC pixel) contain a real number equal to the mean intensity level of the corresponding image patches f_1 and f_2. By the construction of the spectral ratio, the DC pixel of the spectral ratio contains the ratio of the mean intensity levels of the image patches f_1 and f_2.

[0066] In the ideal case in which the image patches f_1 and f_2 have equal mean intensities, the DC pixel of the spectral ratio is equal to 1. In this case, raising the spectral ratio to a power N will preserve the unity value of the DC pixel. Then when the spectral ratio is multiplied by the Fourier transformed patch F_2 to form $F_{(N)}$, the DC value of $F_{(N)}$ will be equal to the DC value of the Fourier transformed patch F_2. Then when $F_{(N)}$ is inverse Fourier transformed to form $f_{(N)}$, the resulting artificial bokeh patch will have the same mean intensity level as the original patch f_2. If this ideal case holds across all of patches in the original images, then when the artificial bokeh patches are assembled, the intensity of the resulting composite image will be consistent with the original image in all regions.

[0067] On the other hand, if the image patches f_1 and f_2 have unequal mean intensities, the DC pixel of the spectral ratio is not equal to 1. In this case, raising the spectral ratio to a power N will change the value of the DC pixel. Then, when the spectral ratio is multiplied by the Fourier transformed patch F_2 to form $F_{(N)}$, the DC value of $F_{(N)}$ will not be equal to the DC value of the Fourier transformed patch F_2. Then, when $F_{(N)}$ is inverse Fourier transformed to form $f_{(N)}$, the resulting artificial bokeh patch will have a different mean intensity level compared to the original patch f_2. If this more realistic case holds across all of patches in the original images, then when the artificial bokeh patches are assembled, the intensity of the resulting composite image will be inconsistent with the original image. Furthermore, the inconsistencies in mean intensity level will likely vary from patch to patch. The resulting composite image will have a distracting blocky appearance.

[0068] To avoid this blocky appearance artefact, the spectral ratio may be normalised by dividing all pixels of the spectral ratio by the DC value of the spectral ratio, before raising it to the power N. This ensures that the mean intensity levels of the patches composing the final output image will be consistent and the resulting composite image will not have this blocky appearance.

Noise reduction

[0069] Digital images are typically subject to imaging noise. The process of raising the spectral ratio to a power may tend to amplify the effects of noise. If noise perturbs the amplitude of a particular spatial frequency to a higher value in the spectral ratio, that noise will be enhanced when the spectral ratio is raised to a power, resulting in increased noise in the final image. It is therefore advantageous to apply one or more noise reduction steps to the processing.

[0070] In one implementation, the spectral ratio may be smoothed by a filtering process to remove outlying pixel values before raising to a power, for example using a block-based median filter, a Gaussian filter, or some other smoothing filter. A median filter may operate on complex numbers either by selecting real and imaginary parts independently and combining them to give a complex result, or by selecting a complex value by consideration of the modulus while ignoring the phase.

[0071] In another implementation, the spectral ratio may be modified by multiplying the pixel values by a weighting function, which varies from pixel to pixel, before raising to a power. Weights for the weighting operation are determined by the phases of the set of frequency domain pixel values. An example weighting function may be constructed by considering the complex phase value ϕ of each pixel in the spectral ratio. The complex phase ϕ of each pixel is an angular value which may be mapped on to the range $-\pi$ to $+\pi$ radians. An example weighting function $W(\phi)$ is then given by

$$W(\phi) = \left(\frac{\pi - |\phi|}{\pi} \right)^k \qquad (10)$$

where k is a real number. Preferred values of k include 1, 2, and other positive integers. Such a weighting function reduces the amplitude of pixels in the spectral ratio in a manner such that pixels with absolute phase values closer to π have their amplitudes reduced by a

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greater amount than do pixels with absolute phase values closer to 0. Pixels with absolute phase values approaching π tend to correspond to spatial frequencies with little spectral energy in the original images, meaning the spectral ratio amplitude may be substantially adversely affected by imaging noise. Weighting such pixels with a small weighting value reduces their influence on the final image. Other weighting functions based on the phases of pixels of the spectral ratio may also be used.

[0072] In another implementation, the patches selected for processing may overlap, thus producing multiple potential values for output pixels in the final image. The value of each pixel in the final image may be calculated using some combination of the potential values produced by different overlapping patches, for example the mean or the median of the values.

[0073] In a further implementation, a combination of the above noise reduction methods may be used. The noise reduction methods provide a further advantage in that they allow better differentiation of blurring amount between objects at different depths than may appear in a single image patch. The use of overlapping patches in particular allows fine detail around the edges of in-focus objects to be rendered accurately.

Processing speed

[0074] To reduce the number of Fourier transforms required and speed up processing, the methods described above may be applied selectively to subregions of the input images. A main advantage of the methods is accuracy of artificial bokeh around the edges of object boundaries. In regions away from object boundaries, alternative methods may provide a speed advantage while not reducing the aesthetic quality of the final output image.

[0075] In one implementation, the input images may be segmented into "foreground" and "background" regions. This may be done, for example, by using a known DFD method to produce a depth map, then thresholding to produce a binary segmentation. The "foreground" region should contain objects close to the focal plane, while the "background" region should contain objects far from the focal plane. A "boundary" region may then be defined by selecting pixels within a predetermined distance from the segmentation edge between the foreground and background regions. The foreground region is left unblurred,

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the background region may be blurred using a large blur kernel, and the boundary region may be rendered using the artificial bokeh methods described above. The three regions may then be composited into a final output image. This provides for an advantageous combination of relatively computationally inexpensive processing for much of the image, with accurate rendering of edges around object boundaries.

Example 1

[0076] The arrangements presently disclosed may be implemented on a variety of hardware platforms, including in an imaging device such as a camera, or on a general purpose computer (PC), or in a cloud computing implementation. This example relates to a general purpose computing implementation.

[0077] Figs. 4A and 4B depict a general-purpose computer system 400, upon which the various arrangements described can be practiced.

[0078] As seen in Fig. 4A, the computer system 400 includes: a computer module 401; input devices such as a keyboard 402, a mouse pointer device 403, a scanner 426, a camera 427 (such as a compact camera 110), and a microphone 480; and output devices including a printer 415, a display device 414 and loudspeakers 417. An external Modulator-Demodulator (Modem) transceiver device 416 may be used by the computer module 401 for communicating to and from a communications network 420 via a connection 421. The communications network 420 may be a wide-area network (WAN), such as the Internet, a cellular telecommunications network, or a private WAN. Where the connection 421 is a telephone line, the modem 416 may be a traditional "dial-up" modem. Alternatively, where the connection 421 is a high capacity (e.g., cable) connection, the modem 416 may be a broadband modem. A wireless modem may also be used for wireless connection to the communications network 420.

[0079] The computer module 401 typically includes at least one processor unit 405, and a memory unit 406. For example, the memory unit 406 may have semiconductor random access memory (RAM) and semiconductor read only memory (ROM). The computer module 401 also includes an number of input/output (I/O) interfaces including: an audio-video interface 407 that couples to the video display 414, loudspeakers 417 and

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microphone 480; an I/O interface 413 that couples to the keyboard 402, mouse 403, scanner 426, camera 427 and optionally a joystick or other human interface device (not illustrated); and an interface 408 for the external modem 416 and printer 415. In some implementations, the modem 416 may be incorporated within the computer module 401, for example within the interface 408. The computer module 401 also has a local network interface 411, which permits coupling of the computer system 400 via a connection 423 to a local-area communications network 422, known as a Local Area Network (LAN). As illustrated in Fig. 4A, the local communications network 422 may also couple to the wide network 420 via a connection 424, which would typically include a so-called "firewall" device or device of similar functionality. The local network interface 411 may comprise an Ethernet™ circuit card, a Bluetooth™ wireless arrangement or an IEEE 802.11 wireless arrangement; however, numerous other types of interfaces may be practiced for the interface 411.

[0080] The I/O interfaces 408 and 413 may afford either or both of serial and parallel connectivity, the former typically being implemented according to the Universal Serial Bus (USB) standards and having corresponding USB connectors (not illustrated). Storage devices 409 are provided and typically include a hard disk drive (HDD) 410. Other storage devices such as a floppy disk drive and a magnetic tape drive (not illustrated) may also be used. An optical disk drive 412 is typically provided to act as a non-volatile source of data. Portable memory devices, such optical disks (e.g., CD-ROM, DVD, Blu-ray Disc™), USB-RAM, portable, external hard drives, and floppy disks, for example, may be used as appropriate sources of data to the system 400.

[0081] The components 405 to 413 of the computer module 401 typically communicate via an interconnected bus 404 and in a manner that results in a conventional mode of operation of the computer system 400 known to those in the relevant art. For example, the processor 405 is coupled to the system bus 404 using a connection 418. Likewise, the memory 406 and optical disk drive 412 are coupled to the system bus 404 by connections 419. Examples of computers on which the described arrangements can be practised include IBM-PC's and compatibles, Sun Sparcstations, Apple Mac™ or a like computer systems.

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[0082] The methods of artificial bokeh rendering may be implemented using the computer system 400 wherein the artificial bokeh processes of Figs. 8 to 13, to be described, may be implemented as one or more software application programs 433 executable within the computer system 400. In particular, the steps of the method of artificial bokeh rendering are effected by instructions 431 (see Fig. 4B) in the software 433 that are carried out within the computer system 400. The software instructions 431 may be formed as one or more code modules, each for performing one or more particular tasks. The software may also be divided into two separate parts, in which a first part and the corresponding code modules performs the artificial bokeh rendering methods and a second part and the corresponding code modules manage a user interface between the first part and the user.

[0083] The software may be stored in a computer readable medium, including the storage devices described below, for example. The software is loaded into the computer system 400 from the computer readable medium, and then executed by the computer system 400. A computer readable medium having such software or computer program recorded on the computer readable medium is a computer program product. The use of the computer program product in the computer system 400 preferably effects an advantageous apparatus for artificial bokeh rendering.

[0084] The software 433 is typically stored in the HDD 410 or the memory 406. The software is loaded into the computer system 400 from a computer readable medium, and executed by the computer system 400. Thus, for example, the software 433 may be stored on an optically readable disk storage medium (e.g., CD-ROM) 425 that is read by the optical disk drive 412. A computer readable medium having such software or computer program recorded on it is a computer program product. The use of the computer program product in the computer system 400 preferably effects an apparatus for artificial bokeh rendering.

[0085] In some instances, the application programs 433 may be supplied to the user encoded on one or more CD-ROMs 425 and read via the corresponding drive 412, or alternatively may be read by the user from the networks 420 or 422. Still further, the software can also be loaded into the computer system 400 from other computer readable media. Computer readable storage media refers to any non-transitory tangible storage medium that provides recorded instructions and/or data to the computer system 400 for

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execution and/or processing. Examples of such storage media include floppy disks, magnetic tape, CD-ROM, DVD, Blu-ray™ Disc, a hard disk drive, a ROM or integrated circuit, USB memory, a magneto-optical disk, or a computer readable card such as a PCMCIA card and the like, whether or not such devices are internal or external of the computer module 401. Examples of transitory or non-tangible computer readable transmission media that may also participate in the provision of software, application programs, instructions and/or data to the computer module 401 include radio or infra-red transmission channels as well as a network connection to another computer or networked device, and the Internet or Intranets including e-mail transmissions and information recorded on Websites and the like.

[0086] The second part of the application programs 433 and the corresponding code modules mentioned above may be executed to implement one or more graphical user interfaces (GUIs) to be rendered or otherwise represented upon the display 414. Through manipulation of typically the keyboard 402 and the mouse 403, a user of the computer system 400 and the application may manipulate the interface in a functionally adaptable manner to provide controlling commands and/or input to the applications associated with the GUI(s). Other forms of functionally adaptable user interfaces may also be implemented, such as an audio interface utilizing speech prompts output via the loudspeakers 417 and user voice commands input via the microphone 480.

[0087] Fig. 4B is a detailed schematic block diagram of the processor 405 and a "memory" 434. The memory 434 represents a logical aggregation of all the memory modules (including the HDD 409 and semiconductor memory 406) that can be accessed by the computer module 401 in Fig. 4A.

