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Date: **Monday, December 18, 2017**

By /Peter J. Gutierrez, III/
Peter J. Gutierrez, III
Reg. No. 56,732

## U.S. CONTINUATION APPLICATION TRANSMITTAL

Sir:

Transmitted herewith for filing is the patent application of

Inventor(s): **Filip Piekniewski**
**Vadim Polonichko**
**Eugene Izhikevich**

For: **OPTICAL DETECTION APPARATUS AND METHODS**

Included herewith are:

(X) Specification, including twenty-three (23) claims and abstract, in thirty-six (36) sheets.

(X) Eleven (11) sheet(s) of formal drawings including twenty (20) figures.

(X) This application is a continuation of and claims the benefit of priority to U.S. Patent Application Serial No. 14/321,736 filed on July 1, 2014 of the same title.

(X) Preliminary Amendment (6 pages).

(X) Application Data Sheet (8 pages).

**CLAIMS AS FILED**

| FOR | NUMBER FILED | NUMBER EXTRA | RATE | FEE |
|---|---|---|---|---|
| Basic Filing Fee | | | $ 70 | $ 70 |
| Utility Search Fee | | | $300 | $300 |
| Utility Examination Fee | | | $360 | $360 |
| Total Claims | 1 - 20 = | 0 × | $ 40 | $0 |
| Independent Claims | 1 - 3 = | 0 × | $210 | $0 |
| If application contains any multiple dependent claims(s), then add | | | $390 | $0 |
| | | | **TOTAL FILING FEE:** | **$730.00** |

Respectfully submitted,

GAZDZINSKI & ASSOCIATES, PC

Dated: December 18, 2017

By: /Peter J. Gutierrez, III/

Peter J. Gutierrez, III
Registration No. 56,732
Attorney of Record
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| Application Data Sheet 37 CFR 1.76 | Attorney Docket Number | BRAIN.052C1/BC201416C1 |
|---|---|---|
| | Application Number | |
| Title of Invention | OPTICAL DETECTION APPARATUS AND METHODS | |

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

## Secrecy Order 37 CFR 5.2:

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

## Inventor Information:

**Inventor 1** Remove

**Legal Name**

| Prefix | Given Name | Middle Name | Family Name | Suffix |
|---|---|---|---|---|
| | Filip | | Piekniewski | |

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

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| Postal Code | 92130 | Country | US |

**Inventor 2** Remove

**Legal Name**

| Prefix | Given Name | Middle Name | Family Name | Suffix |
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| | Vadim | | Polonichko | |

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| Postal Code | 92128 | Country | US |

**Inventor 3** Remove

**Legal Name**

| Prefix | Given Name | Middle Name | Family Name | Suffix |
|---|---|---|---|---|
| | Eugene | | Izhikevich | |

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

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|---|---|---|
| | Application Number | |
| Title of Invention | OPTICAL DETECTION APPARATUS AND METHODS | |

| City | San Diego | State/Province | CA | Country of Residence | US |
|---|---|---|---|---|---|

**Mailing Address of Inventor:**

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| **City** | San Diego | **State/Province** | CA |
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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

## Correspondence Information:

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

☐ **An Address is being provided for the correspondence Information of this application.**

| | | | |
|---|---|---|---|
| **Customer Number** | 132059 | | |
| **Email Address** | Docket@gazpat.com | Add Email | Remove Email |

## Application Information:

| | | | |
|---|---|---|---|
| **Title of the Invention** | OPTICAL DETECTION APPARATUS AND METHODS | | |
| **Attorney Docket Number** | BRAIN.052C1/BC201416C1 | **Small Entity Status Claimed** | ☒ |
| **Application Type** | Nonprovisional | | |
| **Subject Matter** | Utility | | |
| **Total Number of Drawing Sheets (if any)** | 11 | **Suggested Figure for Publication (if any)** | |

## Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

| Application number of the previously filed application | Filing date (YYYY-MM-DD) | Intellectual Property Authority or Country |
|---|---|---|
| | | |

## 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.

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| Application Data Sheet 37 CFR 1.76 | Attorney Docket Number | BRAIN.052C1/BC201416C1 |
|---|---|---|
| | Application Number | |
| Title of Invention | OPTICAL DETECTION APPARATUS AND METHODS | |

## Representative Information:

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

| Please Select One: | (●) Customer Number | ( ) US Patent Practitioner | ( ) Limited Recognition (37 CFR 11.9) |
|---|---|---|---|
| Customer Number | 132059 | | |

## Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the "Application Number" field blank.

| Prior Application Status | | | Remove |
|---|---|---|---|
| Application Number | Continuity Type | Prior Application Number | Filing or 371(c) Date (YYYY-MM-DD) |
| | Continuation of | 14/321736 | 2014-07-01 |

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

## Foreign Priority Information:

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

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

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

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| Application Data Sheet 37 CFR 1.76 | Attorney Docket Number | BRAIN.052C1/BC201416C1 |
|---|---|---|
| | Application Number | |
| Title of Invention | OPTICAL DETECTION APPARATUS AND METHODS | |

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

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

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| Application Data Sheet 37 CFR 1.76 | Attorney Docket Number | BRAIN.052C1/BC201416C1 |
|---|---|---|
| | Application Number | |
| Title of Invention | OPTICAL DETECTION APPARATUS AND METHODS | |

## Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

**NOTE**: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

**1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)**

**A. Priority Document Exchange (PDX)** - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

**B. Search Results from U.S. Application to EPO** - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

**2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)**

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

**NOTE:** Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

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| Application Data Sheet 37 CFR 1.76 | Attorney Docket Number | BRAIN.052C1/BC201416C1 |
|---|---|---|
| | Application Number | |
| Title of Invention | OPTICAL DETECTION APPARATUS AND METHODS | |

## 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**

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

Clear

| | | |
|---|---|---|
| ◉ Assignee | ○ Legal Representative under 35 U.S.C. 117 | ○ Joint Inventor |
| ○ Person to whom the inventor is obligated to assign. | ○ Person who shows sufficient proprietary interest | |

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

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

| Organization Name | Brain Corporation |
|---|---|

**Mailing Address Information For Applicant:**

| | | | |
|---|---|---|---|
| **Address 1** | 9401 Waples Street, Suite 100 | | |
| Address 2 | | | |
| **City** | San Diego | **State/Province** | CA |
| **Country** | US | Postal Code | 92121 |
| Phone Number | | Fax Number | |
| Email Address | | | |

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

## Assignee Information including Non-Applicant Assignee Information:

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

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| Application Data Sheet 37 CFR 1.76 | Attorney Docket Number | BRAIN.052C1/BC201416C1 |
|---|---|---|
| | Application Number | |
| Title of Invention | OPTICAL DETECTION APPARATUS AND METHODS | |

**Assignee 1**

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

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

| Prefix | **Given Name** | Middle Name | **Family Name** | Suffix |
|---|---|---|---|---|
| | | | | |

**Mailing Address Information For Assignee including Non-Applicant Assignee:**

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

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

## Signature:

**NOTE:** This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

| **Signature** | /Peter J. Gutierrez, III/ | | | Date (YYYY-MM-DD) | 2017-12-18 |
|---|---|---|---|---|---|
| First Name | PETER | Last Name | GUTIERREZ | Registration Number | 56,732 |

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

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| Application Data Sheet 37 CFR 1.76 | Attorney Docket Number | BRAIN.052C1/BC201416C1 |
|---|---|---|
| | Application Number | |
| Title of Invention | OPTICAL DETECTION APPARATUS AND METHODS | |

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.**

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

| | | |
|---|---|---|
| Applicant | : | Filip Piekniewski et al. |
| Appl. No. | : | To be Assigned |
| Filed | : | Herewith |
| For | : | **OPTICAL DETECTION APPARATUS AND METHODS** |
| Examiner | : | Unknown |
| Group Art Unit | : | Unknown |

**CUSTOMER NO. 132059**

**CERTIFICATE OF ELECTRONIC (EFS-WEB) TRANSMISSION**

I hereby certify that this correspondence is being transmitted via the Office electronic filing system in accordance with 37 C.F.R. § 1.8(a)(1)(i)(C) from the Pacific Time Zone of the United States on the local date shown below.

Date: December 18, 2017

By: /Peter J. Gutierrez, III/
Peter J. Gutierrez, III, Reg. No. 56,732

**PRELIMINARY AMENDMENT**

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

Dear Sir:

Before a first action on the merits, please amend the above-referenced application as follows:

IN THE SPECIFICATION

1. At page 1 of Applicant's specification as filed, immediately before the heading "Copyright" and after the title, please add the following text as follows:

-- This application is a continuation of and claims the benefit of priority to U.S. Patent Application Serial No. 14/321,736 filed on July 1, 2014 of the same title, the contents of which being incorporated herein by reference in its entirety. --

2. Please insert the following text after paragraph [0015] of Applicant's specification as filed and immediately before paragraph [0016] of Applicant's specification as filed that begins with "*These and other objects ...* ":

-- In another aspect of the present disclosure, a method of navigating a robotic apparatus is disclosed. In one embodiment, the robotic apparatus includes a controller, an actuator and a sensor, and the method includes: obtaining, through a lens, at least one image associated with surroundings of the apparatus using the sensor, the sensor including a plurality of image detectors disposed at an angle with respect to a plane of the lens, each of the plurality of image detectors being associated with an extent located in the surroundings; analyzing the at least one image to detect a presence of one or more objects in the at least one image; during the navigating of the robotic apparatus, detecting a distance to the one or more objects based on the presence of at least one of the one or more objects within the extent located in the surroundings; determining that the detected object includes one of either a target or an obstacle; and causing the controller to selectively activate the actuator based on the determination.

In another aspect of the present disclosure, an apparatus is disclosed. In one embodiment, the apparatus is configured to cause a robotic device to navigate a trajectory, and the apparatus includes a non-transitory computer-readable medium including a plurality of instructions configured to cause the apparatus to, when executed by a processor: obtain an image associated with surroundings of

the apparatus using a sensor of the device, the sensor including multiple discrete image sensors behind a single lens associated therewith, each of the multiple discrete image sensors being associated with respective extents located in the surroundings of the apparatus; analyze the image to determine a contrast parameter of the image; detect a presence of an object in the image based at least in part on the contrast parameter meeting one or more criteria; and cause a controller of the device to activate an actuator of the device based on the detection of the presence of the object; wherein the actuator is configured to be activated based on a characteristic of the object; and wherein during the navigation of the trajectory by the robotic device, the apparatus is configured to determine (i) a first distance to the object when the presence of the object produces a first in-focus representation within a first extent of the respective extents and (ii) a second distance to the object when the presence of the object produces a second in-focus representation within a second extent of the respective extents. --

IN THE CLAIMS

Please cancel Claims 1 – 23 without prejudice, and add new Claims 24 as follows:

1. – 23. (Canceled)

24. (New) A method of navigating a robotic apparatus comprising a controller, an actuator and a sensor, the method comprising:

obtaining at least one image associated with surroundings of the apparatus using the sensor;

analyzing the at least one image to detect a presence of an object in the at least one image;

determining that the detected object comprises one of either a target or an obstacle; and

causing the controller to selectively activate the actuator based on the determination.



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REMARKS

Claims 1 – 23 were pending in the application. By this paper, Applicant has canceled Claims 1 – 23 without prejudice and added new Claim 24. Accordingly, Claim 24 is presented for examination herein.

*Amendments to Specification*

Applicant has herein amended the specification to include a priority claim to the parent application. Additionally, Applicant has herein amended the specification to update the summary section. No new matter has been added by way of these amendments.

*New Claim*

Applicant has hereby added new Claim 24. Support for newly added Claim 24 may be found at, *inter alia*, originally submitted Claim 22 of Applicant's specification as filed. No new matter has been added by virtue of this newly added claim.

*Other Remarks*

Applicant notes that any claim cancellations or additions made herein are made solely for the purposes of more clearly and particularly describing and claiming the invention. The Examiner should infer no (i) adoption of a position with respect to patentability, (ii) change in the Applicant's position with respect to any claim or subject matter of the invention, or (iii) acquiescence in any way to any position taken by the Examiner, based on such cancellations or additions.

Furthermore, any remarks made with respect to a given claim or claims are limited solely to such claim or claims.

**Appl. No.** : **To Be Assigned**
**Filed** : **Herewith**

If the Office has any questions or comments which may be resolved over the telephone, he is requested to call the undersigned at (858) 675-1670.

Respectfully submitted,

GAZDZINSKI & ASSOCIATES, PC

Dated: December 18, 2017

By: /Peter J. Gutierrez, III/
Peter J. Gutierrez, III
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# OPTICAL DETECTION APPARATUS AND METHODS

Copyright

[0001] A portion of the disclosure of this patent document contains material that is subject to copyright protection. The copyright owner has no objection to the facsimile reproduction by anyone of the patent document or the patent disclosure, as it appears in the Patent and Trademark Office patent files or records, but otherwise reserves all copyright rights whatsoever.

## BACKGROUND

### Field of the Disclosure

[0002] The present disclosure relates to, *inter alia*, computerized apparatus and methods for detecting objects or targets using processing of optical data.

### Description of Related Art

[0003] Object detection may be required for target approach/obstacle avoidance by autonomous robotic devices. Small sized and/or low-cost robotic vehicles may comprise limited processing and/or energy resources (and/or weight budget) for object detection.

[0004] A variety of object detection apparatus (such as IR-based, ultrasonic, and lidar) currently exist, but suffer from various disabilities. Specifically, some existing infrared (IR) optical proximity sensing methods may prove unreliable, particularly when used outdoors and/or in presence of other sources of infrared radiation. Ultrasonic proximity sensors may become unreliable outdoors, particularly on e.g., unmanned aerial vehicles (UAV) comprising multiple motors that may produce acoustic noise. The ultrasonic sensor distance output may also be affected by wind and/or humidity. Lidar based systems are typically costly, heavy, and may require substantial computing resources for processing lidar data.

[0005] Therefore there exists a need for an improved object detection sensor apparatus, and associated methods. Specifically, in one application, the improved detection sensor apparatus would be one or more of small sized, inexpensive, reliable, lightweight, power efficient, and/or capable of effective use outdoors.

## SUMMARY

[0006] The present disclosure satisfies the foregoing need for an improved object detection apparatus and associated methods.

[0007] Specifically, one aspect of the disclosure relates to a non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable to perform a method of detecting a distance to an object.

[0008] Another aspect of the disclosure relates to a non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable on a processing apparatus to detect an object in an image. In one implementation, the detection includes: producing a high-pass filtered version of the image, the high–pass filtered version comprising a plurality of pixels; for at least some of the plurality of pixels, determining a deviation parameter between the value of a given pixel and a reference value; and based on the deviation parameter meeting a criterion, providing an indication of the object being present in the image.

[0009] In one variant, the high–pass filtered version of the image is configured produced based at least on a first convolution operation between a kernel and the image, the kernel characterized by a kernel dimension; and the convolution operation is configured to reduce energy associated spatial scales in the image that are lower than the kernel dimension. The kernel is configured for example based at least on a second convolution operation of a first matrix, the first matrix configured based at least on a Laplacian operator, and a second matrix configured based at least on a Gaussian operator; and the image is characterized by image dimension, the image dimension exceeding the kernel dimension by at least 10ten times (10x).

[0010] In another variant, the criterion comprises meeting or exceeding a prescribed threshold.

[0011] In another aspect of the disclosure, an optical object detection apparatus is disclosed. In one implementation, the apparatus includes: a lens characterized by a depth of field range; an image sensor configured to provide an image comprising one or more pixels; and logic in communication with the image sensor. The logic is configured to in one variant: evaluate at least a portion of the image to determine an image contrast parameter; and produce an object detection indication based on the contrast parameter breaching a threshold meeting one or more criteria, the object indication configured to convey presence of the object within the depth of

field range.

[0012] In another variant, the image sensor comprises an array of photo-sensitive elements arranged in a plane disposed substantially parallel to the lens; and the image comprises an array of pixels, individual pixels being produced by individual ones of the photo-sensitive elements.

[0013] In another aspect, a method of navigating a trajectory by a robotic apparatus is disclosed. In one implementation, the apparatus includes a controller, an actuator and a sensor, and the method includes: obtaining at least one image associated with surroundings of the apparatus using the sensor; analyzing the at least one image to determine a contrast parameter of the image; detecting a presence of an object in the at least one image based at least in part on based on the contrast parameter meeting one or more criteria; and causing the controller to activate the actuator based on the detection of the presence of the object. In one variant, the actuator activation is configured consistent with a characteristic of the object.

[0014] In another variant, the robotic device comprises a vehicle; the object comprises one of a target or an obstacle; and the actuator activation is configured to cause the vehicle to perform at least one of a target approach or obstacle avoidance action.

[0015] In another implementation, the method includes: obtaining at least one image associated with surroundings of the apparatus using the sensor; analyzing the at least one image to detect a presence of an object in the at least one image; determining that the detected object comprises one of either a target or an obstacle; and causing the controller to selectively activate the actuator based on the determination.