[0088] When the computer module 401 is initially powered up, a power-on self-test (POST) program 450 executes. The POST program 450 is typically stored in a ROM 449 of the semiconductor memory 406 of Fig. 4A. A hardware device such as the ROM 449 storing software is sometimes referred to as firmware. The POST program 450 examines hardware within the computer module 401 to ensure proper functioning and typically checks the processor 405, the memory 434 (1409, 406), and a basic input-output systems software (BIOS) module 451, also typically stored in the ROM 449, for correct operation. Once the POST program 450 has run successfully, the BIOS 451 activates the hard disk drive 410 of Fig. 4A. Activation of the hard disk drive 410 causes a bootstrap loader program 452 that is resident on the hard disk drive 410 to execute via the processor 405. This loads an operating system 453 into the RAM memory 406, upon which the operating system 453 commences operation. The operating system 453 is a system level application, executable by the processor 405, to fulfil various high level functions, including processor management, memory management, device management, storage management, software application interface, and generic user interface.

[0089] The operating system 453 manages the memory 434 (1409, 406) to ensure that each process or application running on the computer module 401 has sufficient memory in which to execute without colliding with memory allocated to another process. Furthermore, the different types of memory available in the system 400 of Fig. 4A must be used properly so that each process can run effectively. Accordingly, the aggregated memory 434 is not intended to illustrate how particular segments of memory are allocated (unless otherwise stated), but rather to provide a general view of the memory accessible by the computer system 400 and how such is used.

[0090] As shown in Fig. 4B, the processor 405 includes a number of functional modules including a control unit 439, an arithmetic logic unit (ALU) 440, and a local or internal memory 448, sometimes called a cache memory. The cache memory 448 typically includes a number of storage registers 444 - 446 in a register section. One or more internal busses 441 functionally interconnect these functional modules. The processor 405 typically also has one or more interfaces 442 for communicating with external devices via the system bus 404, using a connection 418. The memory 434 is coupled to the bus 404 using a connection 419.

[0091] The application program 433 includes a sequence of instructions 431 that may include conditional branch and loop instructions. The program 433 may also include data 432 which is used in execution of the program 433. The instructions 431 and the data 432 are stored in memory locations 428, 429, 430 and 435, 436, 437, respectively. Depending upon the relative size of the instructions 431 and the memory locations 428- 430, a particular instruction may be stored in a single memory location as depicted by the instruction shown in the memory location 430. Alternately, an instruction may be segmented into a number of parts each of which is stored in a separate memory location, as depicted by the instruction segments shown in the memory locations 428 and 429.

[0092] In general, the processor 405 is given a set of instructions which are executed therein. The processor 405 waits for a subsequent input, to which the processor 405 reacts to by executing another set of instructions. Each input may be provided from one or more of a number of sources, including data generated by one or more of the input devices 402, 403, data received from an external source across one of the networks 420, 422, data retrieved from one of the storage devices 406, 409 or data retrieved from a storage medium 425 inserted into the corresponding reader 412, all depicted in Fig. 4A. The execution of a set of the instructions may in some cases result in output of data. Execution may also involve storing data or variables to the memory 434.

[0093] The disclosed artificial bokeh rendering arrangements use input variables 454, which are stored in the memory 434 in corresponding memory locations 455, 456, 457. The arrangements produce output variables 461, which are stored in the memory 434 in corresponding memory locations 462, 463, 464. Intermediate variables 458 may be stored in memory locations 459, 460, 466 and 467.

[0094] Referring to the processor 405 of Fig. 4B, the registers 444, 445, 446, the arithmetic logic unit (ALU) 440, and the control unit 439 work together to perform sequences of micro-operations needed to perform "fetch, decode, and execute" cycles for every instruction in the instruction set making up the program 433. Each fetch, decode, and execute cycle comprises:

(a) a fetch operation, which fetches or reads an instruction 431 from a memory location 428, 429, 430;

(b) a decode operation in which the control unit 439 determines which instruction has been fetched; and

(c) an execute operation in which the control unit 439 and/or the ALU 440 execute the instruction.

[0095] Thereafter, a further fetch, decode, and execute cycle for the next instruction may be executed. Similarly, a store cycle may be performed by which the control unit 439 stores or writes a value to a memory location 432.

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[0096] Each step or sub-process in the processes of Figs. 8 to 13 is associated with one or more segments of the program 433 and is performed by the register section 444, 445, 447, the ALU 440, and the control unit 439 in the processor 405 working together to perform the fetch, decode, and execute cycles for every instruction in the instruction set for the noted segments of the program 433.

[0097] The method of artificial bokeh techniques may alternatively be implemented in whole or part in dedicated hardware such as one or more integrated circuits performing the functions or sub functions to be described. Such dedicated hardware may include graphic processors, digital signal processors, or one or more microprocessors and associated memories.

[0098] In another example, a camera may implement the artificial bokeh algorithmic processes to be described in hardware or firmware in order to capture pairs of images with different camera parameters and to process the captured images to provide images with artificial bokeh. In this case, the camera hardware can include a capture mechanism to capture multiple images of a scene. Where the images are suitable for application of artificial bokeh processing, processing can occur in the embedded processor devices of the camera, and results would be retained in a memory of the camera or written to a memory card or other memory storage device connectable to the camera. The embedded devices may be generally equivalent in function to the processor 405 of the computer 401.

[0099] The capture of multiple images of a scene with different capture parameters may be performed by capturing multiple images with a single user operation (a single depression of a capture button of the camera 427) which causes one image to be captured and stored in a memory of the camera, the parameter to be changed, for example the focus of the lens 110 being changed, and a further image to be then captured and stored in the camera memory. Such capturing may occur within approximately 0.001 – 1.0 seconds causing both images to include substantially the same if not identical content and thus substantial common image content upon which artificial bokeh rendering may then be performed.

[00100] In another example, a desktop computer or the like may implement the artificial bokeh processing in software to enable post-capture processing of photos to generate artificial bokeh, which a user can use for image segmentation or further image processing

operations. In this case, the camera 427 would capture multiple images of a scene in a traditional fashion, the images being suitable for application of the artificial bokeh process, and the images would be retained in memory or written to a memory card or other memory storage device. At a later time, the images would be transferred to the computer (e.g. 401), where subsequent steps of the artificial bokeh process would use them as input.

[00101] In yet another example, a cloud computing server or the like may implement the artificial bokeh processing in software to enable post-capture processing of photos to generate artificial bokeh. In this case, the camera 427 would capture multiple images of a scene in a traditional fashion, but with different capture parameters. The images would be uploaded to a cloud computing server, where subsequent steps of the artificial bokeh process would receive and use them as input. The cloud computing server would produce the artificial bokeh images and may then download them back to the camera, or store them for later retrieval by the user.

[00102] Other implementations may capture two images with different camera parameters, the varying parameters being one or more of: focus, zoom, aperture, or any other camera setting that influences the amount of blur in the captured image. In the case of some parameters, such as zoom in particular but also focus and potentially other parameters, the magnification of the captured images may be different. In this case one or more of the images may be scaled to bring the images substantially into registration before applying the artificial bokeh algorithm to render an artificial bokeh image.

[00103] Figs. 5A and 5B illustrate a first pair of exemplary images 501 and 502 respectively upon which the artificial bokeh processing may be performed. The scene content captured by the images 501 and 502 is identical, but the images 501 and 502 capture different image content in view of the image 502 being captured with at least one camera parameter different to the capture of image 501. For example, image 502 may be differently focused relative to the image 501.

[00104] Figs. 5A and 5C illustrate a second pair of exemplary images 501 and 503 respectively upon which artificial bokeh processing may also be performed. The scene content captured by the images 501 and 503 is not identical in total content, however the images 501 and 503 capture a scene that is common, or includes common scene content, to

both images. That common scene content is indicated by dashed rectangles 511 and 513 in Figs 5A and 5C respectively and shows a person standing adjacent to a tree. The common scene content may appear at different positions within the images 501 and 503. The differences in position of the common scene content between the images 501 and 503 may result from, for example, slight camera movement between capture of the two images. The image content of images 501 and 503 within the regions 511 and 513 capturing common scene content may further be different in view of image 503 being captured with at least one camera parameter different to the capture of image 501. For example, image 503 may be differently focused relative to image 501.

[00105] Significantly, in each of Figs. 5A – 5C, a common part of the scene content (being the person adjacent the tree) is captured in each image. Artificial bokeh processing may therefore be performed on pairs of the images to determine a rendered artificial bokeh image for the common part. Note that Figs. 5B and 5C may also represent an image pair upon which artificial bokeh processing may be performed.

[00106] Certain implementations may capture more than two images, with one or more pairs of the images used to render artificial bokeh images using the presently disclosed artificial bokeh algorithm.

[00107] A method of producing an artificial bokeh image from two images of a scene will now be described in detail with reference to Fig. 6 and Fig. 7 and the arrangements of Fig. 4A and 4B where substantive processing occurs within the computer 401. Fig. 6 illustrates a first image 600 of a scene and a second image 610 of the same scene (not illustrated). A selected pixel 620 in the first image 600 is highlighted and a corresponding selected pixel 630 in the second image 610 is highlighted. The correspondence is such that the selected pixel 620 in the first image 600 and the selected pixel 630 in the second image 610 largely correspond to the same point in the scene being imaged. This may be achieved in practice by ensuring that no objects in the scene move in the time between the exposures used to capture the first image 600 and the second image 610 and also that the camera 427 which captures the images 600 and 610 does not move in the time between the exposures, and then selecting pixels from the same (x, y) coordinates on the image sensor. It may also be achieved by an alignment process which explicitly determines which pixels in the first image 600 correspond to pixels in the second image 610. This alignment may address

issues such as motion of objects within the scene between the two exposures, motion of the camera 427 between the two exposures, and changes in the magnification or distortion or both between the two exposures. The alignment may be global across the entire images 600 and 610, local within subregions of the images 600 and 610, or both. Many such alignment processes are known to those skilled in the art.

[00108] Also shown in Fig. 6 are two image patches, which are subsets of the pixels in each image. The first image patch 640 is from the first image 600 and is referred to as f_1. The second image patch 650 is from the second image 610 and is referred to as f_2. The first patch f_1 640 is defined with reference to the first selected pixel 620 in the first image 600 such that the first selected pixel 620 occurs at coordinates (x_1, y_1) with respect to a pixel 642 at the upper left corner of the first patch f_1 640. The second patch f_2 650 is defined with reference to the selected pixel 630 in the second image 610 such that the selected pixel 630 occurs at coordinates (x_2, y_2) with respect to a pixel 652 at the upper left corner of the second patch f_2 650, where $(x_2, y_2) = (x_1, y_1)$. In alternative implementations it may be the case that $(x_2, y_2) \neq (x_1, y_1)$. The patches should be the same size to ensure appropriate comparison of image content contained therein.

[00109] Returning to Figs. 5A to 5C, the patches may be formed by simple division of the images or parts of the images into blocks. In the example of the image pair 501 and 502 shown in Figs. 5A and 5B respectively, the image content is sufficiently aligned that the patches may be formed by dividing the images into a 4×4 configuration of blocks. In the example of the image pair 501 and 503 shown in Figs. 5A and 5C respectively, the regions 511 and 513 showing common scene content may be divided into patches in a similar blockwise manner (not illustrated). Alternatively, the patches may be formed in a manner such that the patches vary in size across the images.

[00110] Fig. 7 illustrates an artificial bokeh process 700 in which an artificial bokeh rendered image 775 is determined. The process 700 operates to modify the blur in at least part of an image of a scene. In an image capture step 710, two images 600 and 610 of a scene are captured by an image capture device 100, such as the camera 427. The images 600 and 610 should include image content of a common part of the scene content. For example, with reference to Fig. 1 the common part could be the object 140. In Figs. 5A and 5C the common part is the person next to the tree, whereas in Figs. 5A and 5B, the

common part is the entirety of the images. The images are captured with at least one of the camera parameters of focus, aperture, zoom, or some other parameter that influences the amount of blur in the image being different, so that the amount of blur is different between the images. Ideally the images are captured such that any motion of the objects in the scene and any relative motion of the camera 427 with respect to the scene is minimised. For example, with reference to Figs. 5A and 5C, which are representative of such relative motion, an alignment process may be performed on the two images to provide that the common parts as found in each image are appropriately aligned prior to artificial bokeh processing. This may involve, for example, aligning the image data within the rectangles 511 and 513 with each other, or cropping the images to those rectangles.

[00111] A specific implementation of the image capture step 710 is described in more detail below with reference to Fig. 8. Typically the images 600 and 610 are captured by the camera 427 and communicated to and received by the computer 401 for storage in one or both of the HDD 410 and memory 406. Where the process 700 is performed within the camera 427, the images 600 and 610 are stored in a memory of the camera 427 for subsequent processing by an embedded processor thereof.

[00112] Steps 720 – 780 of the process 700 may be preferably embodied in and implemented by an embedded processor in the camera 427. Steps 720 – 780 of the process 700 in the present implementation are embodied in and implemented by software, for example stored on the HDD 410 and executable by the processor 405 in concert with the memory 406. In a patch selection step 720 which follows the capture step 710, the corresponding patches f_1 640 and f_2 650 of the two images 600 and 610 are selected and received by the processor 405 from the memory 406.

[00113] In an asymmetric patch selection step 740 which then follows, a determination is made regarding which of the patches f_1 or f_2 is the less blurred patch of the two. Details of a specific implementation of the asymmetric patch selection step 740 will be described below with reference to Fig. 9.

[00114] An artificial bokeh rendering step 750 is then performed in which an artificial bokeh patch $f_{(N)}$ is determined by the processor 405 processing the pixel data in the first patch f_1 640 and the second patch f_2 650. In practice, the artificial bokeh rendering step

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750 may be performed multiple times iteratively for many different pairs of input patches f_1 and f_2, thus producing a set $S\{f_{(N)}\}$ of artificial bokeh patches $f_{(N)}$, each artificial bokeh patch associated with specific input patches f_1 and f_2. The artificial bokeh patches are typically stored in the memory 406. The details of an implementation of the artificial bokeh rendering step 750 will be described below with reference to Fig. 10.

[00115] A patch decision step 760 then follows where a decision is made by the processor 405 on whether there remain any patches in the first image 600 and the second image 610 that have not yet been selected in the patch selection step 720. If there remain patches that have not yet been selected, the artificial bokeh process 700 returns to the patch selection step 720. In practice, the patches may be selected in a systematic order such as by iterating along the rows and down the columns of the first image f_1 600. Accordingly, the steps 720-760 proceed for a current patch of all the patches desired to be processed for artificial bokeh purposes. Each current patch represents a current part of the common part of the scene captured by the images. In some instances, for example the image pair of Figs. 5A and 5B, because all is common, image patches may span the entirety of the images. In an alternative approach, only a subset of the first image f_1 600 may be chosen to be selected, for example by the processor 405 selecting a subset of pixels of the first image f_1 600 to avoid any of the resulting patches from covering areas outside the images, thus avoiding any edge effects. In another alternative, a subset of pixels of the first image f_1 600 may be chosen to be selected by some other means. Once all required patches have been selected ('NO' in step 760), the artificial bokeh process 700 continues to an assembly step 770.

[00116] In the assembly step 770, the artificial bokeh rendered patches calculated in the artificial bokeh rendering step 750 are assembled by the processor 405 to produce an artificial bokeh rendering of the scene captured by the image capture device 100. Such reveals an artificial bokeh image 775 that may be stored by the processor 405 in the memory 406 or HDD 410, and/or reproduced upon the video display 414 or by the printer 415. The details of an implementation of the assembly step 770 will be described below with reference to Fig. 11.

[00117] The artificial bokeh process 700 then ends at end step 780.

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Image capture

[00118] One example of the image capture step 710 will now be described with reference to Fig. 8. In a camera set up step 810, the image capture device (camera 427) is aimed at the desired scene. This can be done for example by aiming a hand-held camera, or by setting up a camera on a tripod.

[00119] In a camera setting step 820, various settings associated with the image capture device are set. This refers to settings that have some effect on the amount of blur recorded in the image and includes setting the lens focus position, the zoom position of the lens if it is capable of zooming, and the aperture of the lens. Other image capture device settings which change the amount of blur in the image are possible. These settings may be performed manually by the operator, or automatically by control software executing within the camera based on the scene to be captured.

[00120] A first image taking step 830 then follows, where a (first) image of the scene is captured using the settings set in the camera setting step 820.

[00121] A camera setting change step 840 follows where the settings of the image capture device are changed from the values set in the camera setting step 820. This may involve changing one or more of: the lens focus position, the lens zoom position, the lens aperture setting, and any other setting which affects the amount of blur recorded in the image. This change may be performed manually or by the camera control software.

[00122] In a second image taking step 850, a (second) image of the scene is captured using the settings set in the camera setting change step 840. The image capture process 710 then ends at end step 870.

[00123] In one implementation, the first image taking step 830, the camera setting change step 840, and the second image taking step 850 are performed automatically by the image capture device 100 in response to a single activation of an image capture function of the device 100, for example pressing the shutter button on a camera.

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Asymmetric patch selection

[00124] One implementation of the asymmetric patch selection step 740 will now be described with reference to Fig. 9. The asymmetric patch selection process 740 begins with the first image patch f_1 620 and the second image patch f_2 640 as data inputs.

[00125] In a first variance calculation step 910, the variance σ_1^2 of the pixel values in the patch f_1 620 is calculated, using the well-known definition of variance. In a second variance calculation step 920, the variance σ_2^2 of the pixel values in the patch f_2 640 is calculated.

[00126] In a variance comparison step 930, the variance σ_1^2 of the pixel values in patch f_1 620 is compared to the variance σ_2^2 of the pixel values in patch f_2 640. If the variance σ_1^2 of the pixel values in patch f_1 620 is greater than or equal to the variance σ_2^2 of the pixel values in patch f_2 640, processing continues with a first patch selection step 940. On the other hand, if the variance σ_1^2 of the pixel values in patch f_1 620 is less than the variance σ_2^2 of the pixel values in patch f_2 640, processing continues to a second patch selection step 945.

[00127] In the first patch selection step 940, patch f_1 is selected as the less blurred patch. In the second patch selection step 945, patch f_2 is selected as the less blurred patch. The asymmetric patch selection process 740 then ends at end step 950.

[00128] Other approaches to performing the asymmetric patch selection step 740 are possible. For example, the patches may first be smoothed using a filter to reduce the effects of outlying pixel values caused by imaging noise. The variances of the filtered patches may then be calculated, and the patch with the highest variance after filtering may then be selected as the less blurred patch. In another example, a two-dimensional gradient operator, such as the Laplacian operator, may be applied to the patches, and then the patch with the greatest range of pixel values (*i.e.* maximum pixel value minus minimum pixel value) in the Laplacian gradient image may be selected as the less blurred patch. In another example, it may be known that the two images 600 and 610 were captured with the aperture value being the only parameter changed between the captures, in which case the

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patch from the image captured with the narrower aperture may simply be selected as the less blurred patch.

Artificial bokeh rendering

[00129] One implementation of the artificial bokeh rendering step 750 will now be described with reference to Fig. 10. The artificial bokeh rendering process 750 begins with the image patch f_1 620 and the image patch f_2 640 as data inputs. In a Fourier transform step 1010, the patches f_1 and f_2 are Fourier transformed, for example using a Fast Fourier Transform (FFT) algorithm, to form Fourier transformed patches F_1 and F_2 respectively. The Fourier transformed image patches F_1 and F_2 will contain complex number values at each pixel.

[00130] A first blur determination step 1020 follows where reference is made to which of the patches f_1 or f_2 was selected as the less blurred patch in asymmetric patch selection step 740. If the image patch f_1 620 was selected as the less blurred patch, the artificial bokeh rendering process 750 continues to a first spectral ratio step 1030a. On the other hand, if the image patch f_2 630 was selected as the less blurred patch, the artificial bokeh rendering process 750 continues to a second spectral ratio step 1030b.

[00131] In the first spectral ratio step 1030a, the Fourier transformed patches F_1 and F_2 are divided pixel-wise to form the spectral ratio image patch F_2/F_1, using complex number division. In the second spectral ratio step 1030b, the Fourier transformed patches F_1 and F_2 are divided pixel-wise to form the spectral ratio image patch F_1/F_2, using complex number division. In both of the spectral ratio steps 1030a and 1030b, the Fourier transformed patch in the denominator of the formed ratio is the Fourier transformed patch of the image patch determined to be the least blurred. As such, a combination of data from the first and second patches is used to calculate at least one Fourier transform value which in turn is based on the determination in the asymmetric patch selection step 740 of which of the patches is the more focussed image patch.

[00132] In a modification step 1040, the spectral ratio formed in step 1030a or step 1030b is modified by a normalisation process, by dividing by the value of the DC pixel of the spectral ratio, forming a normalised spectral ratio. In a variation of the modification step

1040, the spectral ratio is first filtered with a smoothing filter to remove outlying pixel values, before dividing by the value of the DC pixel of the smoothed spectral ratio to achieve the normalisation. The smoothing filter may be a median filter, a Gaussian filter, or some other filter. In another variation of the modification step 1040, the spectral ratio is weighted on a per-pixel basis by multiplication by a weighting function determined by the values of the complex phases of the pixels of the spectral ratio, before dividing by the value of the DC pixel of the weighted spectral ratio to achieve the normalisation.

[00133] A result of steps 1010 – 1040 is the calculation of a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches.

[00134] In an exponentiation step 1050, the normalised spectral ratio is raised to a predetermined power N, in a pixel-wise fashion, using complex arithmetic, forming an amplified spectral ratio.

[00135] A second blur determination step 1060 follows where reference is made to which of the patches f_1 or f_2 was selected as the less blurred patch in asymmetric patch selection step 740. If the image patch f_1 620 was selected as the less blurred patch, the artificial bokeh rendering process 750 continues to a first multiplication step 1070a. On the other hand, if the image patch f_2 630 was selected as the less blurred patch, the artificial bokeh rendering process 750 continues to a second multiplication step 1070b.

[00136] In the first multiplication step 1070a, the amplified spectral ratio is multiplied by the Fourier transform F_1 of patch f_1, forming the Fourier domain patch $F_{(N)}$. In the second multiplication step 1070b, the amplified spectral ratio is multiplied by the Fourier transform F_2 of patch f_2, forming the Fourier domain patch $F_{(N)}$.

[00137] In an inverse transform step 1080, the Fourier domain patch $F_{(N)}$ is inverse Fourier transformed, for example using an FFT algorithm, to form the artificial bokeh patch $f_{(N)}$ 1085.

[00138] The artificial bokeh rendering process 750 then ends at end step 1090.

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[00139] In a preferred implementation, the patch 1085 contains pixels with blur modified with respect to the initial amount of blur in the image patch, in which the amount of modification with respect to blur varies across different regions of the image patch.

[00140] Specifically, the input pair of image patches f_1 and f_2 will in general contain pixels representing various different objects or parts of objects within the scene. These objects or parts of objects will in general be at differing distances from the camera. The processing steps of the artificial bokeh rendering process 750 described above, when applied to a single pair of input patches, will produce an artificial bokeh patch 1085 in which the objects at differing distances from the camera are blurred by different amounts, according to the theory described in the section "Application to artificial bokeh" above.

Image assembly

[00141] The artificial bokeh patches are desirably assembled into an image such that there is a geometric correspondence between the patch locations of each patch selected in the patch selection step 720 and the corresponding artificial bokeh patches that are calculated from those patches in the artificial bokeh rendering step 750. For example, if the first image 600 is 100 × 100 pixels and patches of 10 × 10 pixels are selected by iterating adjoining patches across rows and down columns, then the consecutive artificial bokeh rendered patches can be assembled by tiling them into an image 100 × 100 pixels in size by inserting the rendered patches into successive 10 × 10 blocks of pixels, iterating across rows and down columns. In general, the image assembly step 770 may be more complex than this, and is described below.

[00142] One implementation of the image assembly step 770 will now be described with reference to Fig. 11. The input to the image assembly process is the set $S\{f_{(N)}\}$ of all of the artificial bokeh patches $f_{(N)}$ produced by the iterations of the artificial bokeh step 750.