[0016] These and other objects, features, and characteristics of the system and/or method disclosed herein, as well as the methods of operation and functions of the related elements of structure and the combination of parts and economies of manufacture, will become more apparent upon consideration of the following description and the appended claims with reference to the accompanying drawings, all of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the disclosure. As used in the specification and in the claims, the singular form of "a", "an", and "the" include plural referents unless the context clearly dictates otherwise.

**Brief Description of the Drawings**

[0017] FIG. 1 is a graphical illustration depicting a top view of robotic apparatus configured for optical distance detection, in accordance with one or more implementations.

[0018] FIG. 2 is a diagram illustrating focal configuration of an optical apparatus used for distance detection, according to one or more implementations.

[0019] FIG. 3 is a graphical illustration depicting distance detection volume associated with a three-dimensional image detector, according to one or more implementations.

[0020] FIG. 4A is a graphical illustration depicting an object detection apparatus comprising a slanted linear image detector, according to one or more implementations.

[0021] FIG. 4B is a graphical illustration depicting an object detection apparatus comprising a horizontal linear image detector, according to one or more implementations.

[0022] FIG. 4C is a graphical illustration depicting a distance detection apparatus comprising detectors of multiple wavelengths, according to one or more implementations.

[0023] FIG. 4D is a graphical illustration depicting an extended range distance detection apparatus comprising multiple detectors, according to one or more implementations.

[0024] FIG. 5A is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations.

[0025] FIG. 5B is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations.

[0026] FIG. 6A is a plot illustrating output of an optical signal detection apparatus (e.g., the apparatus 500 of FIG. 5A), according to one or more implementations.

[0027] FIG. 6B is a plot illustrating output of an optical signal detection apparatus (e.g., the apparatus 530 of FIG. 5B), according to one or more implementations.

[0028] FIG. 7A is a plot illustrating de-focused images obtained with an optical distance detection system, according to one or more implementations.

[0029] FIG. 7B is a plot illustrating in-focus images obtained with an optical distance detection system, according to one or more implementations.

[0030] FIG. 8A is a plot illustrating a power spectrum of a de-focused image obtained with an optical distance detection system, according to one or more implementations.

[0031] FIG. 8B is a plot illustrating a power spectrum of an in-focus image obtained with an optical distance detection system, according to one or more implementations.

[0032] FIG. 9 is a functional block diagram illustrating a computerized apparatus for implementing, *inter alia*, object detection in accordance with one or more implementations.

[0033] FIG. 10 is a logical flow diagram illustrating a method of determining a salient feature using encoded video motion information, in accordance with one or more implementations.

[0034] FIG. 11A is a logical flow diagram illustrating a method of image processing useful for object detection by an optical apparatus, in accordance with one or more implementations.

[0035] FIG. 11B is a logical flow diagram illustrating a method of image processing useful for object detection by an optical apparatus, in accordance with one or more implementations.

[0036] FIG. 12 is a logical flow diagram illustrating a method of executing an action by a robotic vehicle, the action execution configured based on an outcome of object detection methodology of the disclosure, in accordance with one or more implementations.

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## DETAILED DESCRIPTION

[0038] Implementations of the present disclosure will now be described in detail with reference to the drawings, which are provided as illustrative examples so as to enable those skilled in the art to practice the present technology. Notably, the figures and examples below are not meant to limit the scope of the present disclosure to a single implementation, but other implementations are possible by way of interchange of or combination with some or all of the described or illustrated elements. Wherever convenient, the same reference numbers will be used throughout the drawings to refer to same or like parts.

[0039] Although the system(s) and/or method(s) of this disclosure have been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred implementations, it is to be understood that such detail is solely for that purpose and that the disclosure is not limited to the disclosed implementations, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit

and scope of the appended claims. For example, it is to be understood that the present disclosure contemplates that, to the extent possible, one or more features of any implementation may be combined with one or more features of any other implementation

[0040] In the present disclosure, an implementation showing a singular component should not be considered limiting; rather, the disclosure is intended to encompass other implementations including a plurality of the same component, and vice-versa, unless explicitly stated otherwise herein.

[0041] Further, the present disclosure encompasses present and future known equivalents to the components referred to herein by way of illustration.

[0042] As used herein, the term "bus" is meant generally to denote all types of interconnection or communication architecture that is used to access the synaptic and neuron memory. The "bus" could be optical, wireless, infrared or another type of communication medium. The exact topology of the bus could be for example standard "bus", hierarchical bus, network-on-chip, address-event-representation (AER) connection, or other type of communication topology used for accessing, e.g., different memories in pulse-based system.

[0043] As used herein, the terms "computer", "computing device", and "computerized device ", include, but are not limited to, personal computers (PCs) and minicomputers, whether desktop, laptop, or otherwise, mainframe computers, workstations, servers, personal digital assistants (PDAs), handheld computers, embedded computers, programmable logic device, personal communicators, tablet or "phablet" computers, portable navigation aids, J2ME equipped devices, smart TVs, cellular telephones, smart phones, personal integrated communication or entertainment devices, or literally any other device capable of executing a set of instructions and processing an incoming data signal.

[0044] As used herein, the term "computer program" or "software" is meant to include any sequence or human or machine cognizable steps which perform a function. Such program may be rendered in virtually any programming language or environment including, for example, C/C++, C#, Fortran, COBOL, MATLAB™, PASCAL, Python, assembly language, markup languages (e.g., HTML, SGML, XML, VoXML), and the like, as well as object-oriented environments such as the Common Object Request Broker Architecture (CORBA), Java™ (including J2ME, Java Beans), Binary Runtime Environment (e.g., BREW), and other languages.

[0045] As used herein, the terms "connection", "link", "synaptic channel", "transmission

channel", "delay line", are meant generally to denote a causal link between any two or more entities (whether physical or logical/virtual), which enables information exchange between the entities.

[0046] As used herein the term feature may refer to a representation of an object edge, determined by change in color, luminance, brightness, transparency, texture, and/or curvature. The object features may comprise, *inter alia*, individual edges, intersections of edges (such as corners), orifices, and/or curvature

[0047] As used herein, the term "memory" includes any type of integrated circuit or other storage device adapted for storing digital data including, without limitation, ROM. PROM, EEPROM, DRAM, Mobile DRAM, SDRAM, DDR/2 SDRAM, EDO/FPMS, RLDRAM, SRAM, "flash" memory (e.g., NAND/NOR), memristor memory, and PSRAM.

[0048] As used herein, the terms "processor", "microprocessor" and "digital processor" are meant generally to include all types of digital processing devices including, without limitation, digital signal processors (DSPs), reduced instruction set computers (RISC), general-purpose (CISC) processors, microprocessors, gate arrays (e.g., field programmable gate arrays (FPGAs)), PLDs, reconfigurable computer fabrics (RCFs), array processors, secure microprocessors, and application-specific integrated circuits (ASICs). Such digital processors may be contained on a single unitary IC die, or distributed across multiple components.

[0049] As used herein, the term "network interface" refers to any signal, data, or software interface with a component, network or process including, without limitation, those of the FireWire (e.g., FW400, FW800, and/or other FireWire implementation.), USB (e.g., USB2), Ethernet (e.g., 10/100, 10/100/1000, Gigabit Ethernet, 10-Gig-E), MoCA, Coaxsys (e.g., TVnet™), radio frequency tuner (e.g., in-band or OOB, cable modem), Wi-Fi (802.11), WiMAX (802.16), PAN (e.g., 802.15), cellular (e.g., 3G, LTE/LTE-A/TD-LTE, GSM, and/or other cellular interface implementation) or IrDA families.

[0050] As used herein, the term "Wi-Fi" refers to, without limitation, any of the variants of IEEE-Std. 802.11 or related standards including 802.11 a/b/g/n/s/v and 802.11-2012.

[0051] As used herein, the term "wireless" means any wireless signal, data, communication, or other interface including without limitation Wi-Fi, Bluetooth, 3G (3GPP/3GPP2), HSDPA/HSUPA, TDMA, CDMA (e.g., IS-95A, WCDMA, and/or other wireless interface implementation.), FHSS, DSSS, GSM, PAN/802.15, WiMAX (802.16),

802.20, narrowband/FDMA, OFDM, PCS/DCS, LTE/LTE-A/TD-LTE, analog cellular, CDPD, RFID or NFC (e.g., EPC Global Gen. 2, ISO 14443, ISO 18000-3), satellite systems, millimeter wave or microwave systems, acoustic, and infrared (e.g., IrDA).

[0052] The present disclosure provides, among other things, apparatus and methods for detecting objects at a given distance from a moving device (such as e.g., a robotic device) in real time.

[0053] An optical distance/detection apparatus may comprise sensory apparatus, such as a camera comprising an imaging sensor with a lens configured to project a representation of a visual scene onto the imaging sensor. For a given lens, objects at different distances in front the lens may appear to focused at different ranges behind the lens. The lens may be characterized by a range of sharp focus (also referred to as depth of field). For a given range between the image sensor and the lens, one or more objects present within the range of focus may produce in-focus images. Objects disposed outside the range of focus may produce smeared (or out of focus) images. In-focus representations of objects may be characterized by a greater contrast parameter compared to out-of-focus representations. One or more images provided by the detection apparatus may be analyzed in order to determine image contrast parameter of a given image. Based on one or more criteria (e.g., the image contrast breaching a threshold), an object detection indication may be produced by the apparatus.

[0054] When operated from a moving vehicle or device (e.g., a car, an aerial vehicle) the image on the detector may gradually get sharper as the vehicle approaches an object. Upon breaching a given contrast (given sharpness) threshold, the detection apparatus may produce an indication conveying presence of an object within the range of focus in front of the lens.

[0055] FIG. 1 depicts a top view of mobile robotic apparatus comprising an optical object detection device configured for object detection in accordance with some implementations. The apparatus 100 may comprise for instance a robotic car, an unmanned aerial vehicle, and/or other apparatus configured to move in space in one or more dimensions. The apparatus 100 may comprise the optical object detection device 106. The apparatus 100 may navigate in a direction 104. One or more objects may be present in front of the apparatus 100, e.g., a ball 112 and a box 122, disposed at distance 110, 120, respectively, from the apparatus 100. The object detection device 106 may be configured to detect the presence of one or more objects (e.g., 112, 122) during, for example trajectory navigation by the apparatus 100 using the methodology of the

disclosure.

[0056] FIG. 2 illustrates a configuration of an optical apparatus used for object detection, according to one or more implementations. The apparatus 300 of FIG. 2, may comprise a lens 302 characterized by a focal length 332. A portion of the space to the left of the lens 302 in FIG. 2 may be referred to as the front (e.g., object space). A lens may be characterized by a relative aperture (also referred to as the f-number and/or focal number and defined as a ratio of lens focal length (e.g., element 332 in FIG. 2) to the diameter of the lens entrance pupil).

[0057] The apparatus 300 may comprise an image sensor disposed behind the lens 304. In some implementations, the sensor may be located at a fixed distance from the lens, e.g., in the focal plane 334 of the lens 302.

[0058] The lens 302 may be characterized by an area of acceptable contrast which also may be referred to as a circle of confusion (CoC). In optics, a circle of confusion may correspond to a region in a plane of the detector formed by a cone of light rays from a lens that may not coming to a perfect focus when imaging a point source. The area of acceptable contrast may also be termed to as disk of confusion, circle of indistinctness, blur circle, or region. The area of acceptable contrast of the lens 302 (denoted by bold segment in FIG. 2) of extent 304 may correspond to an extent of acceptably sharp focus 324 in front of the lens 302. In some implementations, the dimension (e.g., vertical in FIG. 2) of the acceptable contrast 304 may be configured based on, for example, one or more criteria such as an acceptable difference in brightness between (i) pixels corresponding to the light rays falling onto the detector within the area 304, and (ii) pixels corresponding the light rays falling onto the focal plane outside the area 304. The magnitude of the pixel brightness difference may be configured in accordance with parameters of a particular application (e.g., object distance, size, shape, image resolution, acquisition time and/or other parameters). In some implementations of object detection from an aerial vehicle for example, the magnitude of the pixel brightness difference may be selected between 10% and 20%.

[0059] In some implementations of still or video image processing, dimension of the circle of confusion may be determined based on a size of the largest blur spot that may still be perceived by the processing apparatus as a point. In some photography implementations wherein the detector may comprise a human eye, a person with a good vision may be able to distinguish an image resolution of 5 line pairs per millimeter (lp/mm) at 0.25 m, which corresponds to CoC

of 0.2 mm.

[0060] In one or more implementations of computerized detectors, the DOF dimension may be determined as

$$R \sim 1/dc,\ dc \sim d/dr/Rv \qquad \text{(Eqn. 1)}$$

where:

d is the viewing distance, dr is the minimum detectable resolution at a reference viewing distance, Rv – is the reference viewing distance.

[0061] For a given detector size and/or location, and sharpness threshold, the dimension 304 of the area of acceptable contrast may increase with an increasing f-number of the lens 302. By way of an illustration, the circle of confusion of a lens with f-number of 1.4 (f/1.4) will be twice that of the f/2.8 lens. Dimension of the area of acceptably sharp focus 324 in FIG. 2 (also referred to as the depth of field (DOF)) may be inversely proportional to the dimension 304 of the area of acceptable contrast and the lens f-number. In the above example, the DOF of the f/1.4 lens will be half that of the f/2.8 lens.

[0062] A plurality of objects (denoted by circles 312, 314, 316, 318 in FIG. 2) may be present in front of the lens 302. Axial extents denoted by arrows 322 and 326 in FIG. 2 may be referred to as out-of-focus portions, while the extent 324 may be referred to as the in-focus portion of the space in front of the lens. Objects that may be present within the DOF (e.g., the objects 314, 316 shown by solid circles in FIG. 2) produce in-focus image representations in the focal plane 334. Objects that may be present outside the DOF (e.g., the objects 312, 318 shown by open circles in FIG. 2) produce out-of-focus image representations in the focal plane 334. By way of an illustration, the object 312 may produce an out of focus image at the detector plane 334, the object 314 may produce an in-focus image at the detector plane 334.

[0063] In some implementations, a lens with a lower relative aperture (smaller f number) may be capable of producing a shallower depth of field (e.g., 324 in FIG. 2). An optical detection apparatus characterized by a shallow depth of field may reduce uncertainty associated with detecting objects using image contrast methodology described herein. A detection system 300

characterized by a shallower area of acceptably sharp focus may be used to achieve reliable detection (e.g., characterized by a lower rate of false positives) compared to a detection system characterized by a deeper area of acceptably sharp focus. In some implementations of object detection from a moving platform and/or detection of moving objects, a detection system characterized by the shallower DOF may be operated at an increased temporal resolution (compared to the deeper DOF system) in order to detect objects that may pass through the area of acceptably sharp focus.

[0064] In some implementations, e.g., such as illustrated in FIG. 1, the apparatus 200 may be disposed on a moving platform. As the platform approaches an object (e.g., 122 in FIG. 1) being present in the out-of focus area 322, the object, when at location 312 in FIG. 2, may produce an out of focus representation in the image. When the object becomes located within the apparatus 300 DOF (e.g., the location 314, and/or 316 of the extent 324 or there between), it may produce an in-focus representation. The in-focus representation may be characterized by one or more changes, such as e.g., an increased contrast as compared to the output focus representations. In such a case, analysis of the image contrast may be utilized in order to determine the presence of one or more objects in the image, e.g., as described below with respect to FIGS. 6-8B.

[0065] In some implementations, the contrast determination process may comprise one or more computer-implemented mathematical operations, including down-sampling the image produced by the detector; performing a high-pass filter operation on the acquired image; and/or determining a deviation parameter of pixels within the high–pass filtered image relative a reference value. FIG. 3 depicting an exemplary distance detection apparatus 400 comprising a three-dimensional image detector, according to one or more implementations. The apparatus 400 may comprise for instance a lens 402, and a three dimensional image sensor 410. The image sensor may comprise a charge-coupled device (CCD), CMOS device, an active-pixel sensor (APS), photodiode array, and/or other sensor technology. The image sensor may be configured to provide two-dimensional (e.g. X-Y) matrices of a pixel intensity values refreshed at, e.g., a 25 Hz or other suitable frame rate. In one or more implementations, the image sensor may operate at a single wavelength, or at multiple wavelengths. It will be appreciated that while many applications of the apparatus 400 may be configured to operate within the visual band of wavelengths, the present disclosure contemplates use of other wavelengths of electromagnetic

energy including, without limitation, those in IR, microwave, x-ray, and/or gamma-ray bands, or combinations of the foregoing. A given pixel may be characterized by one or more values, e.g., corresponding to individual wavelengths (R, G, B), and/or exposure. Individual values may be characterized by bit depth (e.g., comprising 8, 12, 16, or other number of bits). It will be appreciated by those skilled in the art when given this disclosure that the above-referenced image parameters are merely exemplary, and many other image representations (e.g., bitmap, luminance-chrominance (YUV, YCbCr), grayscale, and/or other image representations) are equally applicable to and useful with the various aspects of the present disclosure. Furthermore, data frames corresponding to other (non-visual) signal modalities such as infrared (IR), ultraviolet (UV) images may be compatible with the processing methodology of the disclosure, or yet other configurations.