[00143] The image assembly process begins with an output image formation step 1110, in which an output image is formed, ready to hold pixel values of the artificial bokeh image. The output image is preferably an image of pixel size equal to the input images captured in image capture step 710. The output image may alternatively be of a different size to the input images, such as with a number of pixels trimmed from the borders. The pixel

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coordinates (x_o, y_o) of the output image are related to the pixel coordinates (x_{ik}, y_{ik}) of the kth input image by a relation

$$(x_o, y_o) + (n_{xk}, n_{yk}) = (x_{ik}, y_{ik}) \tag{10}$$

for some fixed pair of integers (n_{xk}, n_{yk}). If there is no shift between the input images, then (n_{xk}, n_{yk}) is the same for all k input images, but this may not be true in the case when there is motion shift between the input images.

[00144] In a pixel selection step 1120, a pixel p_o of the output image is selected, with coordinates (x_o, y_o). The selected pixel p_o is a pixel that has not previously been selected by an earlier iteration of step 1120. In practice, all of the pixels in the output image may be selected in successive iterations of step 1120 by iterating across rows and down columns. Pixels p_{ik} in each of the input images are defined with respect to p_o by equation (10).

[00145] In a patch determining step 1130, it is determined which artificial bokeh patches $f_{(N)}$ from the set of patches $S\{f_{(N)}\}$ calculated in artificial bokeh rendering step 750 were calculated using input patches containing the pixels p_{ik} corresponding to the output image pixel p_o selected in pixel selection step 1120. In other words, which of the patches $f_{(N)}$ were calculated from patches f_1 and f_2 of the original images which contain the pixels p_{ik} with coordinates (x_{ik}, y_{ik}) satisfying equation (10). The patches $f_{(N)}$ that are determined to satisfy this condition are placed in a subset $T\{f_{(N)}\}$ of patches.

[00146] In a patch counting step 1140, a decision is made based on whether the subset $T\{f_{(N)}\}$ of patches determined in patch determining step 1130 contains more than one patch. If the subset $T\{f_{(N)}\}$ contains exactly one patch, processing continues with a first output calculation step 1150a. Alternatively, if the subset $T\{f_{(N)}\}$ contains more than one patch, processing continues with a second output calculation step 1150b. The case where the subset $T\{f_{(N)}\}$ contains no patches should not occur if the output image formed in output image formation step 1110 is sized appropriately.

[00147] In the first output calculation step 1150a, the output pixel p_o is assigned the value of the corresponding pixel from the patch $f_{(N)}$ which is the only member of the subset

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$T\{f_{(N)}\}$ of patches determined in patch determining step 1130. The correspondence is determined with reference to the input image patches f_1 and f_2 of the original images and equation (10).

[00148] In the second output calculation step 1150b, the output pixel p_o is assigned a value calculated from the values of the corresponding pixels p^T from each of the patches $f_{(N)}$ which are members of the subset $T\{f_{(N)}\}$ of patches determined in patch determining step 1130. The correspondence is determined with reference to the input image patches f_1 and f_2 of the original images and equation (10). The value of the pixel p_o may be assigned by some mathematical combination of the values of the pixels p^T, for example the mean of the values of the pixels p^T. In an alternative implementation, the value of the pixel p_o may be assigned the median of the values of the pixels p^T. In another alternative implementation, the value of the pixel p_o may be assigned the mean or median of a subset of the values of the pixels p^T after some values are rejected as outliers by some statistical method.

[00149] In a pixel decision step 1160, a decision is made based on whether there are more pixels remaining in the output image that have not yet been assigned values by either the first output calculation step 1150a or the second output calculation step 1150b. If more pixels remain to be assigned values, processing returns to the pixel selection step 1120. If no more pixels remain to be assigned values, the image assembly process 770 terminates at the end step 1170.

Example 2

[00150] Fig. 12 illustrates an artificial bokeh process 1200 in which an artificial bokeh rendered image is determined. In an image capture step 1210, two images 600 and 610 of a scene are captured by an image capture device 100, such as the camera 427. The images 600 and 610 should include image content of a common part of the scene content, as described previously. A specific implementation of the image capture step 1210 is the method 710 described above with reference to Fig. 8.

[00151] Steps 1220 – 1290 of the process 1200 are preferably embodied in and implemented by an embedded processor in the camera 427. Steps 1220 – 1290 of the

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process 1200 may also be embodied in and implemented by software, for example stored on the HDD 410 and executable by the processor 405 in concert with the memory 406.

[00152] In a segmentation step 1220, at least one of the two images 600 and 610 are segmented into foreground and background regions, preferably such that the foreground region generally comprises image regions corresponding to objects close to the focal plane, while the background region generally comprises image regions corresponding to objects far from the focal plane. Note that the background region can include image regions between the focal plane and the camera (in the relatively extreme foreground), as well as those beyond the focal plane. In this regard, 'background' is intended to cover those objects or regions of the captured image that are not the subject of the photograph. Typically this includes ordinary background objects, but can include near foreground objects. For example, the images may be segmented by applying a DFD algorithm to the images to produce a depth map, followed by thresholding the resulting depth map to produce a binary segmentation. Several such binary depth segmentation methods are known in the art, though they often have poor accuracy around the object boundaries.

[00153] In a boundary determination step 1230, a boundary region between the foreground and background regions is determined. For example, the boundary region may be determined by selecting all pixels within a predetermined radius r of the segmentation edge between the foreground and background regions. Preferably, the radius r is a size close to the maximum expected error in the location of the boundary between the foreground and background regions produced in segmentation step 1220, in pixels, plus the size of the patches used in steps 1240 – 1280. The boundary region should separate the foreground and background regions, and may be disjoint if there are several objects in the images.

[00154] In a patch selection step 1240, the corresponding patches f_1 640 and f_2 650 of the two images 600 and 610 are selected and received by the processor 405 from the memory 406. In this implementation, the selected patches f_1 640 and f_2 650 need only cover the boundary region determined in step 1230. Patches which do not contain pixels in the boundary region are not selected.

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[00155] In an asymmetric patch selection step 1250 which then follows, a determination is made regarding which of the patches f_1 or f_2 is the less blurred patch of the two. Details of a specific implementation of the asymmetric patch selection step 1250 are described above with reference to the method 740 of Fig. 9.

[00156] An artificial bokeh rendering step 1260 is then performed in which an artificial bokeh patch $f_{(N)}$ is determined by the processor 405 processing the pixel data in the first patch f_1 640 and the second patch f_2 650. In practice, the artificial bokeh rendering step 1260 may be performed multiple times iteratively for many different pairs of input patches f_1 and f_2, thus producing a set $S\{f_{(N)}\}$ of artificial bokeh patches $f_{(N)}$, each artificial bokeh patch associated with specific input patches f_1 and f_2. The artificial bokeh patches are typically stored in the memory 406. The details of an exemplary implementation of the artificial bokeh rendering step 1260 are described above with reference to the method 750 of Fig. 10.

[00157] A patch decision step 1270 then follows where a decision is made by the processor 405 on whether there remain any patches in the first image 600 and the second image 610 which include pixels in the boundary region determined in step 1230, and that have not yet been selected in the patch selection step 1240. If there remain patches that have not yet been selected, the artificial bokeh process 1200 returns to the patch selection step 1240. Accordingly, the steps 1250-1270 proceed for a current patch of all the patches which contain pixels in the boundary region. Once all required patches have been selected ('NO' in step 1270), the artificial bokeh process 1200 continues to an assembly step 1280.

[00158] In the assembly step 1280, the artificial bokeh rendered patches calculated in the artificial bokeh rendering step 1260 are assembled by the processor 405 to produce an artificial bokeh rendering 1285 of the boundary region determined in step 1230. The details of an exemplary implementation of the assembly step 1280 are described above with reference to the method 770 of Fig. 11, noting that the assembly 1280 produces pixels only within the boundary region.

[00159] In a composite image step 1290, the artificial bokeh rendering 1285 assembled in step 1280 is combined with the foreground and background regions determined in step 1220 to form a composite rendered image 1292. Before combination, the background

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region may be blurred by convolution with a blur kernel. The foreground, blurred background, and artificial bokeh rendered boundary regions are then composited to produce a single image 1292. Such reveals an artificial bokeh image that may be stored by the processor 405 in the memory 406 or HDD 410.

[00160] The artificial bokeh process 1200 then ends at end step 1295.

Variations and User Cases

[00161] Many variations of the processes of Figs. 7, 8, 9, 10, 11, and 12 may be performed. For example, the processes may be applied to different colour channels of the input image patches, thereby calculating separate artificial bokeh images for each colour channel, which may then be combined, for example using demosaicing algorithms known to those skilled in the art, to produce a colour artificial bokeh image.

[00162] In another variation, the processes may be applied to a luminance channel and colour difference channels of the input image patches, thereby calculating separate artificial bokeh images for the luminance channel and colour difference channels, which may then be combined to produce a colour artificial bokeh image.

[00163] In another variation, the processes may be applied to a luminance channel of the input image patches, thereby calculating an artificial bokeh images for the luminance channel, which may then be combined with unprocessed colour difference channels to produce a colour artificial bokeh image.

[00164] In another variation, multiple artificial bokeh pixel values may be calculated from each pair of input image patches by using different variations of the processes. Then final pixel values may be obtained from the multiple values, averaged or combined in some other manner, or selected from using some selection criterion, to give a final output artificial bokeh image.

INDUSTRIAL APPLICABILITY

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[00165] The arrangements described are applicable to the computer and data processing industries and particularly for the processing of images captured by cameras having a large depth of field, to thereby emulate capture by a camera having a narrow depth of field. The arrangements disclosed therefore have specific utility in the processing of images captured by so-called "compact' digital cameras, and operate to amplify any bokeh present in the captured images. This bokeh amplification can make a compact camera emulate an SLR camera.

[00166] The foregoing describes only some embodiments of the present invention, and modifications and/or changes can be made thereto without departing from the scope and spirit of the invention, the embodiments being illustrative and not restrictive.

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WE CLAIM:

1. A method of modifying the blur in at least a part of an image of a scene, said method comprising:

capturing at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images;

selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur;

calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches;

raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and

combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

2. A method according to claim 1, wherein the set of frequency domain pixel values are modified before being raised to the predetermined power.

3. A method according to claim 2, wherein the modification includes a median filtering operation.

4. A method according to claim 2, wherein the modification includes a smoothing filtering operation.

5. A method according to claim 2, wherein the modification includes a normalisation operation.

6. A method according to claim 2, wherein the modification includes a weighting operation.

7. A method according to claim 6, wherein weights for the weighting operation are determined by the phases of the set of frequency domain pixel values.

8. A method according to claim 1, wherein:

the at least two images of the scene are divided into a plurality of corresponding image patches in each of the captured images; and

the output image patches are combined to produce an output image.

9. A method according to claim 8, wherein the plurality of corresponding image patches in each of the captured images form a tiling substantially covering the area of the captured images, and the output image is formed by tiling the output image patches.

10. A method according to claim 8, wherein the plurality of corresponding image patches in each of the captured images overlap, and the output image is formed by combining the pixel values of the output image patches.

11. A method according to claim 8, wherein:

the plurality of corresponding image patches in each of the captured images cover part of the area of the captured images; and

the output image patches are combined with the area of at least one of the captured images not covered by the plurality of corresponding image patches to produce an output image.

12. A method according to claim 11, wherein at least part of the area of the at least one of the captured images not covered by the plurality of corresponding image patches is blurred by convolution with a blur kernel.

13. A camera comprising an image capture system coupled to memory in which captured images are stored, a processor, and a program executable by the processor to modify the blur in at least a part of an image of a scene, said program comprising:

code for causing the capture system to capture at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images;

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code for selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur;

code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches;

code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and

code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

14. A camera system comprising:

a lens formed of optics producing a relatively large depth of field;

a sensor configured capture an image of a scene focussed through the lens;

a memory in which images captured by the sensor are stored;

a capture mechanism configured to capture at least two images of the scene with different capture parameters and to store the images in the memory;

a processor;

a program stored in the memory and executable by the processor to modify blur in at least a part of one of the captured images of the scene, said program comprising:

code for causing the capture system to capture at least two images of the scene with different camera parameters to produce a different amount of blur in each of the captured images;

code for selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur;

code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches;

code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and

code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

15. A non-transitory computer readable storage medium having a program recorded thereon, the program being executable by a processor to modify blur in at least a part of an image of a scene, said program comprising:

code for receiving at least two images of the scene, said images being captured with different camera parameters to produce a different amount of blur in each of the captured images;

code for selecting a corresponding image patch in each of the captured images, each of the selected image patches having an initial amount of blur;

code for calculating a set of frequency domain pixel values from a combined function of Fourier transforms of two of the selected image patches;

code for raising each of the pixel values in the set of frequency domain pixel values to a predetermined power, thereby forming an amplified set of frequency domain pixel values; and

code for combining the amplified set of frequency domain pixel values with the pixels of the selected image patch in one of the captured images to produce an output image patch with blur modified with respect to the initial amount of blur in the image patch, wherein the amount of modification with respect to blur varies across different regions of the image patch.