[0066] The image sensor 410 may comprise one or more sensing layers arranged along dimension shown by arrow 404. Individual layers (not shown) may comprise a plurality of photo sensitive elements (photosites) configured to produce arrays of pixels. Individual sensing layers may be configured partially translucent so as to permit light delivered by the lens 402 propagation through a prior layer (with respect to the lens) to subsequent layer(s). Axial displacement of individual layers (e.g., along dimension 404) may produce an axial distribution of focal planes./ Light rays propagating through the lens 402 at different angles may be focused at different locations, as shown by broken lines 406, 408 in FIG. 3. Spatial separation of multiples focal planes may enable detection of objects disposed within the extent 412 in front of the lens. Objects disposed at different ranges 414 from the lens within the extent 410 may produce in focus images at a respective focal plane of the image sensor 410. In some implementations, the apparatus 400 may be used to provide distance to the detected object.

[0067] FIG. 4A illustrates an object detection apparatus comprising a slanted linear image detector, according to one or more implementations. The apparatus 420 of FIG. 4A may comprise a lens 402, and one or more image sensors 422, 424. Individual image sensors 422, 424 may comprise a linear array of photosites disposed at an angle with respect to the plane of the lens 402. Configuring the image sensor 422, 424 at an angle with respect to the lens 402 may enable the apparatus 420 to produce one or more areas of focus 426, 428. Areas of focus may be characterized by an axial horizontal extent, e.g., element 429 of the area 426 in FIG. 4A. Slanted areas of focus may correspond to multiple in-focus extents to the left of the lens 402, e.g. shown

by arrows 423, 425. Objects occurring within the one or more extents 423, 425 may produce an in-focus representation on the respective sensor. Use of one or more slanted image sensors may enable the apparatus 420 to detect objects at multiple locations that differ by distance from the lens plane and the cross axis position. In some implementations, detection of objects at multiple distances may enable a robotic vehicle to determine as to whether obtain information if its approaching an object (or if it is approached by an object) and undertake a relevant action (e.g. avoid an obstacle and/or move away from a trajectory of another object). In one or more implementations, the detection apparatus 420 may be employed to determine shape and/or aspect ratio of an object. By way of an illustration, number and/or location of activated slant sensors (e.g., 422, 424) of the slant array may convey information about object's location, orientation and/or shape.

[0068] FIG. 4B illustrates an object detection apparatus comprising a horizontal linear image detector, according to one or more implementations. The apparatus 430 of FIG. 4B may comprise a lens 402, and an image sensor 432 comprising a linear array of photosites disposed along axial direction of the lens 402. Disposing the image sensor 432 at a right angle with respect to the lens 402 plane may enable the apparatus 430 to produce in-focus images when an object may be present within the in-focus range 433 in front of the lens 402. When one or more objects may occur within the range 433 at different ranges from the lens, distance to individual objects may be resolved by, in one implementation, analyzing in-focus representations corresponding to light rays 436, 438 in FIG. 4B.

[0069] FIG. 4C illustrates a distance detection apparatus comprising an image sensor comprising detectors of multiple wavelengths, according to one or more implementations. The apparatus 440 of FIG. 4C may comprise a lens 402, and an image sensor 441. The image sensor 441 may comprise a linear array of photosites disposed along focal plane direction (vertical in FIG. 4C) of the lens 402. The photosite array may comprise elements configured to respond to light waves of different wavelength. The sensor 441 shown in FIG. 4C comprises three element types depicted by open, solid, and hashed rectangles denoted 444, 446, 442, respectively. Individual photosites of a given type (e.g., 444, 446, 442 in FIG. 4C) may be configured in an array, thus producing multiple image sensors disposed within the focal plane of the lens 402.

[0070] Due to light dispersion within the lens, light traveling along different paths may focus in different areas behind the lens. Conversely, objects disposed at different distances from

the lens may produce in-focus representations at image sensors responding to different light wavelengths. By way of an illustration, light from objects within the distance range 453 may travel along ray paths 454 and produce in focus image on photosite type 444 array. Light from objects within the distance range 455 may travel along ray paths 456 and produce in focus image on photosite type 446 array. Light from objects within the distance range 457 may travel along ray paths 452 and produce in focus image on photosite type 442 array. Accordingly, the optical apparatus comprising one or more image sensors operating at multiple wavelengths may be capable of providing distance information for objects located at different distance from the lens. Although chromatic aberration is known in the arts, most modern lenses are constructed such as to remove or minimize effects of chromatic aberration. Such achromatic and/or apochromatic lenses may be quite costly, heavy, and/or large compared to simpler lenses with chromatic aberration. The methodology of the present disclosure may enable use of simpler, less costly, and/or more compact lens designs for detecting objects compared to existing approaches.

[0071] FIG. 4D illustrates an extended range distance detection apparatus comprising multiple detectors, according to one or more implementations.

[0072] The apparatus 480 of FIG. 4B may comprise a lens 402, and multiple image sensors 482, 484, 486. Individual image sensors 482, 484, 486 may be configured to respond to light of one or more wavelengths. Individual image sensors 482, 484, 486 may be disposed at different optical distances from the lens 402. In some implementations, such as shown in FIG. 4D, one or more light deflection components may be used in order to divert a portion of light gathered by the lens into two or more portions. In one or more implementations, the components 488, 490 may comprise a beam splitter, a polarizing prism, and/or a thin half-silvered mirror (pellicle mirror).

[0073] By way of an illustration, a portion of the light from the lens 402 may be diverted by semi-permeable mirror 488 along direction shown by arrow 496 towards the sensor 486 while a portion 492 of light may be passed through towards the sensor 482. All or a portion of the light from the lens 402 may be diverted by the semi-permeable mirror 490 along direction shown by arrow 494 towards the sensor 484. A portion 492 of the incident light may be passed through towards the sensor 482. Cumulative path lengths for light sensed by elements 482, 484, 486 may also be configured different from one another. Accordingly, the light traveling along paths denoted by arrows 481, 483, 485 may correspond to depth of field regions 493, 495, 497 in front

of the lens 402 in FIG. 4D. Optical apparatus comprising multiple image sensors characterized by different light path lengths may be capable of providing detection information for objects located at different distance from the lens.

[0074] FIG. 5A is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations. The apparatus 500 of FIG. 5A may comprise one or more sensors 504 configured to produce one or more pixels corresponding to sensory input 502. In one or more implementations, the sensory input may comprise light gathered by a lens. In one or more implementations of optical distance detection, the sensor component 504 may comprise one or more image sensor components, such as e.g., those described above with respect to FIGS. 3-4D.

[0075] The sensor 504 may provide output 506 comprising one or more pixels. In some implementations, the output 506 may comprise an array of pixels characterized by one or more channels (e.g., R,G,B) and a bit depth (e.g., 8/12/16 bits).

[0076] The output 506 may be high-pass (HP) filtered by the filter component 520. In some implementations, the filter component 520 may be configured to downsample the input 506. The filter component 520 operation may comprise a convolution operation with a Laplacian and/or another sharpening kernel, a difference of Gaussian operation configured to reduce low frequency energy, a combination thereof, and/or other operations configured to reduce low frequency energy content. In some implementations, the filter component 520 may be configured as described below with respect to FIGS. 6A.

[0077] In some implementations, the output 506 might be cropped prior to further processing (e.g., filtering, and/or transformations). Multiple crops of an image in the output 506 (performed with different cropping setting) may be used. In some implementations crops of the high-passed image may be utilized. In some implementations, the output 506 may be processed using a band-pass filter operation. The band pass filter may comprise a high-pass filtering operation, subsampling, and/or a blurring filter operation. The blurring filter operation on an image may comprise a convolution of a smoothing kernel (e.g., Gaussian, box, circular, and/or other kernel whose Fourier transform has most of energy in a low part of spectrum) with the image.

[0078] Filtered output 508 may be provided to a processing component 522 configured to execute a detection process. The detection process may comprise determination of a parameter,

quantity, or other value, such as e.g., a contrast parameter. In one or more implementations, the contrast parameter may be configured based on a maximum absolute deviation (MAD) of pixels within the filtered image from a reference value. The reference value may comprise a fixed pre-computed value, an image mean, image median, and/or a value determined using statistics of multiple images. In some implementations, the contrast parameter for a plurality of images value may be low-pass filtered using a running mean, an exponential filter, and/or other filter approach configured to reduce inter-image variability of the detection process, or accomplish some other desirable operation to enhance detection. The averaging window may be configured in accord with requirements of a given application. By way of an illustration, a detection apparatus configured to detect objects in a video acquired at 25 fps from a robotic rover device may utilize averaging window between 2 and 50 frames. It will be appreciated by those skilled in the arts that averaging parameters may be configured based on requirements of an applications, e.g., vehicle speed, motion of objects, object size, and/or other parameters. For autonomous ground vehicle navigation the averaging window may be selected smaller than 2 seconds.

[0079] The contrast parameter may be evaluated in light of one or more detection or triggering criteria; e.g., compared to a threshold, and/or analysis of a value produced by the contrast determination process. Responsive to the contrast parameter for a given image breaching the threshold (e.g., 604, 624 in FIGS. 6A-6B, below), the processing component 522 may produce output 510 indicative of a presence of an object in the sensory input 500. In one or more implementations, the threshold value may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. By way of an illustration, the threshold may be configured to provide greater sensitivity at dusk/dawn, and reduce sensitivity during the day and/or increase sensitivity in high light conditions, while reducing sensitivity in low light conditions.

[0080] FIG. 5B illustrates an exemplary object detection apparatus, according to one or more implementations. The apparatus 530 of FIG. 5B may comprise one or more sensors 504 configured to produce output 536 comprising one or more pixels corresponding to sensory input 502. In one or more implementations, the sensory input may comprise light gathered by a lens. In one or more implementations of optical distance detection, the sensor component 504 may comprise one or more image sensor components described above with respect to FIGS. 3-4D. The output 536 may comprise an array of pixels characterized by one or more channels (e.g.,

R,G,B) and a bit depth (e.g., 8/12/16 bits).

[0081] The output 536 may be processed by a processing component 538. In some implementations, the component 538 may be configured to assess spatial and/or temporal characteristics of the camera component output 536. In some implementations, the assessment process may comprise determination of a two-dimensional image spectrum using, e.g., a discrete Fourier transform described below with respect to FIG. 6B. The resultant spectrum may be analyzed to evaluate high-frequency (small scale) energy content. In some implementations, the high frequency energy content determination may comprise a determination of energy parameter (Ehi) associated with energy content in the image spectrum at spatial scales that are lower than 0.5-2/3 of the Nyquist frequency (3-10) pixels.

[0082] Responsive to a determination that the high frequency (small spatial scale) energy content in the image meets one or more criteria (e.g., breaches a threshold), the processing component 538 may produce output 540 indicative of a presence of an object in the sensory input 502. In one or more implementations, the threshold value may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[0083] In one or more implementations, the object detection may be effectuated based on a comparison of the Ehi parameter to another energy parameter (El) associated with energy content in the image spectrum at spatial scales that exceed a prescribed number of pixels.

[0084] In one or more implementations, processing components 520, 522, 524, 538 may be embodied within one or more integrated circuits, one or more computerized devices, and/or implemented using machine executable instructions (e.g., a software library) executed by one or more processors and/or ASICs.

[0085] FIGS. 6A-8B illustrate operation of object detection system of the disclosure configured in accordance with one or more implementations.

[0086] One or more images may an acquired using, e.g. a camera component 504 shown and described with respect to FIG. 5A mounted on a vehicle (e.g., a robotic vehicle 100 such as that shown in FIG. 1). The vehicle may approach an object (e.g., a flower). FIGS. 7A-7B present two exemplary images acquired with a camera apparatus comprising a lens (e.g., 302 in FIG. 2) characterized by an exemplary f/1.8 aperture and 35 mm focal length, and an imaging sensor (e.g., 304 in FIG. 2) characterized by dimensions of 23.1 mm by 15.4 mm. The image sensor may comprise an array of photosites and be characterized by a physical resolution (e.g.,

6,016 x 4,000) of photosites. The image sensor may produce an image comprising an array of pixels. Individual pixels may correspond to signal associated with a given photosite (raw resolution) or a group of photosites (subsampled image). Images provided by the sensor may be down-sampled to e.g., 320 pixels×180 pixels rectangle and converted to greyscale 8-bit representation. Various other resolutions, bit depths and/or image representations may be utilized. The pixels dimension may determine the smallest resolvable spatial scale (e.g., smallest change) in the image. For example, smaller pixels may enable resolving of smaller scales (higher detail) in the image.

[0087] Image 700 in FIG. 7A represents the down-sampled image comprising an out of-focus representation of the object (e.g., the flower), denoted by arrow 702. Image 720 in FIG. 7B represents the down-sampled image comprising an in-focus representation 722 of the flower.

[0088] The images may be high-pass processed by a filtering operation. The filtering operation may comprise determination of a Gaussian blurred image using a Gaussian kernel. In the implementation illustrated in FIGS. 6A-7B the Gaussian kernel standard deviation is selected equal to 5 pixels in vertical and horizontal dimensions. It may be appreciated by those skilled in the relevant arts that the image acquisition and/or processing parameters (e.g., bit depth, down-sampled image size, Gaussian kernel, and/or other parameters) may be configured in accordance with application requirements; e.g., expected object size, processing and/or energy capacity available for object detection, image sensor size, resolution, frame rate, noise floor, and/or other parameters.

[0089] In one or more implementations, the high-passed image Ih may be obtained by subtracting Gaussian blurred image Ig from the original image I, as follows:

$$Ih = I + m - Ig \qquad \text{(Eqn.2)}$$

where m denotes an offset value. In some implementations (e.g., such as illustrated in FIGS. 6A, 7A-7B), the offset m may be selected equal to a middle value of the grayscale brightness level (e.g., 128).

[0090] Panels 710, 740 FIGS. 7A-7B, respectively, depict output of the filtering operation of Eqn.~~Eqn.~~1. As may be observed in FIG. 7A, image of panel 710 (corresponding to

the out of focus image of panel 700) is substantially void of high frequency content (e.g., the location 712 corresponding to the representation of the flower does not contain readily discernable feature(s)). As may be observed in FIG. 7B, the image of panel 740 (corresponding to the in-focus image of panel 720) comprises a plurality of high frequency features (e.g., the flower representation the location 732 may be readily discerned from the grey background).

[0091] In order to obtain a quantitative measure of an object presence in a given image (e.g., 720 in FIG. 7B), the corresponding high–pass filtered image (e.g., 740 in FIG. 7B) may be analyzed. The analysis may comprise for instance determination of deviation of pixel values from the mean intensity value within the image (e.g., 128 in some implementations of 8-bit greyscale images). In some implementations, the analysis may comprise determination of a contrast parameter configured based on a maximum of absolute deviation of a pixel value within the image from the image median value. In some implementations, the contrast parameter may be low-pass filtered using a running mean, an exponential filter, and/or other filter approach configured to reduce frame-to-frame variability. The exemplary filtered contrast parameter data shown by curve 602 in FIG. 6A were obtained using a running mean window of 25 frames in width, although it is appreciated that other values may readily be used consistent with the present disclosure. Temporal filtering may be employed in order to reduce number of false positives generated e.g. by thermal noise on the detector, camera shake, and/or other sources of noise.

[0092] The contrast parameter for a given image may be evaluated in light of one or more criteria (e.g., compared to a threshold) in order to determine presence of an object in the associated image. FIG. 6A illustrates contrast parameter values (curve 602) obtained for a plurality of images and the corresponding detection output (curve comprising portions 614, 616, 618. Data shown by curve 602 may correspond to output 510 of the component 522 of the detection the apparatus 500 of FIG. 5A. Data shown by segments 614, 616, 618 may correspond to output 512 of the apparatus 500 of FIG. 5A.

[0093] Detection threshold used for determining the presence of an object is shown by broken line 604 in FIG. 6A. In one or more implementations, the threshold value 604 may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. Values of the curve 602 that fall in the range 608 below the threshold 604 may cause a negative detection signal (e.g., equal to zero as shown by the segments 614, 618 in FIG. 6A). Values of the curve 602 that fall in the range 606 at and/or above the threshold 604

may cause a positive detection signal (e.g., equal to one as shown by segment 616 in FIG. 6A).

[0094] FIGS. 6B and 8A-8B illustrate object detection using of spectral approach to image contrast analysis (by, e.g., the apparatus 530 of FIG. 5B), according to one or more implementations.