ABSTRACT

A method of modifying the blur in at least a part of an image of a scene captures at least two images of the scene with different camera parameters to produce a different amount of blur in each image. A corresponding patch in each of the captured images is selected each having an initial amount of blur is used to calculate a set of frequency domain pixel values from a function of transforms of the patches. Each of the pixel values in the set are raised to a predetermined power, forming an amplified set of frequency domain pixel values. The amplified set of frequency domain pixel values is combined with the pixels of the patch in one of the captured images to produce an output image patch with blur modified relative to the initial amount of blur in the image patch.

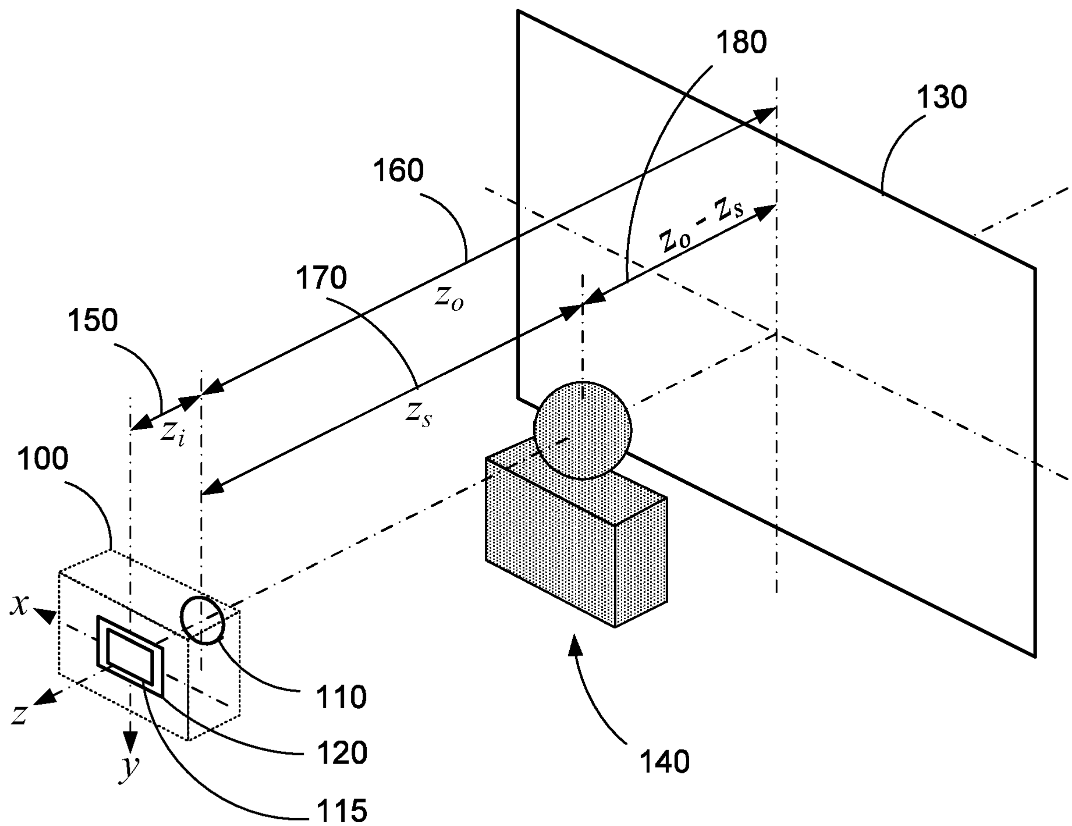


Fig. 1

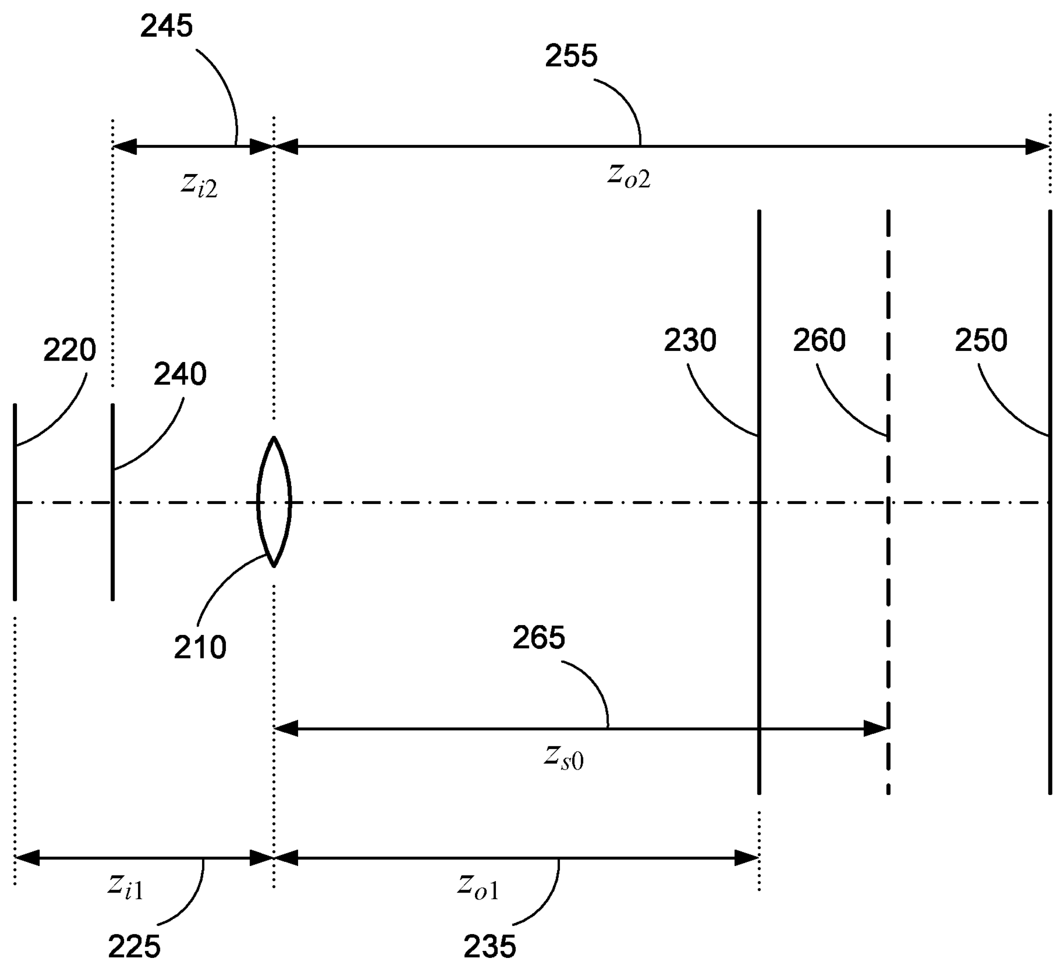


Fig. 2

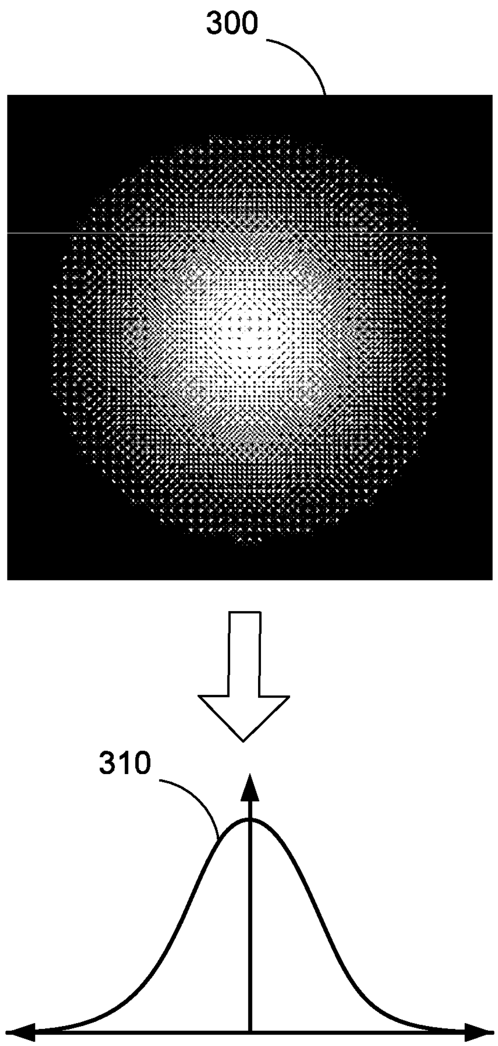


Fig. 3A