[0095] The input image (e.g., image 700, 720) may be transformed using a Fourier transformation, e.g., discrete Fourier transform (DFT), cosine Fourier transform, a Fast Fourier transform (FFT) or other spatial scale transformation. FIG. 8A illustrates a power spectrum of the de-focused image shown in panel 700 of FIG. 7A. FIG. 8B illustrates a power spectrum of the in-focus image shown in panel 720 of FIG. 7B.

[0096] The image spectra may be partitioned into a low-frequency portion and a high frequency portion. In some implementations, e.g., such as illustrated in FIG. 6B, the spectral partitioning may be configured based on an elliptical or circular curve area around the origin (e.g., zero frequency point). In some implementations, e.g., shown in FIG. 6B, the data were obtained using an ellipse with (x,y) axes selected at (37, 65) units of cycles along corresponding axis. Low frequency energy portion Elo may be obtained by determining a sum of power spectral values within the ellipse area. The high frequency energy portion Ehi may be obtained by determining a sum of power spectral values outside the ellipse area.

[0097] Detection of an object in a given image may comprise determination of a contrast parameter for a given image. In some implementations, the contrast parameter may be configured based on a comparison of the high frequency energy portion and the low frequency energy portion. In some implementations, the contrast parameter (C) may be determined based on a ratio or other relationship of the high frequency energy portion and the low frequency energy portion, such as the exemplary relationship of Eqn. 2 below.

$$C = Ehi/Elo \qquad \text{(Eqn. 2)}$$

[0098] The contrast parameter for a given image may be compared to a threshold in order to determine presence of an object in the associated image. FIG. 6B presents the contrast parameter (curve 622) for a series of images acquired by an optical object detection device disposed on a moving platform. The thick segments 634, 636, 638 in FIG. 6B depicts the



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detection output corresponding detection output. Data shown by segments 634, 636, 638 may correspond to output 540 of the component 538 of the detection the apparatus 530 of FIG. 5B.

[0099] The detection threshold used for determining the presence of an object is shown by the broken line 624 in FIG. 6B. In one or more implementations, the threshold value 624 may be selected (e.g., equal one in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. Values of the contrast parameter of curve 622 that fall in the range 628 below the threshold 624 may cause a negative detection signal (e.g., equal to zero as shown by the segments 634, 638 in FIG. 6B). Values of the curve 622 that fall in the range 626 at and/or above the threshold 624 may cause a positive detection signal (e.g., equal to one as shown by segment 636 in FIG. 6B).

[00100] FIG. 9 illustrates a computerized apparatus for implementing, *inter alia*, object detection in accordance with one or more implementations. The apparatus 900 may comprise a processing module 916 configured to receive sensory input from sensory block 920 (e.g., camera 106 in FIG. 1). The processing module 916 may be configured to implement signal processing functionality (e.g., object detection).

[00101] The apparatus 900 may comprise memory 914 configured to store executable instructions (e.g., operating system and/or application code, raw and/or processed data such as raw image fames, image spectrum, and/or contrast parameter, information related to one or more detected objects, and/or other information).

[00102] In some implementations, the processing module 916 may interface with one or more of the mechanical 918, sensory 920, electrical 922, power components 924, communications interface 926, and/or other components via driver interfaces, software abstraction layers, and/or other interfacing techniques. Thus, additional processing and memory capacity may be used to support these processes. However, it will be appreciated that these components may be fully controlled by the processing module. The memory and processing capacity may aid in processing code management for the apparatus 900 (e.g. loading, replacement, initial startup and/or other operations). Consistent with the present disclosure, the various components of the device may be remotely disposed from one another, and/or aggregated. For example, the instructions operating the detection process may be executed on a server apparatus that may control the mechanical components via a network or a radio connection. In some implementations, multiple mechanical, sensory, electrical units, and/or

other components may be controlled by a single robotic controller via network/radio connectivity.

[00103] The mechanical components 918 may include virtually any type of device capable of motion and/or performance of a desired function or task. Examples of such devices may include one or more of motors, servos, pumps, hydraulics, pneumatics, stepper motors, rotational plates, micro-electro-mechanical devices (MEMS), electroactive polymers, shape memory alloy (SMA) activation, and/or other devices. The sensor devices may interface with the processing module, and/or enable physical interaction and/or manipulation of the device.

[00104] The sensory component may be configured to provide sensory input to the processing component. In some implementations, the sensory input may comprise camera output images.

[00105] The electrical components 922 may include virtually any electrical device for interaction and manipulation of the outside world. Examples of such electrical devices may include one or more of light/radiation generating devices (e.g. LEDs, IR sources, light bulbs, and/or other devices), audio devices, monitors/displays, switches, heaters, coolers, ultrasound transducers, lasers, and/or other electrical devices. These devices may enable a wide array of applications for the apparatus 900 in industrial, hobbyist, building management, medical device, military/intelligence, and/or other fields.

[00106] The communications interface may include one or more connections to external computerized devices to allow for, *inter alia*, management of the apparatus 900. The connections may include one or more of the wireless or wireline interfaces discussed above, and may include customized or proprietary connections for specific applications. The communications interface may be configured to receive sensory input from an external camera, a user interface (e.g., a headset microphone, a button, a touchpad, and/or other user interface), and/or provide sensory output (e.g., voice commands to a headset, visual feedback, and/or other sensory output).

[00107] The power system 924 may be tailored to the needs of the application of the device. For example, for a small hobbyist robot or aid device, a wireless power solution (e.g. battery, solar cell, inductive (contactless) power source, rectification, and/or other wireless power solution) may be appropriate. However, for building management applications, battery backup/direct wall power may be superior, in some implementations. In addition, in some

implementations, the power system may be adaptable with respect to the training of the apparatus 900. Thus, the apparatus 900 may improve its efficiency (to include power consumption efficiency) through learned management techniques specifically tailored to the tasks performed by the apparatus 900.

[00108] FIGS. 10-12 illustrate methods 1000, 1100, 1130, 1200 for determining and using object information from images. The operations of methods 1000, 1100, 1130, 1200 presented below are intended to be illustrative. In some implementations, methods 1000, 1100, 1130, 1200 may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. Additionally, the order in which the operations of method 1000, 1100, 1130, 1200 are illustrated in FIGS. 10-12 and described below is not intended to be limiting.

[00109] In some implementations, methods 1000, 1100, 1130, 1200 may be implemented in one or more processing devices (e.g., a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information). The one or more processing devices may include one or more devices executing some or all of the operations of methods 1000, 1100, 1130, 1200 in response to instructions stored electronically on an electronic storage medium. The one or more processing devices may include one or more devices configured through hardware, firmware, and/or software to be specifically designed for execution of one or more of the operations of methods 1000, 1100, 1200, 1300.

[00110] FIG. 10 illustrates a method of determining presence of an object in an image using image contrast information in accordance with one or more implementations.

[00111] At operation 1002 of method 1000, one or more input images may be acquired. In one or more implementations, individual images may be provided by an optical apparatus (e.g., 200 of FIG. 2) comprising a lens and an image sensor (e.g., CCD, CMOS device, and/or APS, photodiode arrays, and/or other image sensors). In some implementations, the input images may comprise a pixel stream downloaded from a file, such as a stream of two-dimensional matrices of red green blue RGB values (e.g., refreshed at a 25 Hz or other suitable frame rate). It will be appreciated by those skilled in the art when given this disclosure that the above-referenced image parameters are merely exemplary, and many other image representations (e.g., bitmap, luminance-chrominance YUV, YCbCr, grayscale, and/other image representations)

may be applicable to and useful with the various implementations. The images may form real-time (live) video.

[00112] At operation 1004, image contrast parameter may be determined. In one or more implementations, the contrast parameter determination may be effectuated by a processing apparatus (e.g., the apparatus described with respect to FIGS 5A-5B) using an image-domain based approach (e.g., such as described with respect to FIG. 6A), an image spectrum domain based approach (e.g., such as described with respect to FIG. 6B and/or Eqn. 2), and/or other applicable methodologies. In some implementations, (e.g., such as described with respect to FIG. 6A, the contrast parameter for a given image may be obtained using a smoothing operation (e.g., based on a block averaging filter, exponential filter, and/or other operation configured to reduce variability of the contrast parameter from one image to another).

[00113] At operation 1006, a determination may be made as to whether the parameter(s) of interest meet the relevant criterion or criteria (e.g., the contrast parameter is within detection range). In some implementations, the determination of operation 1006 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIGS 6A-6B. In one or more implementations, the threshold value may be selected (e.g., equal one in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00114] Responsive to a determination at operation 1006 that the contrast parameter is within the detection range (e.g., breached the threshold), the method 1000 may proceed to operation 1008 wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller.

[00115] FIG. 11A illustrates a method of image analysis useful for object detection by an optical apparatus, in accordance with one or more implementations. The operations of method 1100 may be performed by an optical object detection apparatus (e.g., such as that of FIGS. 2-5A) disposed on, e.g., a mobile robotic device.

[00116] At operation 1102, an image may be obtained. In some implementations, the image may comprise a 2-array of pixels characterized by one or more channels (grayscale, RGB, and/or other representations) and/or pixel bit depth.

[00117] At operation 1104, the obtained image may be evaluated. In some implementations, the image evaluation may be configured to determine a processing load of an image analysis apparatus (e.g., components of the apparatus 500, 530 of FIGS. 5A-5B, and/or 916 of FIG. 9, described above). The evaluation may comprise re-sampling (e.g., down sampling/up-sampling) the image to a given reference resolution. By way of an illustration, an image analysis component may comprise an ASIC configured to accept images of a given resolution (e.g., 320x180 pixels, 640x360 pixels, and/or other resolution). The operation 1104 may be configured to adapt the input image into a compatible resolution. In some implementations, the image evaluation operation may comprise modification of image bit depths (e.g., from 12 to 8 bits), and/or a channel combination operation e.g., configured to produce a grayscale image from RGB image.

[00118] At operation 1106 a high-passed version of the image produced by operation 1104 may be obtained. In one or more implementations, the high–pass filtered image version may be produced using a filter operation configured based on a convolution operation with a Laplacian, a difference of Gaussian operation, a combination thereof, and/or other operations. In some implementations, filter operation may be configured based on a hybrid kernel determined using a convolution of the Gaussian smoothing kernel with the Laplacian kernel. The hybrid kernel may be convolved with the image produced by operation 1104 in order to obtain the high-pass filtered image version. In some implementations of down-sampling and high-pass filtering, the image may be convolved with the processing kernel at a subset of locations in the image corresponding to the subsampling parameters, by applying the kernel on a grid of n pixels, where n is the down-sampling parameter.

[00119] At operation 1108, a contrast parameter of the high–pass filtered image may be determined. In one or more implementations, the contrast parameter determination may be effectuated by the processing component 522 of the apparatus 500 described with respect to FIG. 5A using an image-domain based approach. The contrast parameter determination using the image-domain based approach may comprise determination of a maximum absolute deviation of individual pixel values within the filtered image from a reference value. The reference value may comprise a fixed pre-computed value, an image mean, image median, and/or a value determined using statistics of multiple images. In some implementations, the contrast parameter for a plurality of images value may be low-pass filtered using a running mean, an exponential

filter, and/or other filter approach configured to reduce inter-image variability of the detection process.

[00120] At operation 1110, a determination may be made as to whether the contrast parameter may fall within detection range. In some implementations, the determination of operation 1110 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIG 6A. In one or more implementations, the threshold value may be selected (e.g., equal to 12% of the maximum deviation as in FIG. 6A) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00121] Responsive to a determination at operation 1110 that the contrast parameter may be within the detection range (e.g., breached the threshold), the method 1100 may proceed to operation 1112 wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller, an alert indication to a user, and/or to another entity.

[00122] FIG. 11B illustrates a method of image analysis useful for object detection by an optical apparatus, in accordance with one or more implementations. Operations of method 1130 may be performed by an optical object detection apparatus (e.g., of FIGS. 2-4D, 5B) disposed on a mobile robotic device.

[00123] At operation 1122 an image may be obtained. In some implementations, the image may comprise a 2-array of pixels characterized by one or more channels (grayscale, RGB, and/or other representations) and/or pixel bit depth.

[00124] At operation 1124, the image may be evaluated. In some implementations, the image evaluation may be configured to determine a processing load of an image analysis apparatus (e.g., components of the apparatus 530 of FIGS. 5B, and/or 916 of FIG. 9, described above). The evaluation may comprise re-sampling (e.g., down sampling/up-sampling) the image to a given reference resolution. By way of an illustration, an image analysis component may comprise an ASIC configured to accept images of a given resolution (e.g., 320x180 pixels, 640x360 pixels, and/or other resolution). The operation 1124 may be configured to adapt the input image into a compatible resolution. In some implementations, the image evaluation

operation may comprise modification of image bit depths (e.g., from 12 to 8 bits), and/or a channel combination operation e.g., configured to produce a grayscale image from RGB image.

[00125] At operation 1126, a spectrum of the image produced by operation 1124 may be obtained. In one or more implementations, the spectrum may be determined using a discrete Fourier transform, and/or other transformation.

[00126] At operation 1128, a contrast parameter of the image may be determined. In one or more implementations, the contrast parameter determination may be effectuated by the processing component 538 of the apparatus 530 described with respect to FIG. 5B using an image spectrum-domain based approach spectral domain based approach (e.g., such as described with respect to FIG. 6B and/or Eqn. 2). The contrast parameter determination using the image spectrum-domain based approach may comprise partitioning of the image spectrum into a low spatial frequency portion and a high spatial frequency portion. In some implementations, the spectrum partitioning may be configured by selecting a first area within e.g., circular, elliptical and/or other shape, around the origin (e.g., zero frequency), and a second area comprising the remaining portion of the spectrum (i.e., outside the ellipse/circle). The contrast image parameter may be determined for instance using a ratio of integral power within the first are to the integral power within the second area. In some implementations of a detection system with sensors elements disposed along multiple dimensions (e.g., as in FIG. 3, FIG. 4A, and/or FIG. 4D, image spectrum analysis may enable determination of objects of one or more orientation. For example, a given detector configuration may be more sensitive to objects of one orientation (e.g., vertical) and less sensitive to objects of another orientation (e.g., horizontal). In some implementations, an asymmetrical Laplacian kernel and/or Gabor type filter may be used to facilitate detection of objects at a target orientation.

[00127] At operation 1130, a determination may be made as to whether the contrast parameter may fall within detection range. In some implementations, the determination of operation 1130 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIG 6B. In one or more implementations, the threshold value may be selected (e.g., equal one as in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters, as previously described herein.

[00128] Responsive to a determination at operation 1130 that the contrast parameter is



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within the detection range (e.g., breached the threshold) the method 1120 may proceed to operation 1132, wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a wireless transmission, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller, an alert indication to a user, and/or to another entity.

[00129] FIG. 12 illustrates a method of executing an action by a robotic vehicle, the action execution configured based on an outcome of object detection methodology of the disclosure, in accordance with one or more implementations.

[00130] At operation 1202, a vehicle (e.g., the vehicle 100 of FIG. 1) may be operated, such as to for example navigate a trajectory. The trajectory navigation may be configured to for instance track and/or acquire video of a subject of interest (e.g., a user) from an aerial vehicle (e.g., a quad-copter), for example as described in U.S. Patent Application Serial Nos. 62/007,311, entitled "APPARATUS AND METHODS FOR TRACKING USING AERIAL VIDEO", filed on June 3, 2014 the foregoing being incorporated herein by reference in its entirety. In some implementations, the vehicle may comprise a robotic device equipped with a learning controller, e.g., such as described in U.S. Patent Application Serial No. 13/842,530, entitled "ADAPTIVE PREDICTOR APPARATUS AND METHODS", filed herewith on March 15, 2013, the foregoing being incorporated herein by reference in its entirety. In some implementations, the trajectory navigation may comprise one or more actions configured to enable landing of the aerial vehicle, e.g., as described in U.S. Patent Application Serial Nos. 14/285,466, entitled "APPARATUS AND METHODS FOR ROBOTIC OPERATION USING VIDEO IMAGERY", filed herewith on May 22, 2014, and/or 14/285,414, entitled "APPARATUS AND METHODS FOR DISTANCE ESTIMATION USING MULTIPLE IMAGE SENSORS", filed on May 22, 2014, each of the foregoing incorporated herein by reference in its entirety.

[00131] At operation 1204, an image of the surrounding may be obtained. In one or more implementation, the image may comprise representation of one or more objects in the surroundings (e.g., the objects 112, 122 in FIG. 1).

[00132] At operation 1206, the image may be analyzed using to obtain contrast parameter. In one or more implementations, the contrast parameter determination may be configured using

an image-domain approach (e.g., described above with respect to FIGS. 5A, 6A, 7A-7B, and/or 11A) or an image spectrum-domain approach (e.g., described above with respect to FIGS. 5B, 6B, 8A-8B, and/or 11B).

[00133] At operation 1208, a determination may be made as to whether an object may be present in the image obtained at operation 1204. In some implementations, the object presence may be determined based on a comparison of the contrast parameter to a threshold; e.g., as shown and described with respect to FIGS 6A-6B. In one or more implementations, the threshold value may be selected (e.g., equal one as in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00134] Responsive to a determination at operation 1208 that the object is present, the method 1200 may proceed to operation 1210, wherein the trajectory may be adapted. In some implementations, the object presence may correspond to a target being present in the surroundings and/or an obstacle present in the path of the vehicle. The trajectory adaptation may comprise alteration of vehicle course, speed, and/or other parameter. The trajectory adaptation may be configured based on one or more characteristics of the object (e.g., persistence over multiple frames, distance, location, and/or other parameters). In some implementations of target approach and/or obstacle avoidance by a robotic vehicle, when a target may be detected, the trajectory adaptation may be configured to reduce distance between the target and the vehicle (e.g., during landing, approaching a home base, a trash can, and/or other action). When an obstacle may be detected, the trajectory adaptation may be configured to maintain distance (e.g., stop), increase distance (e.g., go away), alter course (e.g., turn) in order to avoid collision. In some implementations, target/obstacle discrimination may be configured based on object color (e.g., approach red ball avoid all other objects); object reflectivity (approach bright objects), shape, orientation, and or other characteristics. In some implementations, object discrimination may be configured based on input from other sensors (e.g., RFID signal, radio beacon signal, acoustic pinger signal), location of the robotic device (e.g., when the vehicle is in the middle of a room all objects are treated as obstacles), and/or other approaches.

[00135] Although the above application of the object detection methodology is described for a vehicle navigation application, it will be appreciated by those skilled in the arts that various other implementations of the methodology of the present disclosure may be utilized. By way of an illustration, a security camera device may be used to observe and detect potential intruders

(e.g., based on sudden appearance of objects) and/or detect theft (e.g., based on a sudden disappearance of previously present objects)

[00136] Implementations of the principles of the disclosure may be further applicable to a wide assortment of applications including computer-human interaction (e.g., recognition of gestures, voice, posture, face, and/or other interactions), controlling processes (e.g., processes associated with an industrial robot, autonomous and other vehicles, and/or other processes), augmented reality applications, access control (e.g., opening a door based on a gesture, opening an access way based on detection of an authorized person), detecting events (e.g., for visual surveillance or people or animal counting, tracking).

[00137] A video processing system of the disclosure may be implemented in a variety of ways such as, for example, a software library, an IP core configured for implementation in a programmable logic device(e.g., FPGA), an ASIC, a remote server, comprising a computer readable apparatus storing computer executable instructions configured to perform feature detection. Myriad other applications exist that will be recognized by those of ordinary skill given the present disclosure.

[00138] Although the system(s) and/or method(s) of this disclosure have been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred implementations, it is to be understood that such detail is solely for that purpose and that the disclosure is not limited to the disclosed implementations, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. For example, it is to be understood that the present disclosure contemplates that, to the extent possible, one or more features of any implementation can be combined with one or more features of any other implementation.

WHAT IS CLAIMED IS:

1. A non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable on a processing apparatus to detect an object in an image by at least:

producing a high-pass filtered version of the image, the high–pass filtered version comprising a plurality of pixels;

for at least some of the plurality of pixels, determining a deviation parameter between the value of a given pixel and a reference value; and

based on the deviation parameter meeting a criterion, providing an indication of the object being present in the image.

2. The non-transitory medium of Claim 1, wherein:

the high–pass filtered version of the image is produced based at least on a first convolution operation between a kernel and the image, the kernel characterized by a kernel dimension; and

the convolution operation is configured to reduce energy-associated spatial scales in the image that are lower than the kernel dimension.

3. The non-transitory medium of Claim 2, wherein:

the kernel is configured based at least on a second convolution operation of a first matrix, the first matrix configured based at least on a Laplacian operator, and a second matrix configured based at least on a Gaussian operator; and

the image is characterized by image dimension, the image dimension exceeding the kernel dimension by at least ten times (10x).

4. The non-transitory medium of Claim 2, wherein

the high–pass filtered version of the image is further produced based on a difference between the image and a smoothed version of the image,

the smoothed version of the image obtained using one or more smoothing operations applied to the image.

5. The non-transitory medium of Claim 2, wherein

the reference value comprises a mean or median brightness of the image; and

the deviation parameter comprises a maximum absolute value of a difference between a given pixel value and the reference value.

6. The non-transitory medium of Claim 2, wherein the contrast parameter is determined based at least on a temporal average of a plurality of contrast parameters, individual ones of the plurality of contrast parameters corresponding to a plurality of images.

7. The non-transitory medium of Claim 1, wherein the criterion comprises meeting or exceeding a prescribed threshold.

8. An optical object detection apparatus comprising:

a lens characterized by a depth of field range;

an image sensor configured to provide an image comprising one or more pixels; and

a logic in communication with the image sensor and configured to:

evaluate at least a portion of the image to determine an image contrast parameter; and

produce an object detection indication based on the contrast parameter meeting one or more criteria, the object indication configured to convey presence of the object within the depth of field range.

9. The apparatus of Claim 8, wherein:

the image sensor comprises an array of photo-sensitive elements arranged in a plane disposed substantially parallel to the lens; and

individual pixels being produced by individual ones of the photo-sensitive elements.

10. The apparatus of Claim 9, wherein:

the array of photo-sensitive elements comprises elements operable to respond to a first wavelength and a second wavelength of electromagnetic energy;

the elements operable for the first wavelength are configured to respond to a first object representation disposed at a first distance from the lens; and

the elements operable for the second wavelength are configured to respond to a second object representation disposed at a second distance from the lens, the second distance being smaller than the first distance.

11. The apparatus of Claim 8, wherein the image sensor comprises two or more arrays

of photo-sensitive elements disposed in first and second plane, the first plane being parallel to the lens, the second plane being oblique to the lens.

12. The apparatus of Claim 8 wherein the image sensor comprises an array of photo-sensitive element s disposed in a plane inclined to the lens.

13. The apparatus of Claim 8, wherein the image sensor comprises an array of photo-sensitive elements disposed in a plane perpendicular to the lens plane.

14. The apparatus of Claim 8, wherein:

image sensor comprises an array of photo sensitive elements arranged in a plane parallel to the lens; and

the image is characterized by an image dimension, the image dimension corresponding to a first resolvable spatial scale;

individual pixels of the one or more pixels are characterized by a pixel dimension, the pixel dimension corresponding to a second resolvable spatial scale; and

the determination of the image contrast parameter comprises:

determination of a two dimensional distribution of energy content within a plurality of groups of pixels of the image, individual ones of the plurality of groups of pixels characterized by a scale of a plurality of spatial scales;

partition of the two dimensional distribution into a first portion and a second portion; and

evaluation of the first portion two dimensional distribution of energy content.

15. The apparatus of Claim 14, wherein:

the first resolvable spatial scale comprises a largest spatial scale in the image;

the first portion comprises an inner portion encompassing the largest spatial scale;

the two dimensional distribution of energy content comprises a plurality of components corresponding to individual ones of the plurality of spatial scales; and

evaluation of the inner portion comprises a comparison of a first sum of components within the inner portion to a second sum of components within the second portion of the two dimensional distribution.

16. The apparatus of Claim 14, wherein:



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the determination of a two dimensional distribution of energy content is based at least in part on performance of a two dimensional Fourier transform operation on the image;

partition of the distribution is configured based on a curve in scale space characterized by a range from the first resolvable spatial scale; and

evaluation of the first portion comprises a determination of a ratio of a first sum of components within the first portion to a second sum of components within the second portion of the two dimensional distribution.

17. The apparatus of Claim 8, wherein the determination of the image contrast parameter comprises:

a determination of a high–pass filtered version of the image configured based on a convolution operation between a kernel and the image, the high passed version comprising a plurality of pixels; and

for a given pixel of the plurality of pixels, a determination of a deviation parameter between value of the given pixel and a reference value.

18. A method of navigating a trajectory by a robotic apparatus comprising a controller, an actuator and a sensor, the method comprising:

obtaining at least one image associated with surroundings of the apparatus using the sensor;

analyzing the at least one image to determine a contrast parameter of the image;

detecting a presence of an object in the at least one image based at least in part on the contrast parameter meeting one or more criteria; and

causing the controller to activate the actuator based on the detection of the presence of the object;

wherein the actuator activation is configured consistent with a characteristic of the object.

19. The method of Claim 18, wherein:

the robotic device comprises a vehicle;

the object comprises one of a target or an obstacle; and

the actuator activation is configured to cause the vehicle to perform at least one of a target approach or obstacle avoidance action.

20. The method of Claim 19, wherein:

the object characteristic comprises a distance of the camera to the object;

for the target approach action the actuator activation is configured to reduce the distance; and

for the obstacle avoidance action the actuator activation is configured to increase the distance.

21. The method of Claim 19, wherein:

the trajectory is characterized by motion direction;

the object characteristic comprises object location with respect to the camera;

for the target approach action the actuator activation is configured to adjust the motion towards the location; and

for the obstacle avoidance action the actuator activation is configured to adjust the motion away the location.

22. A method of navigating a robotic apparatus comprising a controller, an actuator and a sensor, the method comprising:

obtaining at least one image associated with surroundings of the apparatus using the sensor;

analyzing the at least one image to detect a presence of an object in the at least one image;

determining that the detected object comprises one of either a target or an obstacle; and

causing the controller to selectively activate the actuator based on the determination.

23. The method of Claim 21, wherein the selective activation comprises activation of one or more actions by the actuator which will cause the apparatus to either increase or decrease its proximity to the object.

# OPTICAL DETECTION APPARATUS AND METHODS

Abstract of the Disclosure

An optical object detection apparatus and associated methods. The apparatus may comprise a lens (e.g., fixed-focal length wide aperture lens) and an image sensor. The fixed focal length of the lens may correspond to a depth of field area in front of the lens. When an object enters the depth of field area (e.g., sue to a relative motion between the object and the lens) the object representation on the image sensor plane may be in-focus. Objects outside the depth of field area may be out of focus. In-focus representations of objects may be characterized by a greater contrast parameter compared to out of focus representations. One or more images provided by the detection apparatus may be analyzed in order to determine useful information (e.g., an image contrast parameter) of a given image. Based on the image contrast meeting one or more criteria, a detection indication may be produced.



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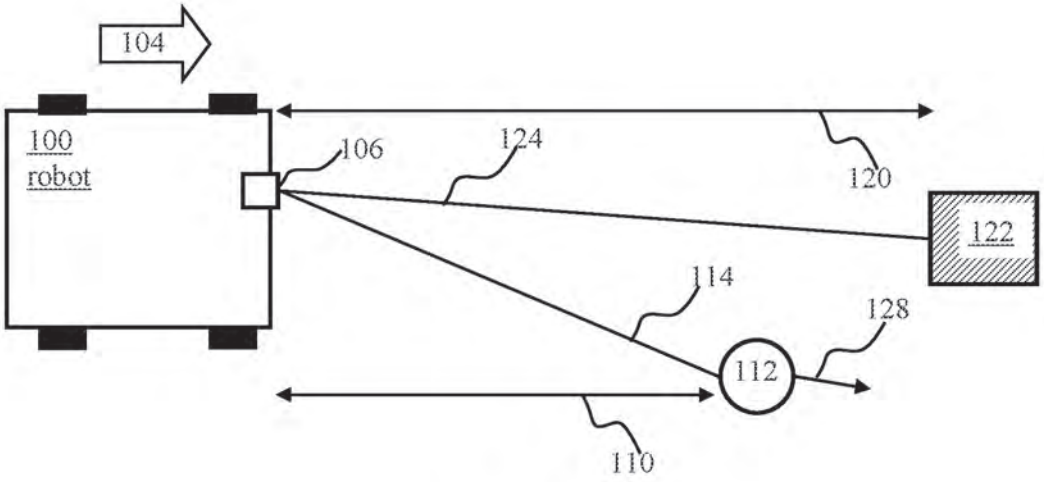

104
100
robot
106
124
120
122
114
128
112
110

FIG. 1

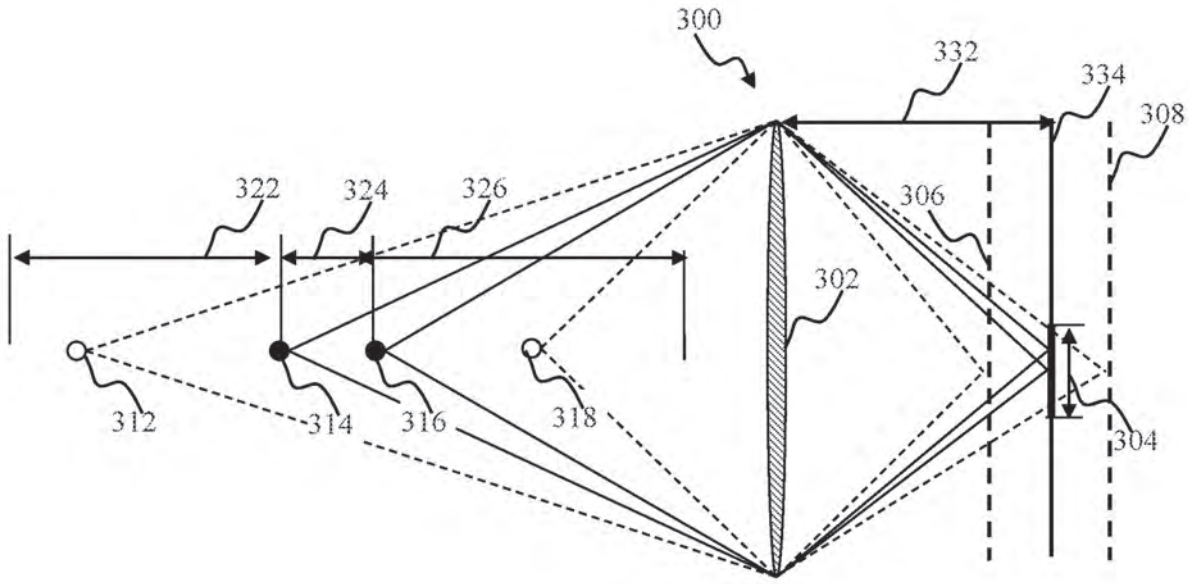

300
332
334
308
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302
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314
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318
304

FIG. 2

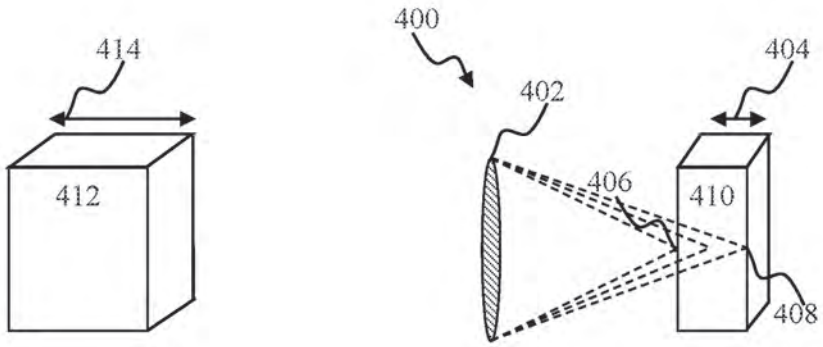



FIG. 3

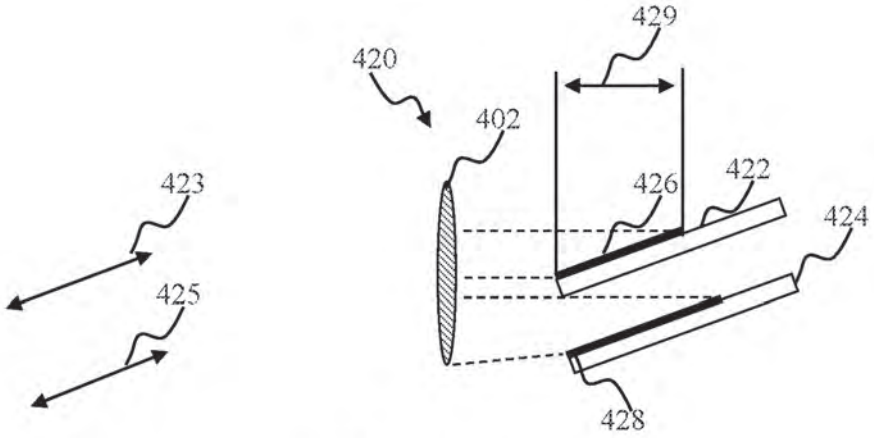



FIG. 4A

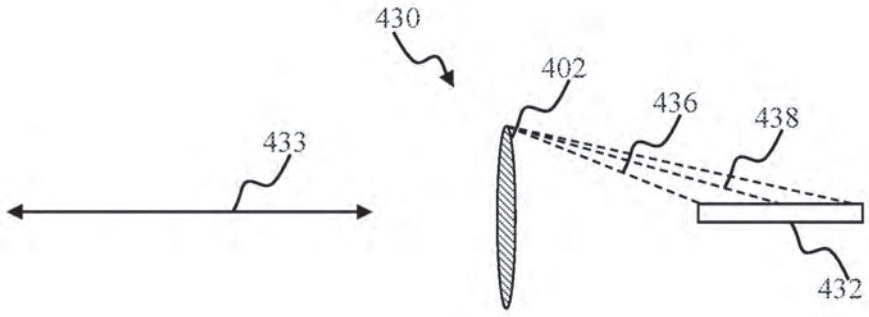



FIG. 4B

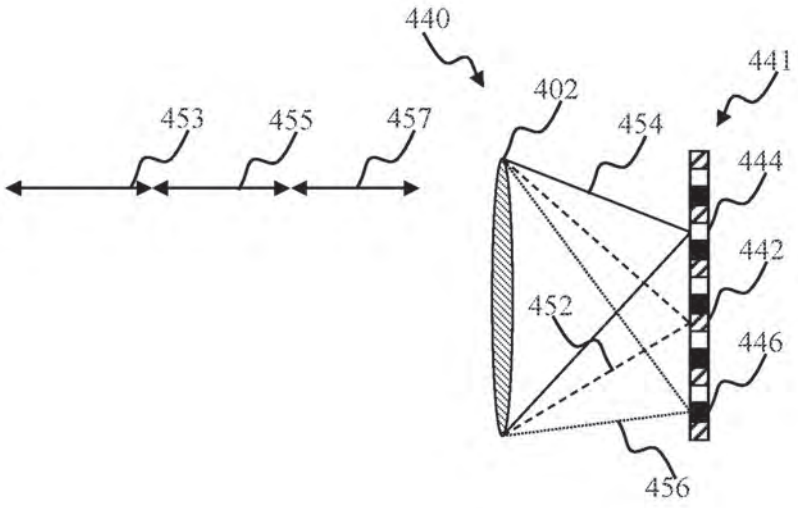

440
441
402
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455
457
454
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442
452
446
456