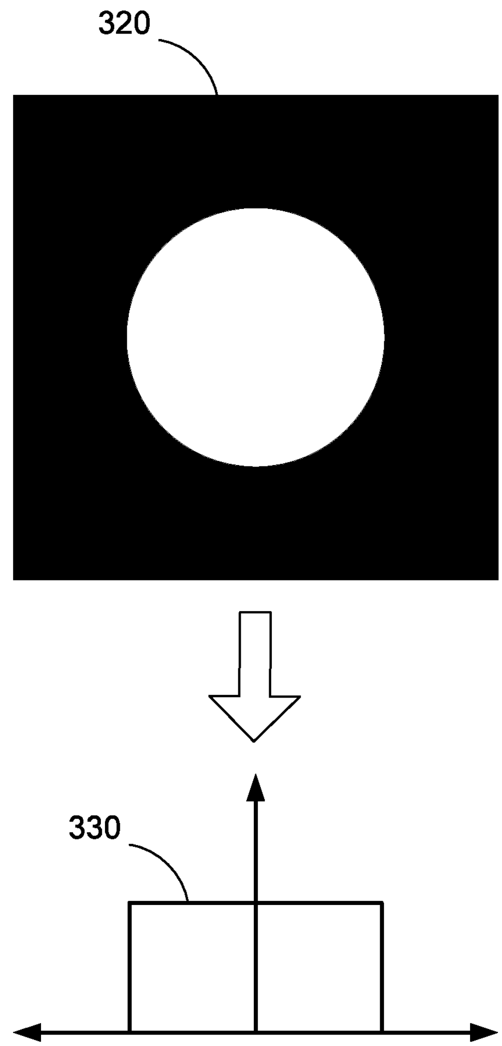


Fig. 3B

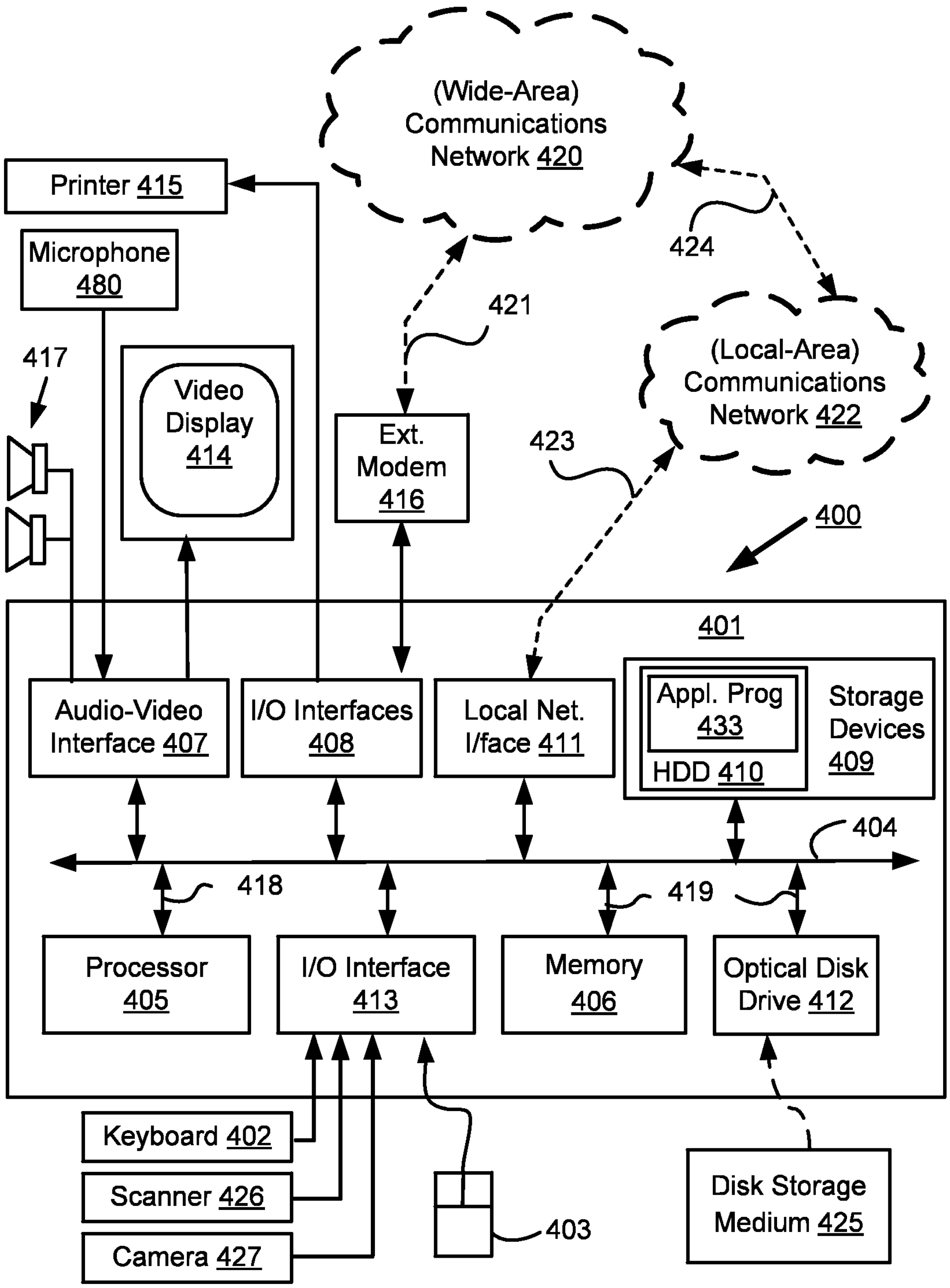

(Wide-Area) Communications Network 420
Printer 415
Microphone 480
424
421
(Local-Area) Communications Network 422
417
Video Display 414
Ext. Modem 416
423
400
401
Audio-Video Interface 407
I/O Interfaces 408
Local Net. I/face 411
Appl. Prog 433
HDD 410
Storage Devices 409
404
418
419
Processor 405
I/O Interface 413
Memory 406
Optical Disk Drive 412
Keyboard 402
Scanner 426
Camera 427
403
Disk Storage Medium 425

Fig. 4A

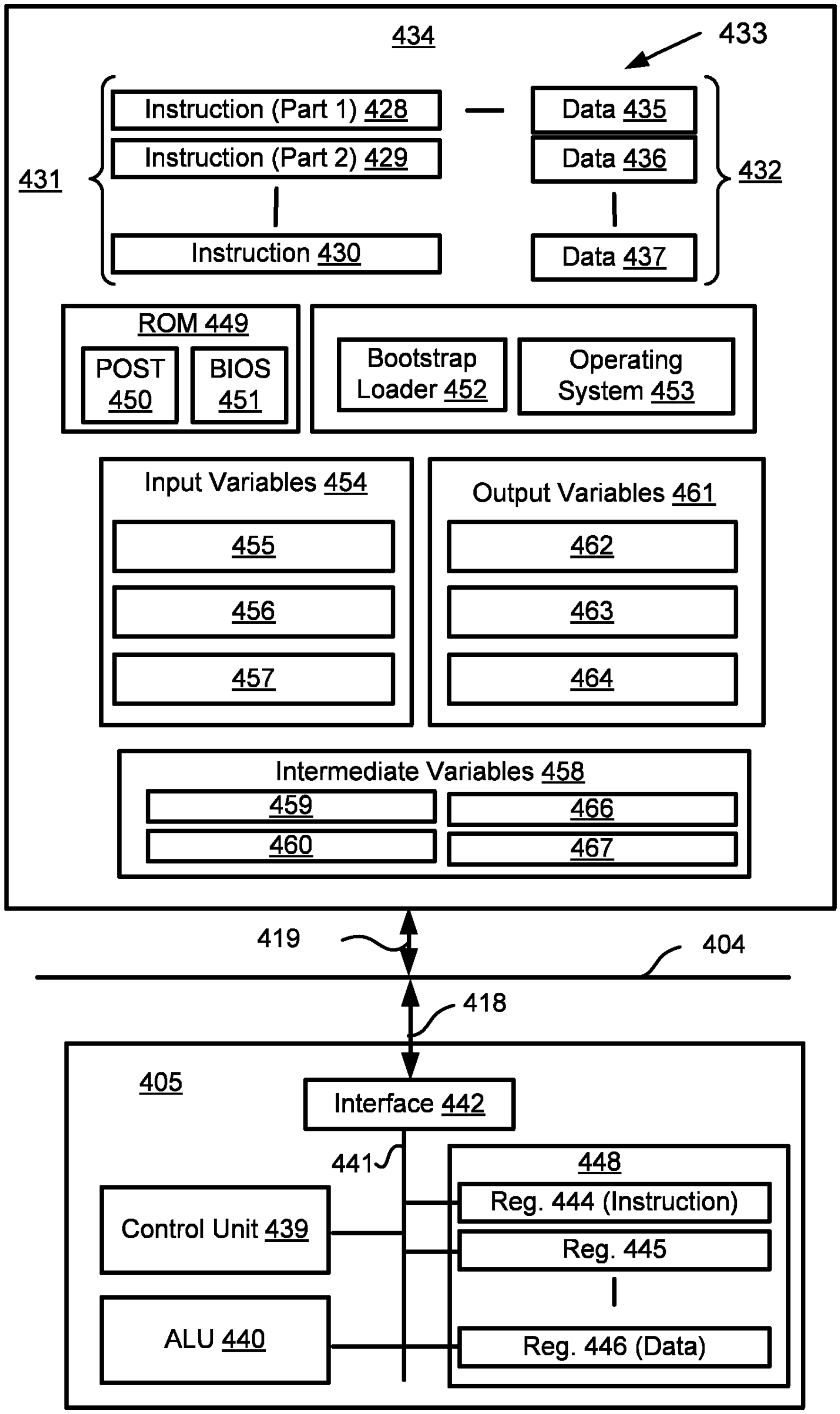

434
433
Instruction (Part 1) 428
Instruction (Part 2) 429
Instruction 430
431
Data 435
Data 436
Data 437
432
ROM 449
POST 450
BIOS 451
Bootstrap Loader 452
Operating System 453
Input Variables 454
455
456
457
Output Variables 461
462
463
464
Intermediate Variables 458
459
460
466
467
419
404
418
405
Interface 442
441
448
Reg. 444 (Instruction)
Reg. 445
Reg. 446 (Data)
Control Unit 439
ALU 440