FIG. 4C

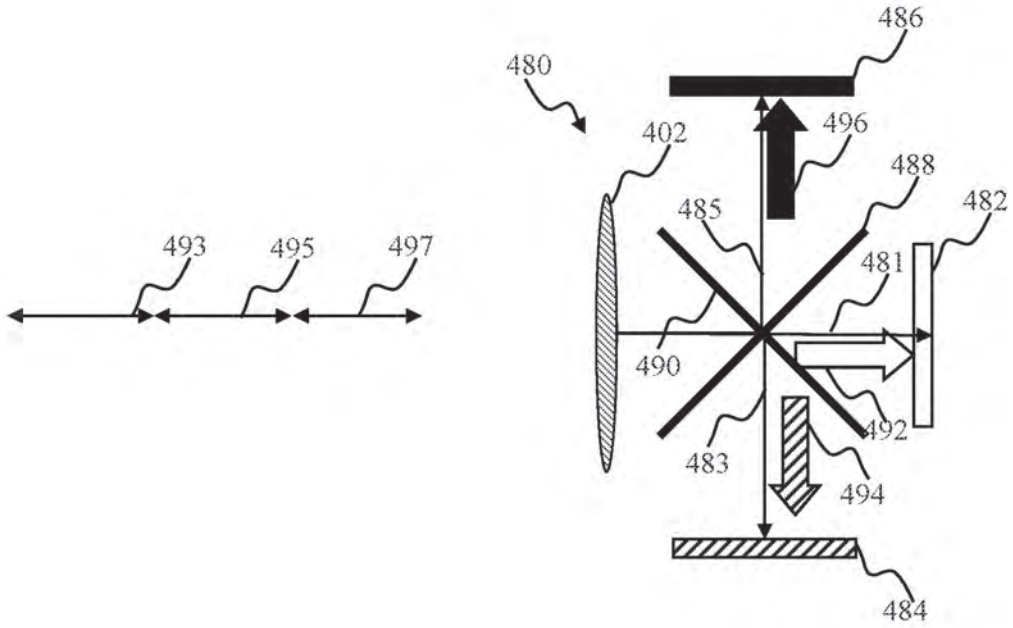

486
480
496
402
488
485
482
493
495
497
481
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494
484

FIG. 4D

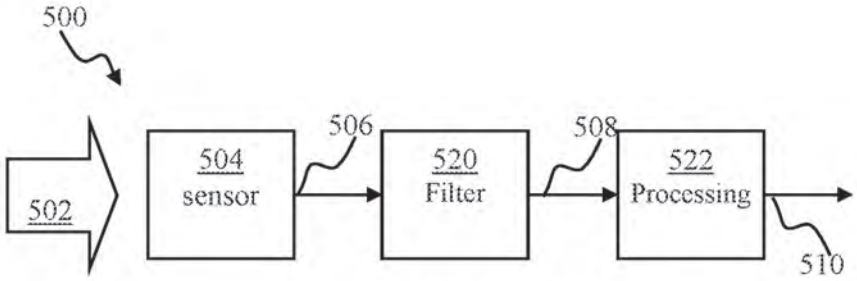

500
502
504
sensor
506
520
Filter
508
522
Processing
510

FIG. 5A

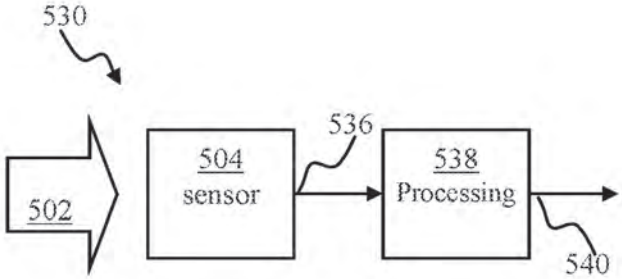

530
502
504
sensor
536
538
Processing
540

FIG. 5B

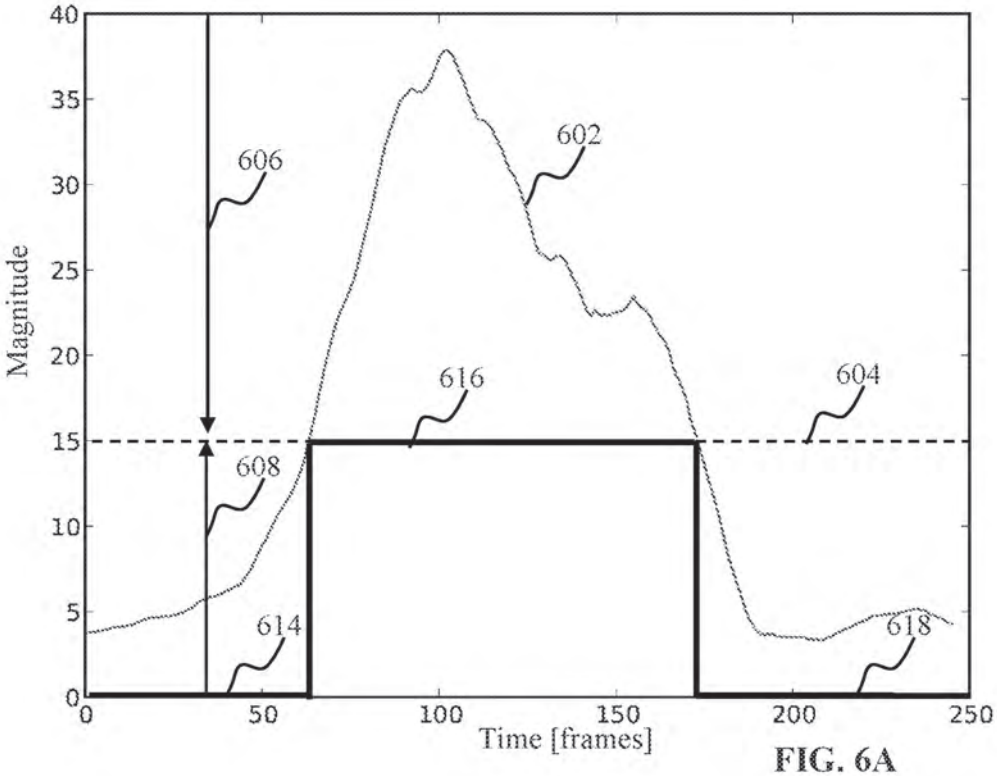

Magnitude
Time [frames]
606
602
616
604
608
614
618
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250

FIG. 6A

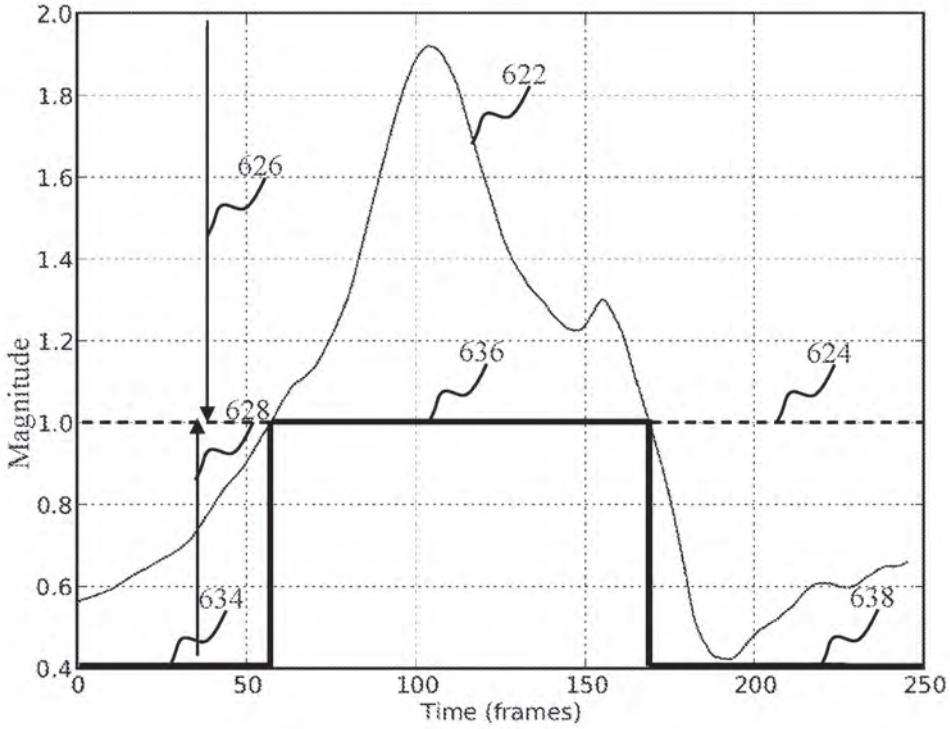
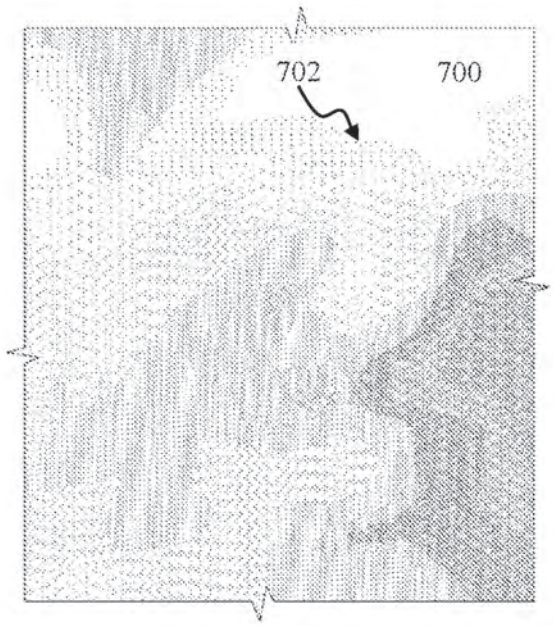
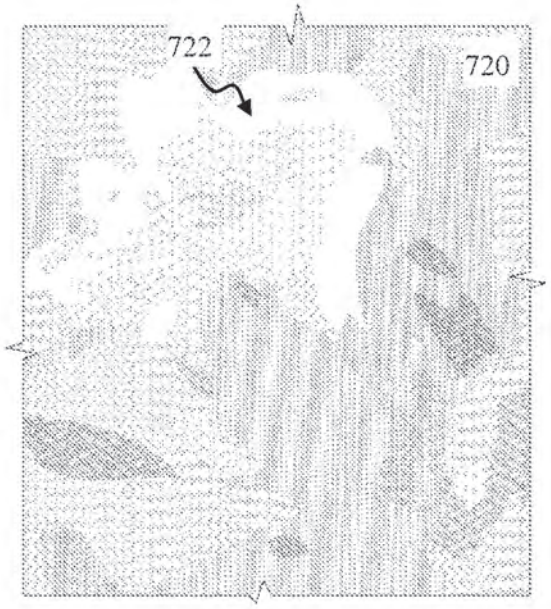
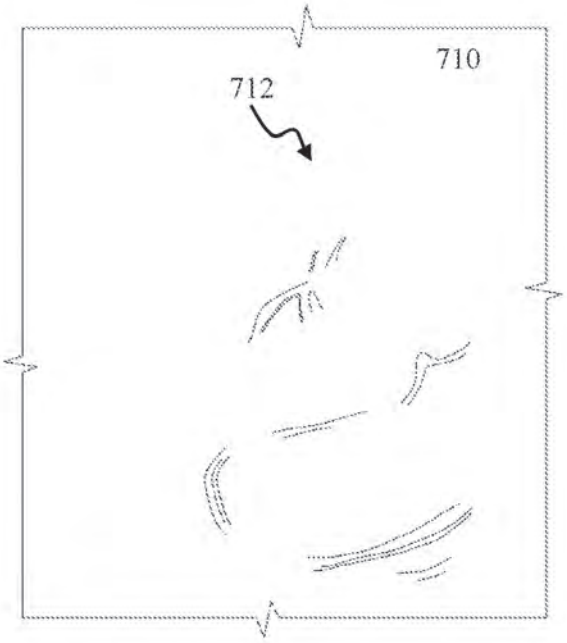

Magnitude
Time (frames)
622
626
636
624
628
634
638
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250