Fig. 4B

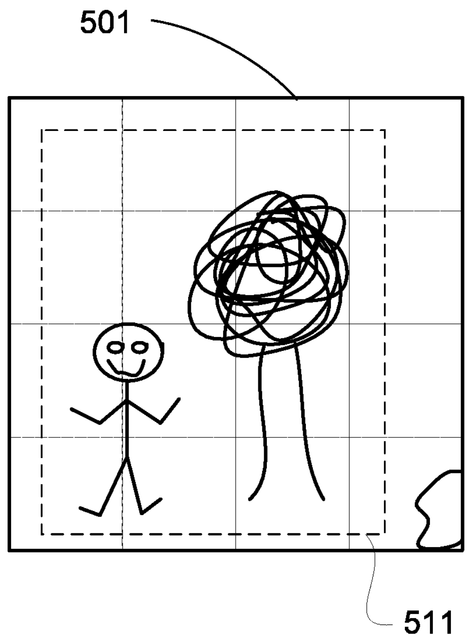


Fig. 5A

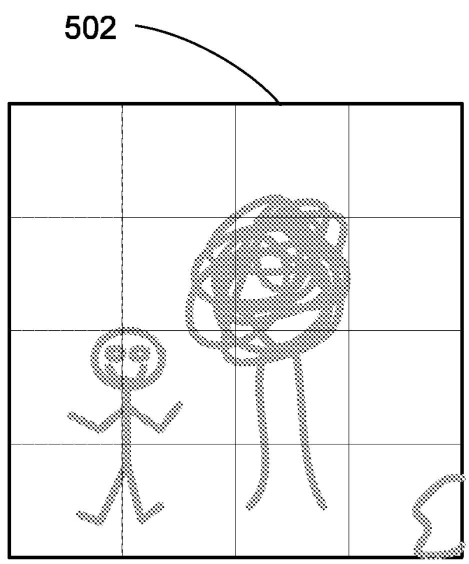


Fig. 5B

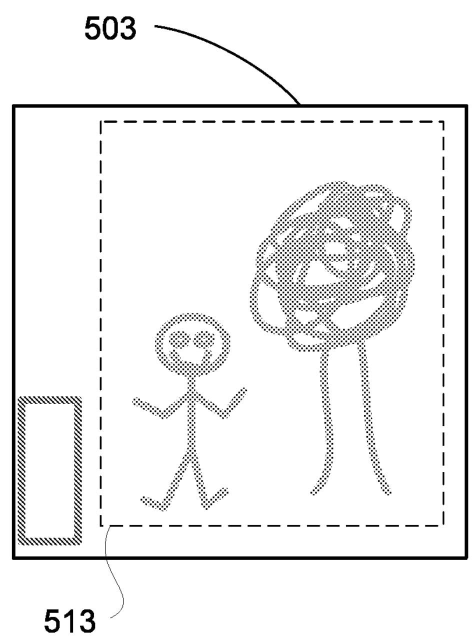


Fig. 5C

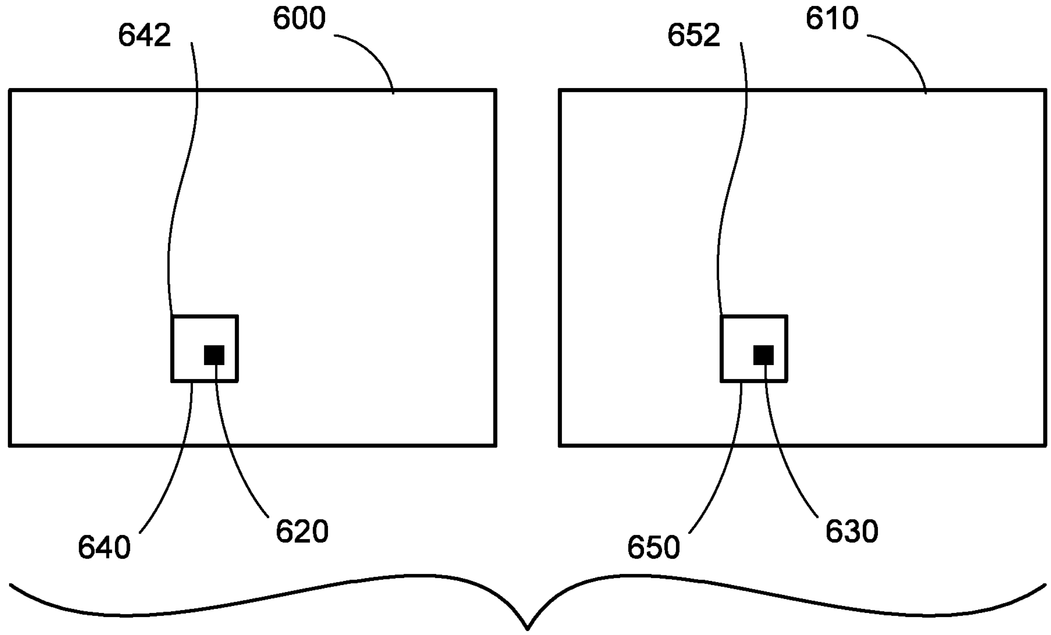


Fig. 6

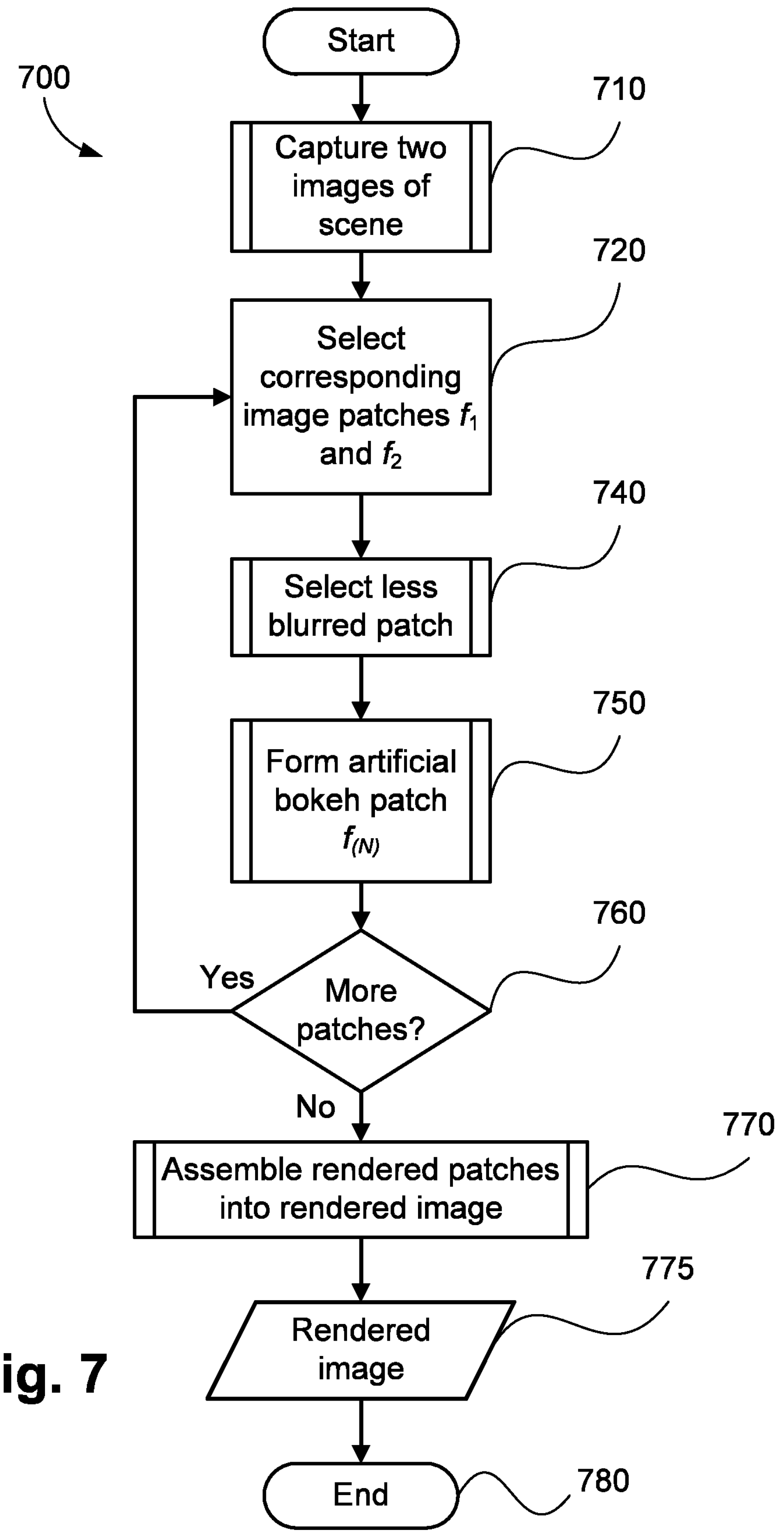

700
Start
Capture two images of scene
710
Select corresponding image patches f_1 and f_2
720
Select less blurred patch
740
Form artificial bokeh patch $f_{(N)}$
750
More patches?
760
Yes
No
Assemble rendered patches into rendered image
770
Rendered image
775
End
780

Fig. 7

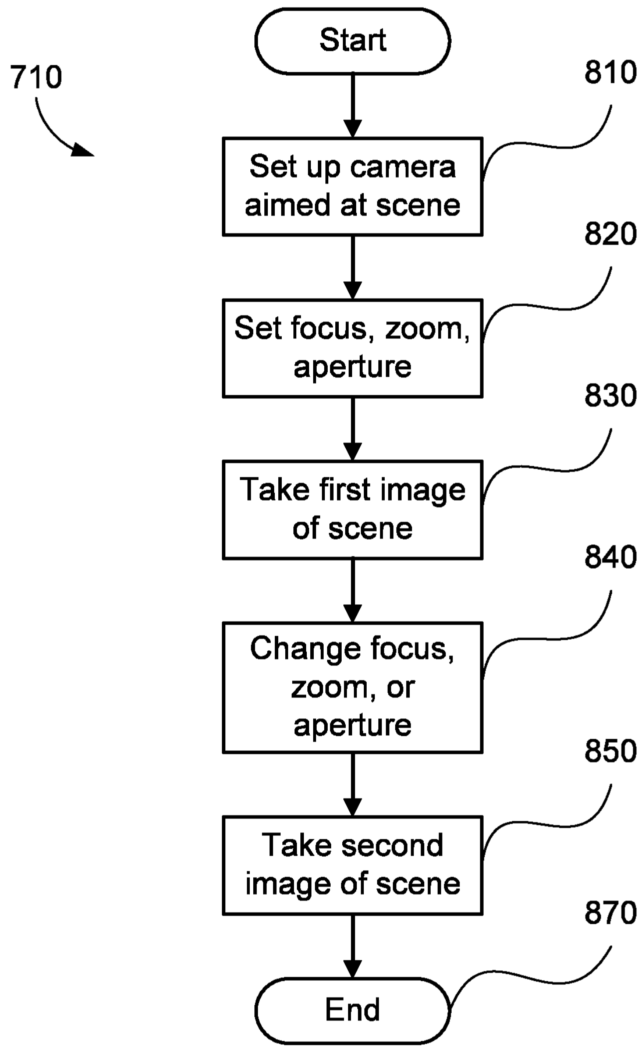

710
Start
810
Set up camera aimed at scene
820
Set focus, zoom, aperture
830
Take first image of scene
840
Change focus, zoom, or aperture
850
Take second image of scene
870
End

Fig. 8

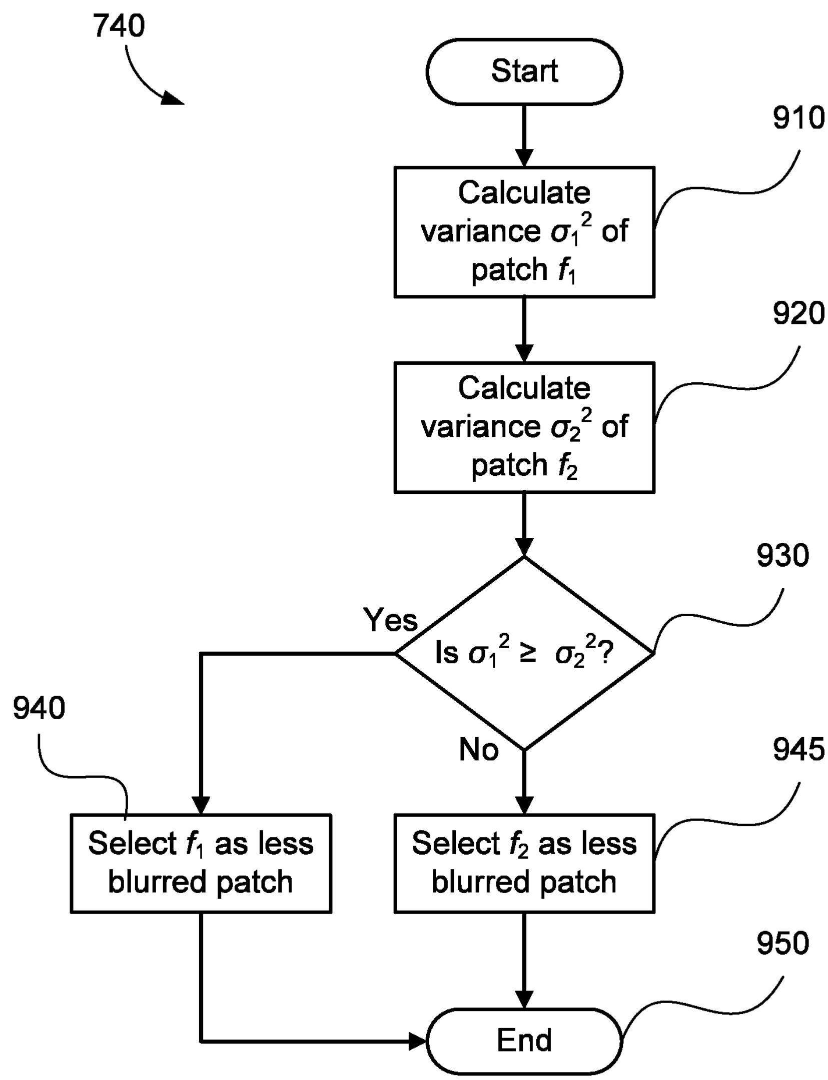

740
Start
910
Calculate variance σ_1^2 of patch f_1
920
Calculate variance σ_2^2 of patch f_2
930
Is $\sigma_1^2 \geq \sigma_2^2$?
Yes
No
940
Select f_1 as less blurred patch
945
Select f_2 as less blurred patch
950
End