FIG. 6B



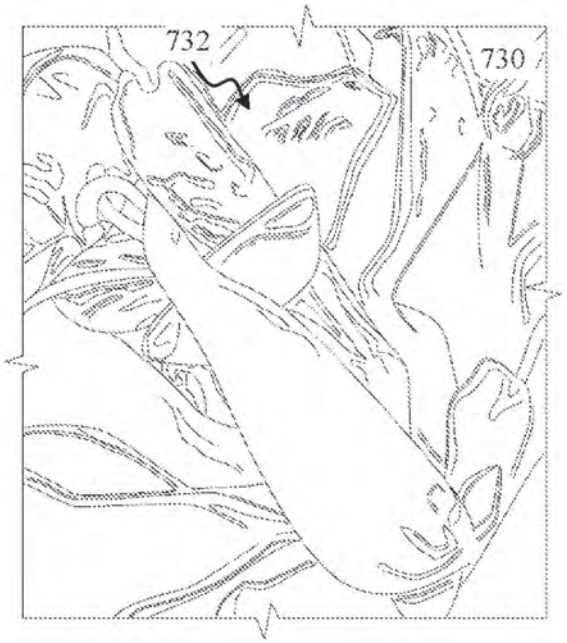




FIG. 7A

FIG. 7B

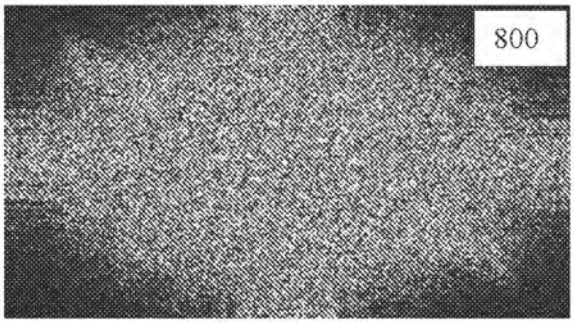



FIG. 8A

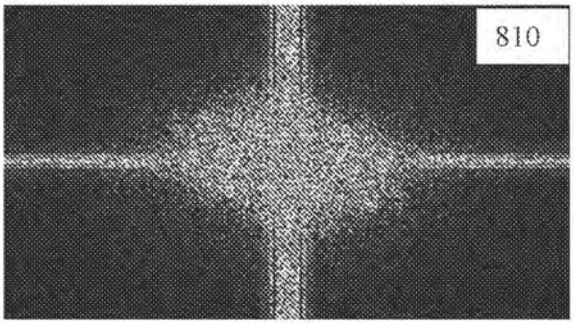



FIG. 8B

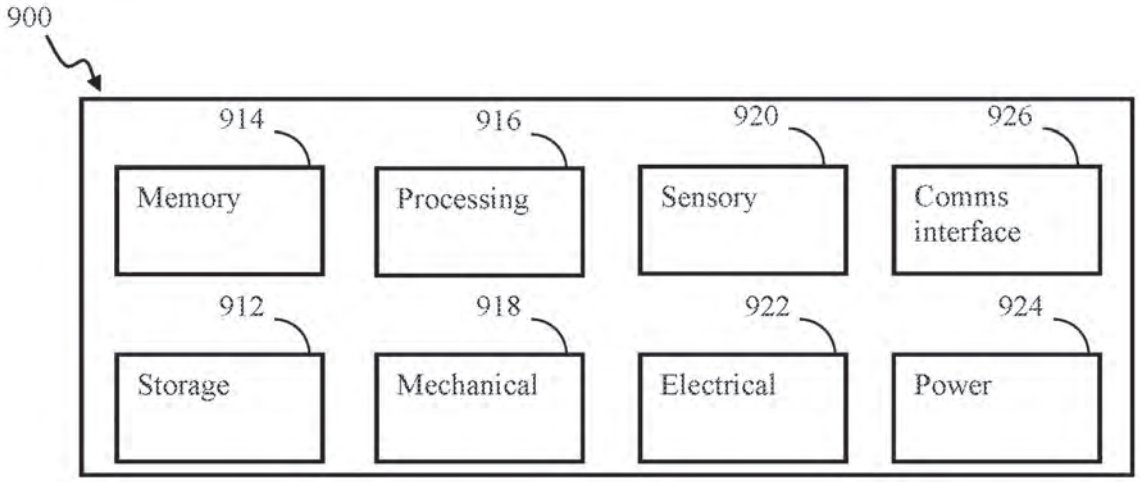



FIG. 9

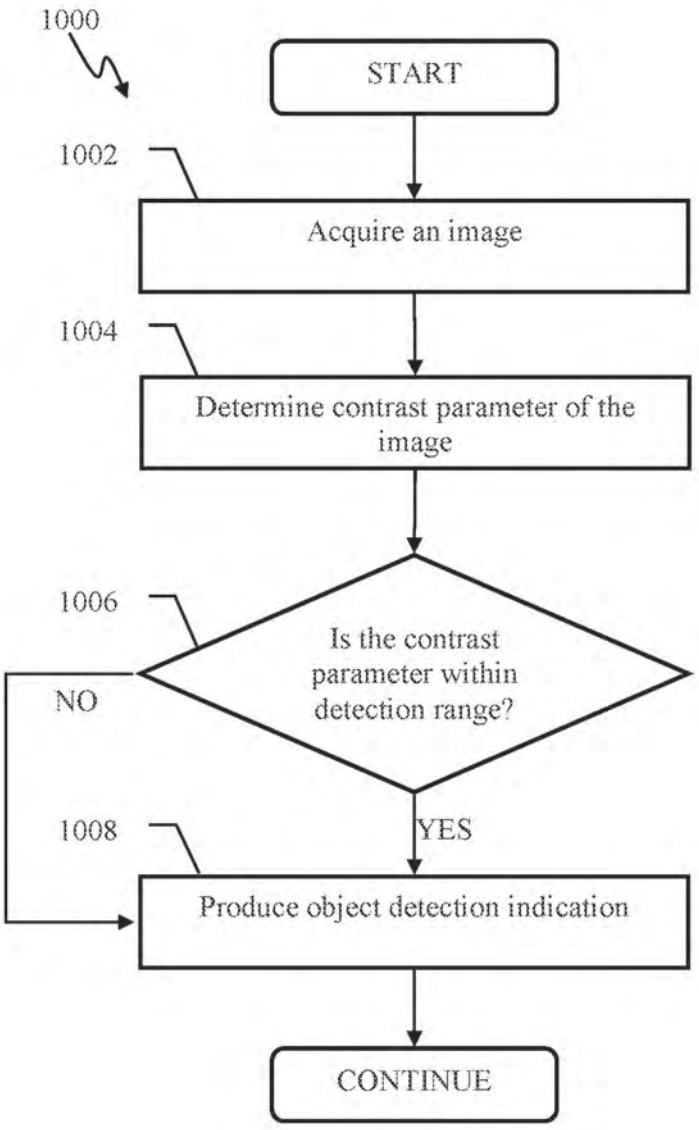

1000
START
1002
Acquire an image
1004
Determine contrast parameter of the image
1006
Is the contrast parameter within detection range?
NO
YES
1008
Produce object detection indication
CONTINUE

FIG. 10

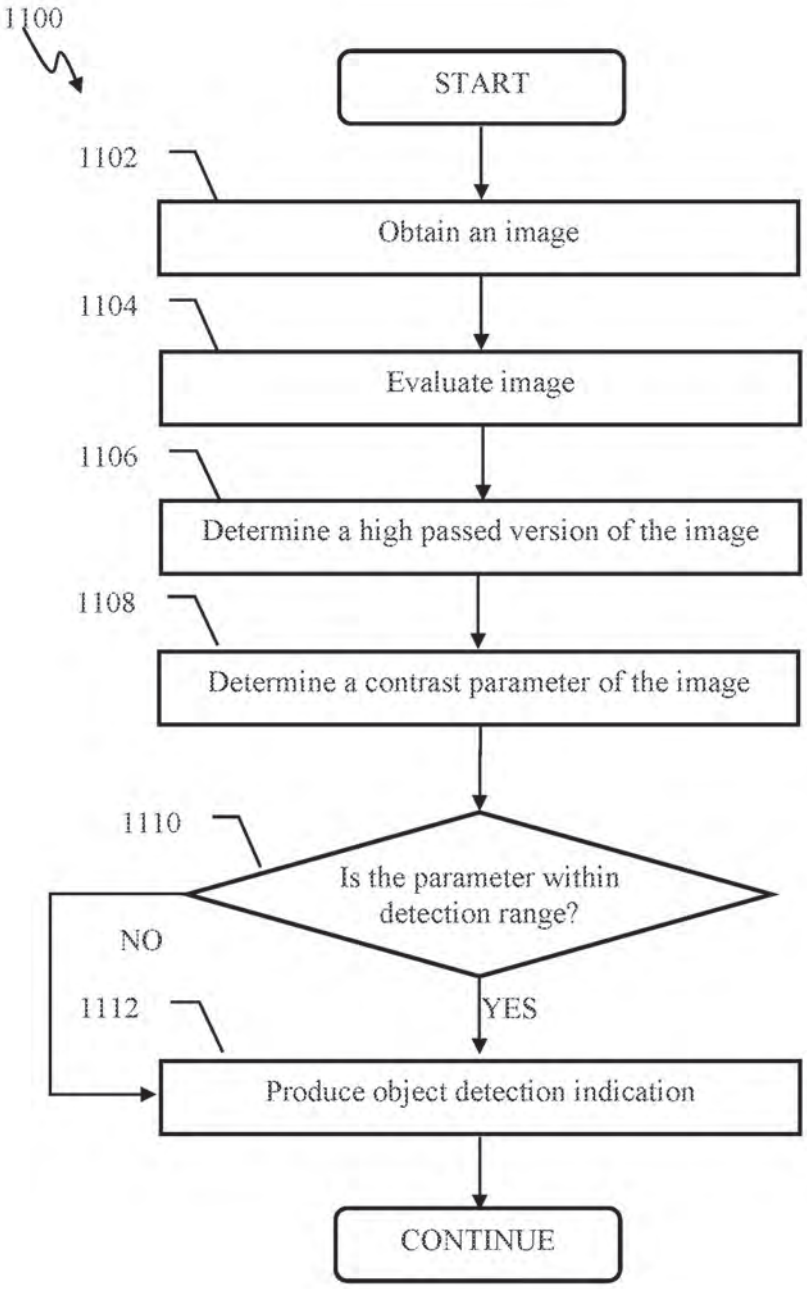

1100
START
1102
Obtain an image
1104
Evaluate image
1106
Determine a high passed version of the image
1108
Determine a contrast parameter of the image
1110
Is the parameter within detection range?
NO
YES
1112
Produce object detection indication
CONTINUE

FIG. 11A

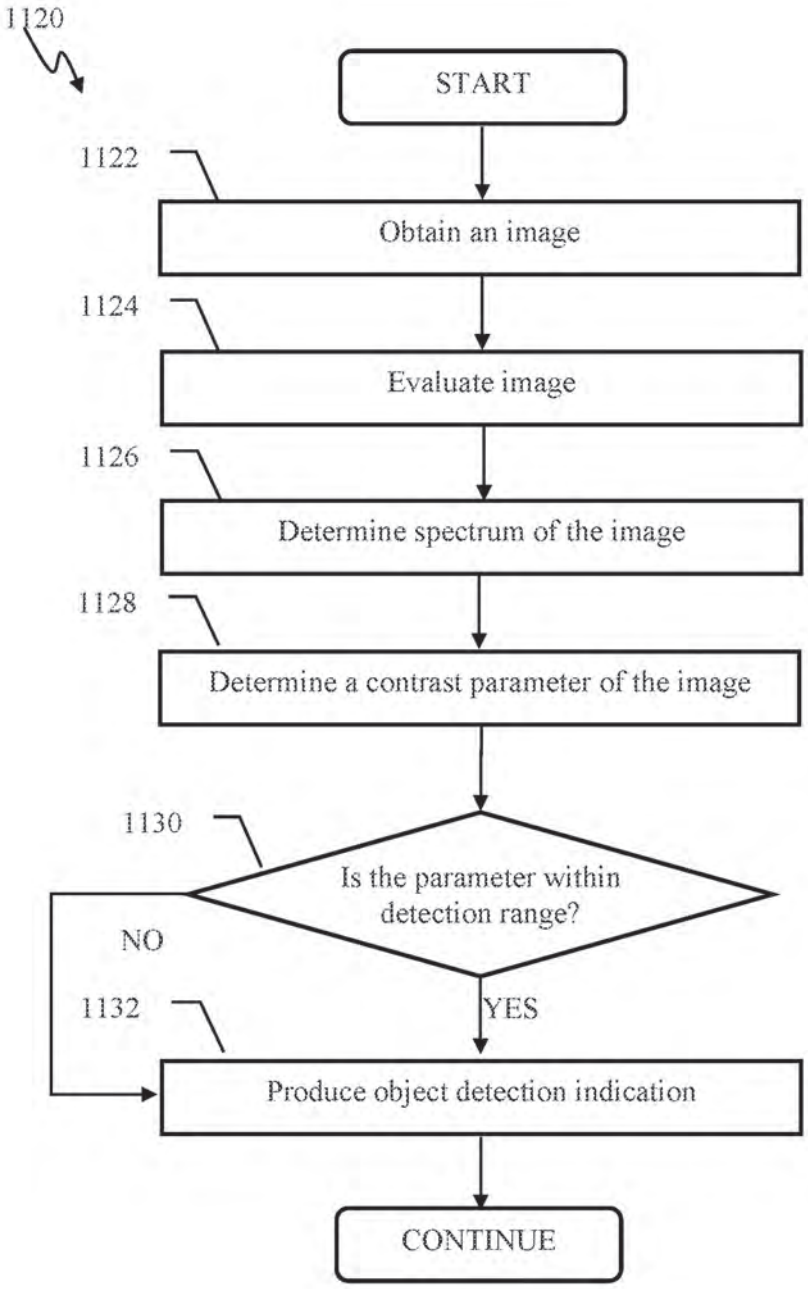

1120
START
1122
Obtain an image
1124
Evaluate image
1126
Determine spectrum of the image
1128
Determine a contrast parameter of the image
1130
Is the parameter within detection range?
NO
YES
1132
Produce object detection indication
CONTINUE

FIG. 11B

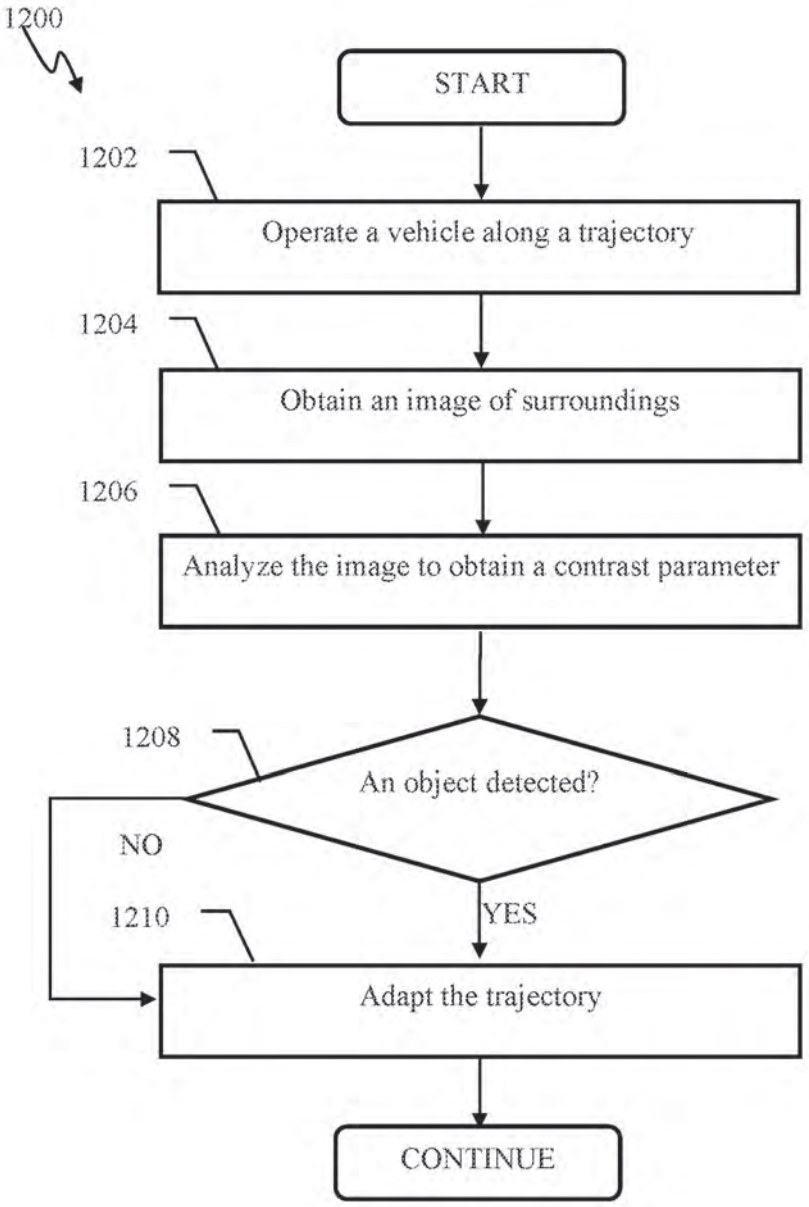

1200
START
1202
Operate a vehicle along a trajectory
1204
Obtain an image of surroundings
1206
Analyze the image to obtain a contrast parameter
1208
An object detected?
NO
YES
1210
Adapt the trajectory
CONTINUE

FIG. 12

# Electronic Acknowledgement Receipt

| | |
|---|---|
| **EFS ID:** | 31263840 |
| **Application Number:** | 15845891 |
| **International Application Number:** | |
| **Confirmation Number:** | 1010 |
| **Title of Invention:** | OPTICAL DETECTION APPARATUS AND METHODS |
| **First Named Inventor/Applicant Name:** | Filip Piekniewski |
| **Customer Number:** | 132059 |
| **Filer:** | Peter John Gutierrez III/Carrie Decoro |
| **Filer Authorized By:** | Peter John Gutierrez III |
| **Attorney Docket Number:** | BRAIN.052C1/BC201416C1 |
| **Receipt Date:** | 18-DEC-2017 |
| **Filing Date:** | |
| **Time Stamp:** | 18:26:10 |
| **Application Type:** | Utility under 35 USC 111(a) |

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| | |
|---|---|
| Submitted with Payment | no |

## File Listing:

| Document Number | Document Description | File Name | File Size(Bytes)/ Message Digest | Multi Part /.zip | Pages (if appl.) |
|---|---|---|---|---|---|
| 1 | Transmittal of New Application | BRAIN052C1_Transmittal.pdf | 79598<br>ffd10f91b5cb980d70218111b06e41feebb840a6 | no | 2 |

**Warnings:**

| Information: | | | | | |
|---|---|---|---|---|---|
| 2 | Application Data Sheet | BRAIN052C1_ADS.pdf | 119921<br>c6f963a1ab2c1473c01e1c8ab2f050cabb041ddc | no | 8 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| This is not an USPTO supplied ADS fillable form | | | | | |
| 3 | Preliminary Amendment | BRAIN052C1_Prelim.pdf | 103539<br>251503c5321f413695b5fd119c0ed13d49421408 | no | 6 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| 4 | Specification | BRAIN052C1_Spec.pdf | 210469<br>e0f44db068d9f09a0cb9e65b24ffe17ee3cb4ef5 | no | 36 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| 5 | Drawings-other than black and white line drawings | BRAIN052C1_Figures.pdf | 580616<br>c107f4570374fe27c7c89d1583974ab16ae45941 | no | 11 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| | | **Total Files Size (in bytes):** | 1094143 | | |