Fig. 9

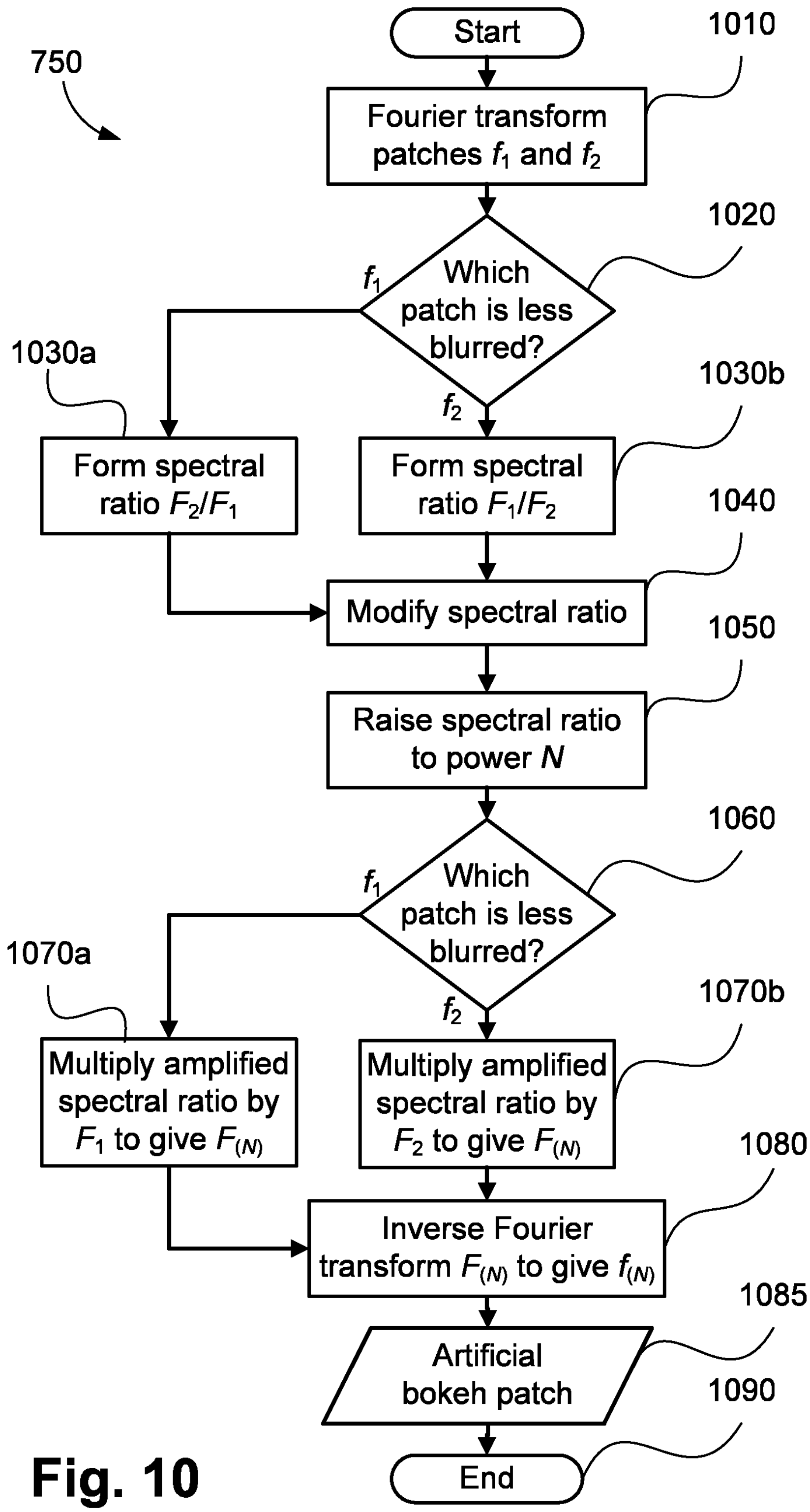
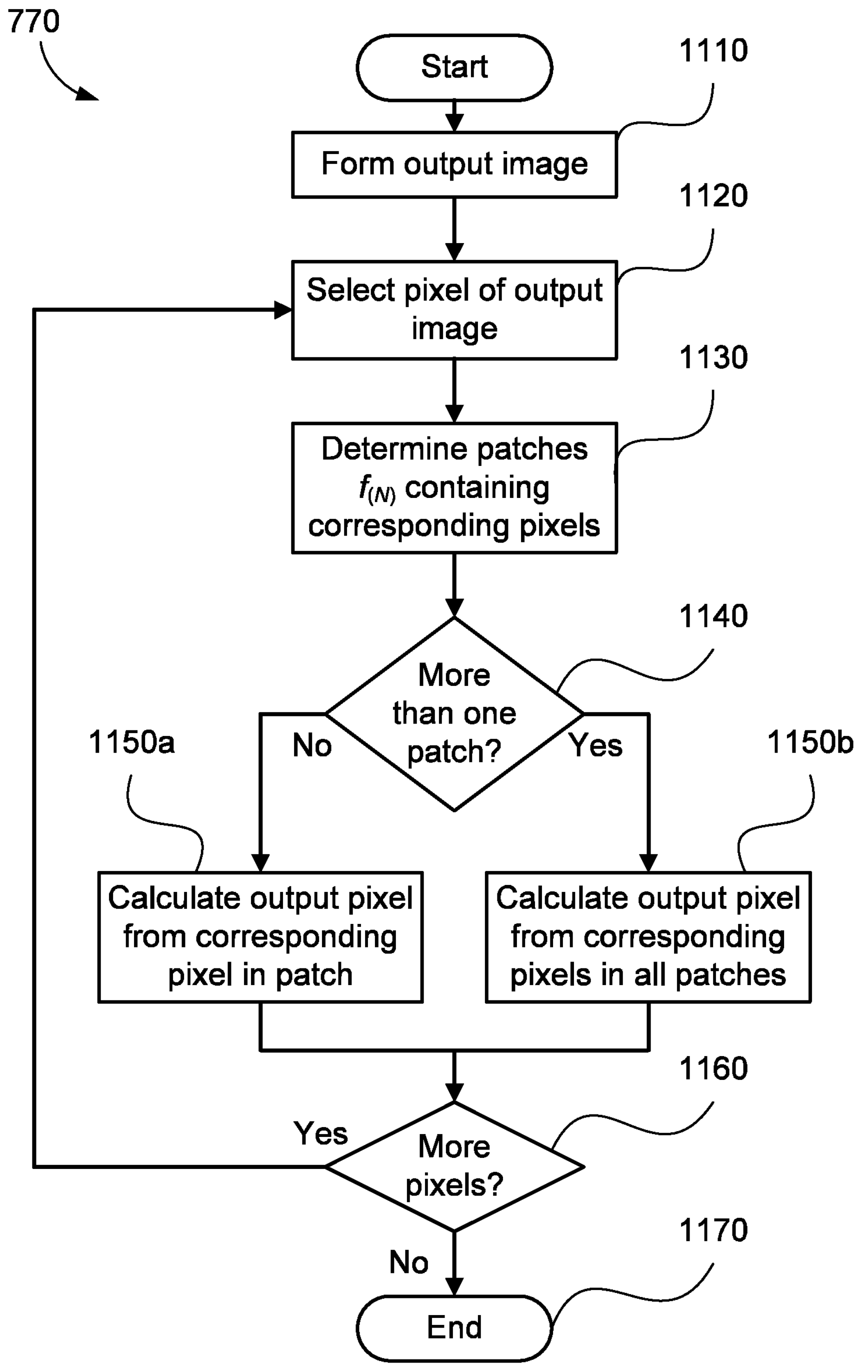

750
Start
1010
Fourier transform patches f_1 and f_2
1020
Which patch is less blurred?
f_1
f_2
1030a
Form spectral ratio F_2/F_1
1030b
Form spectral ratio F_1/F_2
1040
Modify spectral ratio
1050
Raise spectral ratio to power N
1060
Which patch is less blurred?
f_1
f_2
1070a
Multiply amplified spectral ratio by F_1 to give $F_{(N)}$
1070b
Multiply amplified spectral ratio by F_2 to give $F_{(N)}$
1080
Inverse Fourier transform $F_{(N)}$ to give $f_{(N)}$
1085
Artificial bokeh patch
1090
End

Fig. 10



770
Start
1110
Form output image
1120
Select pixel of output image
1130
Determine patches $f_{(N)}$ containing corresponding pixels
1140
More than one patch?
No
Yes
1150a
1150b
Calculate output pixel from corresponding pixel in patch
Calculate output pixel from corresponding pixels in all patches
1160
More pixels?
Yes
No
1170
End

Fig. 11

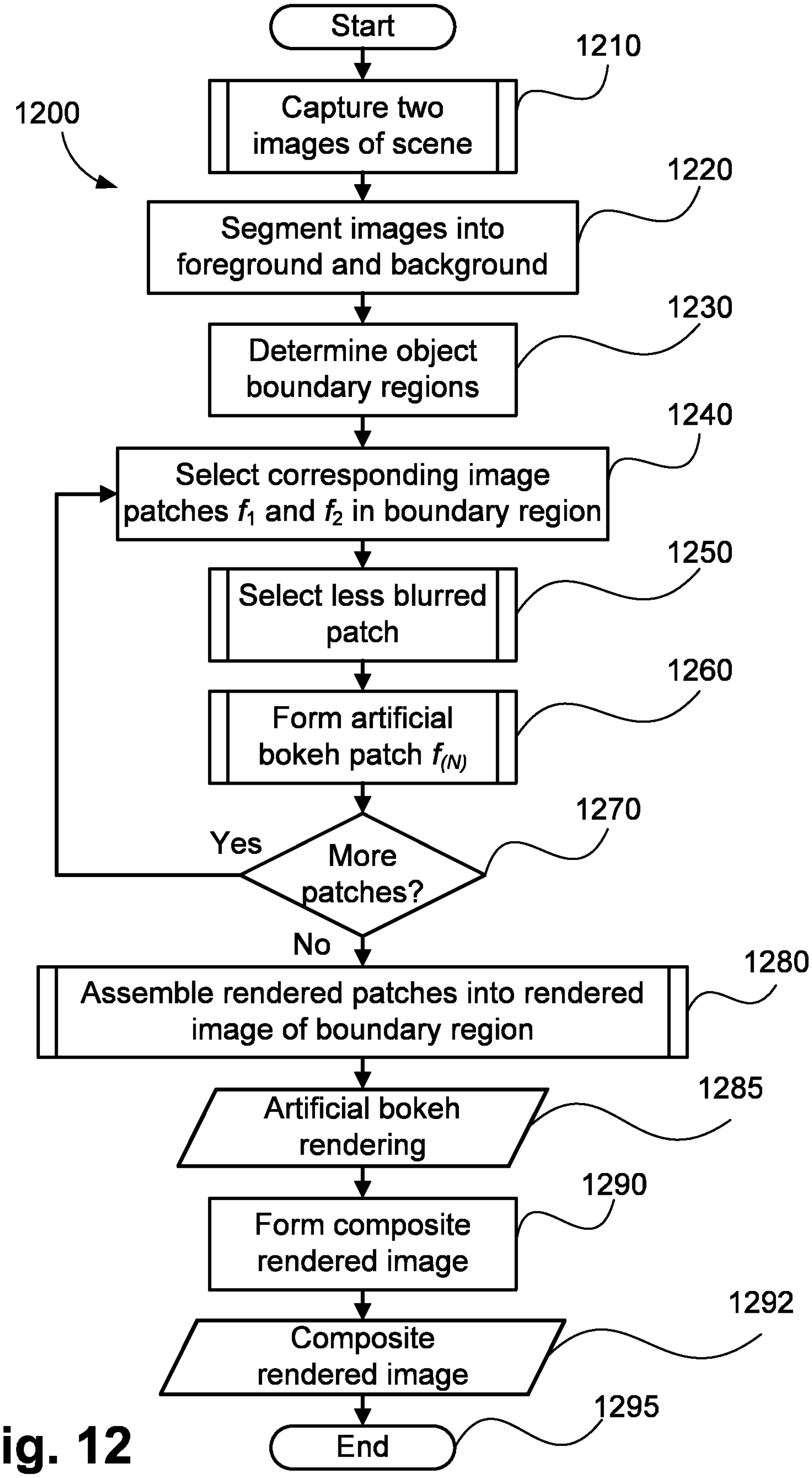

Start
1210
Capture two images of scene
1200
1220
Segment images into foreground and background
1230
Determine object boundary regions
1240
Select corresponding image patches f_1 and f_2 in boundary region
1250
Select less blurred patch
1260
Form artificial bokeh patch $f_{(N)}$
1270
Yes
More patches?
No
1280
Assemble rendered patches into rendered image of boundary region
1285
Artificial bokeh rendering
1290
Form composite rendered image
1292
Composite rendered image
1295
End

Fig. 12

PTO/AIA/14 (03-13)
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	2200-15777-CINC
	Application Number	
Title of Invention	BOKEH AMPLIFICATION	

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.
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☐ 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.)

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	2200-15777-CINC
	Application Number	
Title of Invention	BOKEH AMPLIFICATION	

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

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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.**

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Application Information:

Title of the Invention	BOKEH AMPLIFICATION		
Attorney Docket Number	2200-15777-CINC	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	13	**Suggested Figure for Publication (if any)**	

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

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

Representative Information:

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	2200-15777-CINC
	Application Number	
Title of Invention	BOKEH AMPLIFICATION	

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	34904		

Domestic Benefit/National Stage Information:

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

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

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

Foreign Priority Information:

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

Remove

Application Number	Country i	Filing Date (YYYY-MM-DD)	Access Code i (if applicable)
2012258467	AU	2012-12-03	

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

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	2200-15777-CINC
	Application Number	
Title of Invention	BOKEH AMPLIFICATION	

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.

Authorization to Permit Access:

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

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

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

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

Applicant Information:

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

Applicant 1 Remove

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

Clear

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

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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	CANON KABUSHIKI KAISHA

Mailing Address Information:

Address 1	30-2, Shimomaruko 3-chome, Ohta-ku		
Address 2			
City	Tokyo	**State/Province**	
Country i	JP	Postal Code	146-8501
Phone Number		Fax Number	
Email Address			

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

Non-Applicant Assignee Information:

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

Assignee 1

Complete this section only if non-applicant assignee information is desired to be included on the patent application publication in accordance with 37 CFR 1.215(b). Do not include in this section 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), as the patent application publication will include the name of the applicant(s).

[Remove]

If the Assignee is an Organization check here. ☐

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

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

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

Signature:

Remove

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

Signature	/Jiaxiao Zhang/			Date (YYYY-MM-DD)	2013-11-12
First Name	Jiaxiao	Last Name	Zhang	Registration Number	63235

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

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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 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 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.

SCORE Placeholder Sheet for IFW Content

Application Number: 14079481 Document Date: 11/13/2013

The presence of this form in the IFW record indicates that the following document type was received in electronic format on the date identified above. This content is stored in the SCORE database.

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Form Revision Date: September 30, 2013