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**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.**

DocCode – SCORE

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| APPLICATION NUMBER | FILING or 371(c) DATE | GRP ART UNIT | FIL FEE REC'D | ATTY.DOCKET.NO | TOT CLAIMS | IND CLAIMS |
|---|---|---|---|---|---|---|
| 15/845,891 | 12/18/2017 | 1722 | 0.00 | BRAIN.052C1/BC201416C1 | 1 | 1 |

**CONFIRMATION NO. 1010**

**FILING RECEIPT**

132059
Gazdzinski & Associates, PC
16644 West Bernardo Drive
Suite 201
San Diego, CA 92127



Date Mailed: 01/11/2018

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

**Inventor(s)**

Filip Piekniewski, San Diego, CA;
Vadim Polonichko, San Diego, CA;
Eugene Izhikevich, San Diego, CA;

**Applicant(s)**

Brain Corporation, San Diego, CA;

**Power of Attorney:** None

**Domestic Priority data as claimed by applicant**

This application is a CON of 14/321,736 07/01/2014 PAT 9848112

**Foreign Applications** for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
*Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.*

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The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 15/845,891**

**Projected Publication Date:** To Be Determined - pending completion of Missing Parts

**Non-Publication Request:** No

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

OPTICAL DETECTION APPARATUS AND METHODS

**Preliminary Class**

430

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

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| APPLICATION NUMBER | FILING OR 371(C) DATE | FIRST NAMED APPLICANT | ATTY. DOCKET NO./TITLE |
|---|---|---|---|
| 15/845,891 | 12/18/2017 | Filip Piekniewski | BRAIN.052C1/BC201416C1 |

**CONFIRMATION NO. 1010**

132059
Gazdzinski & Associates, PC
16644 West Bernardo Drive
Suite 201
San Diego, CA 92127

**FORMALITIES LETTER**

*OC000000096606404*

Date Mailed: 01/11/2018

## NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

**FILED UNDER 37 CFR 1.53(b)**

***Filing Date Granted***

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  - late submission of the basic filing fee, search fee, or examination fee,
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- $ **70** basic filing fee.
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- $ **300** search fee.
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- $( **0**) previous unapplied payment amount.
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- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
  Filip Piekniewski
  Vadim Polonichko
  Eugene Izhikevich

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/lvongxay/

## PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 15/845,891

### APPLICATION AS FILED - PART I

| FOR | (Column 1) NUMBER FILED | (Column 2) NUMBER EXTRA | SMALL ENTITY RATE($) | SMALL ENTITY FEE($) | OR | OTHER THAN SMALL ENTITY RATE($) | OTHER THAN SMALL ENTITY FEE($) |
|---|---|---|---|---|---|---|---|
| BASIC FEE (37 CFR 1.16(a), (b), or (c)) | N/A | N/A | N/A | 70 | | N/A | |
| SEARCH FEE (37 CFR 1.16(k), (i), or (m)) | N/A | N/A | N/A | 300 | | N/A | |
| EXAMINATION FEE (37 CFR 1.16(o), (p), or (q)) | N/A | N/A | N/A | 360 | | N/A | |
| TOTAL CLAIMS (37 CFR 1.16(i)) | 1 minus 20 = | * | x 40 = | 0.00 | OR | | |
| INDEPENDENT CLAIMS (37 CFR 1.16(h)) | 1 minus 3 = | * | x 210 = | 0.00 | | | |
| APPLICATION SIZE FEE (37 CFR 1.16(s)) | If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s). | | | 0.00 | | | |
| MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j)) | | | | 0.00 | | | |
| * If the difference in column 1 is less than zero, enter "0" in column 2. | | | TOTAL | 730 | | TOTAL | |

### APPLICATION AS AMENDED - PART II

| | | (Column 1) CLAIMS REMAINING AFTER AMENDMENT | | (Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR | (Column 3) PRESENT EXTRA | SMALL ENTITY RATE($) | SMALL ENTITY ADDITIONAL FEE($) | OR | OTHER THAN SMALL ENTITY RATE($) | OTHER THAN SMALL ENTITY ADDITIONAL FEE($) |
|---|---|---|---|---|---|---|---|---|---|---|
| AMENDMENT A | 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 | |

| | | (Column 1) CLAIMS REMAINING AFTER AMENDMENT | | (Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR | (Column 3) PRESENT EXTRA | RATE($) | ADDITIONAL FEE($) | OR | RATE($) | ADDITIONAL FEE($) |
|---|---|---|---|---|---|---|---|---|---|---|
| AMENDMENT B | Total (37 CFR 1.16(i)) | * | Minus | ** | = | x = | | OR | x = | |
| | Independent (37 CFR 1.16(h)) | * | Minus | *** | = | x = | | OR | x = | |
| | Application Size Fee (37 CFR 1.16(s)) | | | | | | | | | |
| | FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j)) | | | | | | | OR | | |
| | | | | | | TOTAL ADD'L FEE | | OR | TOTAL ADD'L FEE | |

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

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| APPLICATION NUMBER | FILING OR 371(C) DATE | FIRST NAMED APPLICANT | ATTY. DOCKET NO./TITLE |
|---|---|---|---|
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**FORMALITIES LETTER**

*OC000000096606404*

Date Mailed: 01/11/2018

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**FILED UNDER 37 CFR 1.53(b)**

***Filing Date Granted***

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- The statutory basic filing fee is missing.
- The application search fee must be submitted.
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- Surcharge as set forth in 37 CFR 1.16(f) must be submitted.
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  - late submission of inventor's oath or declaration,
  - filing an application that does not contain at least one claim on filing, or
  - submission of an application filed by reference to a previously filed application.

**SUMMARY OF FEES DUE:**

The fee(s) required within **TWO MONTHS** from the date of this Notice to avoid abandonment is/are itemized below. Small entity discount is in effect. If applicant is qualified for micro entity status, an acceptable Certification of Micro Entity Status must be submitted to establish micro entity status. (See 37 CFR 1.29 and forms PTO/SB/15A and 15B.)

- $ **70** basic filing fee.
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- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
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/lvongxay/

# OPTICAL DETECTION APPARATUS AND METHODS

This application is a continuation of and claims the benefit of priority to U.S. Patent Application Serial No. 14/321,736 filed on July 1, 2014 of the same title, the contents of which being incorporated herein by reference in its entirety.

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## BACKGROUND

### Field of the Disclosure

[0002] The present disclosure relates to, *inter alia*, computerized apparatus and methods for detecting objects or targets using processing of optical data.

### Description of Related Art

[0003] Object detection may be required for target approach/obstacle avoidance by autonomous robotic devices. Small sized and/or low-cost robotic vehicles may comprise limited processing and/or energy resources (and/or weight budget) for object detection.

[0004] A variety of object detection apparatus (such as IR-based, ultrasonic, and lidar) currently exist, but suffer from various disabilities. Specifically, some existing infrared (IR) optical proximity sensing methods may prove unreliable, particularly when used outdoors and/or in presence of other sources of infrared radiation. Ultrasonic proximity sensors may become unreliable outdoors, particularly on e.g., unmanned aerial vehicles (UAV) comprising multiple motors that may produce acoustic noise. The ultrasonic sensor distance output may also be affected by wind and/or humidity. Lidar based systems are typically costly, heavy, and may require substantial computing resources for processing lidar data.

[0005] Therefore there exists a need for an improved object detection sensor apparatus, and associated methods. Specifically, in one application, the improved detection sensor apparatus

would be one or more of small sized, inexpensive, reliable, lightweight, power efficient, and/or capable of effective use outdoors.

## SUMMARY

[0006] The present disclosure satisfies the foregoing need for an improved object detection apparatus and associated methods.

[0007] Specifically, one aspect of the disclosure relates to a non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable to perform a method of detecting a distance to an object.

[0008] Another aspect of the disclosure relates to a non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable on a processing apparatus to detect an object in an image. In one implementation, the detection includes: producing a high-pass filtered version of the image, the high–pass filtered version comprising a plurality of pixels; for at least some of the plurality of pixels, determining a deviation parameter between the value of a given pixel and a reference value; and based on the deviation parameter meeting a criterion, providing an indication of the object being present in the image.

[0009] In one variant, the high–pass filtered version of the image is configured produced based at least on a first convolution operation between a kernel and the image, the kernel characterized by a kernel dimension; and the convolution operation is configured to reduce energy associated spatial scales in the image that are lower than the kernel dimension. The kernel is configured for example based at least on a second convolution operation of a first matrix, the first matrix configured based at least on a Laplacian operator, and a second matrix configured based at least on a Gaussian operator; and the image is characterized by image dimension, the image dimension exceeding the kernel dimension by at least 10ten times (10x).

[0010] In another variant, the criterion comprises meeting or exceeding a prescribed threshold.

[0011] In another aspect of the disclosure, an optical object detection apparatus is disclosed. In one implementation, the apparatus includes: a lens characterized by a depth of field range; an image sensor configured to provide an image comprising one or more pixels; and logic in communication with the image sensor. The logic is configured to in one variant: evaluate at

least a portion of the image to determine an image contrast parameter; and produce an object detection indication based on the contrast parameter breaching a threshold meeting one or more criteria, the object indication configured to convey presence of the object within the depth of field range.

[0012] In another variant, the image sensor comprises an array of photo-sensitive elements arranged in a plane disposed substantially parallel to the lens; and the image comprises an array of pixels, individual pixels being produced by individual ones of the photo-sensitive elements.

[0013] In another aspect, a method of navigating a trajectory by a robotic apparatus is disclosed. In one implementation, the apparatus includes a controller, an actuator and a sensor, and the method includes: obtaining at least one image associated with surroundings of the apparatus using the sensor; analyzing the at least one image to determine a contrast parameter of the image; detecting a presence of an object in the at least one image based at least in part on based on the contrast parameter meeting one or more criteria; and causing the controller to activate the actuator based on the detection of the presence of the object. In one variant, the actuator activation is configured consistent with a characteristic of the object.

[0014] In another variant, the robotic device comprises a vehicle; the object comprises one of a target or an obstacle; and the actuator activation is configured to cause the vehicle to perform at least one of a target approach or obstacle avoidance action.

[0015] In another implementation, the method includes: obtaining at least one image associated with surroundings of the apparatus using the sensor; analyzing the at least one image to detect a presence of an object in the at least one image; determining that the detected object comprises one of either a target or an obstacle; and causing the controller to selectively activate the actuator based on the determination.

In another aspect of the present disclosure, a method of navigating a robotic apparatus is disclosed. In one embodiment, the robotic apparatus includes a controller, an actuator and a sensor, and the method includes: obtaining, through a lens, at least one image associated with surroundings of the apparatus using the sensor, the sensor including a plurality of image detectors disposed at an angle with respect to a plane of the lens, each of the plurality of image detectors being associated with an extent located in the surroundings; analyzing the at least one image to detect a presence of one or more objects in the at least one image; during the navigating

of the robotic apparatus, detecting a distance to the one or more objects based on the presence of at least one of the one or more objects within the extent located in the surroundings; determining that the detected object includes one of either a target or an obstacle; and causing the controller to selectively activate the actuator based on the determination.

In another aspect of the present disclosure, an apparatus is disclosed. In one embodiment, the apparatus is configured to cause a robotic device to navigate a trajectory, and the apparatus includes a non-transitory computer-readable medium including a plurality of instructions configured to cause the apparatus to, when executed by a processor: obtain an image associated with surroundings of the apparatus using a sensor of the device, the sensor including multiple discrete image sensors behind a single lens associated therewith, each of the multiple discrete image sensors being associated with respective extents located in the surroundings of the apparatus; analyze the image to determine a contrast parameter of the image; detect a presence of an object in the image based at least in part on the contrast parameter meeting one or more criteria; and cause a controller of the device to activate an actuator of the device based on the detection of the presence of the object; wherein the actuator is configured to be activated based on a characteristic of the object; and wherein during the navigation of the trajectory by the robotic device, the apparatus is configured to determine (i) a first distance to the object when the presence of the object produces a first in-focus representation within a first extent of the respective extents and (ii) a second distance to the object when the presence of the object produces a second in-focus representation within a second extent of the respective extents.

[0016] These and other objects, features, and characteristics of the system and/or method disclosed herein, as well as the methods of operation and functions of the related elements of structure and the combination of parts and economies of manufacture, will become more apparent upon consideration of the following description and the appended claims with reference to the accompanying drawings, all of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the disclosure. As used in the specification and in the claims, the singular form of "a", "an", and "the" include plural referents unless the context clearly dictates otherwise.

**Brief Description of the Drawings**

[0017] FIG. 1 is a graphical illustration depicting a top view of robotic apparatus configured for optical distance detection, in accordance with one or more implementations.

[0018] FIG. 2 is a diagram illustrating focal configuration of an optical apparatus used for distance detection, according to one or more implementations.

[0019] FIG. 3 is a graphical illustration depicting distance detection volume associated with a three-dimensional image detector, according to one or more implementations.

[0020] FIG. 4A is a graphical illustration depicting an object detection apparatus comprising a slanted linear image detector, according to one or more implementations.

[0021] FIG. 4B is a graphical illustration depicting an object detection apparatus comprising a horizontal linear image detector, according to one or more implementations.

[0022] FIG. 4C is a graphical illustration depicting a distance detection apparatus comprising detectors of multiple wavelengths, according to one or more implementations.

[0023] FIG. 4D is a graphical illustration depicting an extended range distance detection apparatus comprising multiple detectors, according to one or more implementations.

[0024] FIG. 5A is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations.

[0025] FIG. 5B is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations.

[0026] FIG. 6A is a plot illustrating output of an optical signal detection apparatus (e.g., the apparatus 500 of FIG. 5A), according to one or more implementations.

[0027] FIG. 6B is a plot illustrating output of an optical signal detection apparatus (e.g., the apparatus 530 of FIG. 5B), according to one or more implementations.

[0028] FIG. 7A is a plot illustrating de-focused images obtained with an optical distance detection system, according to one or more implementations.

[0029] FIG. 7B is a plot illustrating in-focus images obtained with an optical distance detection system, according to one or more implementations.

[0030] FIG. 8A is a plot illustrating a power spectrum of a de-focused image obtained with an optical distance detection system, according to one or more implementations.

[0031] FIG. 8B is a plot illustrating a power spectrum of an in-focus image obtained with an optical distance detection system, according to one or more implementations.

[0032] FIG. 9 is a functional block diagram illustrating a computerized apparatus for implementing, *inter alia*, object detection in accordance with one or more implementations.

[0033] FIG. 10 is a logical flow diagram illustrating a method of determining a salient feature using encoded video motion information, in accordance with one or more implementations.

[0034] FIG. 11A is a logical flow diagram illustrating a method of image processing useful for object detection by an optical apparatus, in accordance with one or more implementations.

[0035] FIG. 11B is a logical flow diagram illustrating a method of image processing useful for object detection by an optical apparatus, in accordance with one or more implementations.

[0036] FIG. 12 is a logical flow diagram illustrating a method of executing an action by a robotic vehicle, the action execution configured based on an outcome of object detection methodology of the disclosure, in accordance with one or more implementations.

[0037] All Figures disclosed herein are © Copyright 2014 Brain Corporation. All rights reserved.

## DETAILED DESCRIPTION

[0038] Implementations of the present disclosure will now be described in detail with reference to the drawings, which are provided as illustrative examples so as to enable those skilled in the art to practice the present technology. Notably, the figures and examples below are not meant to limit the scope of the present disclosure to a single implementation, but other implementations are possible by way of interchange of or combination with some or all of the described or illustrated elements. Wherever convenient, the same reference numbers will be used throughout the drawings to refer to same or like parts.

[0039] Although the system(s) and/or method(s) of this disclosure have been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred implementations, it is to be understood that such detail is solely for that purpose and that the disclosure is not limited to the disclosed implementations, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit

and scope of the appended claims. For example, it is to be understood that the present disclosure contemplates that, to the extent possible, one or more features of any implementation may be combined with one or more features of any other implementation

[0040] In the present disclosure, an implementation showing a singular component should not be considered limiting; rather, the disclosure is intended to encompass other implementations including a plurality of the same component, and vice-versa, unless explicitly stated otherwise herein.

[0041] Further, the present disclosure encompasses present and future known equivalents to the components referred to herein by way of illustration.

[0042] As used herein, the term "bus" is meant generally to denote all types of interconnection or communication architecture that is used to access the synaptic and neuron memory. The "bus" could be optical, wireless, infrared or another type of communication medium. The exact topology of the bus could be for example standard "bus", hierarchical bus, network-on-chip, address-event-representation (AER) connection, or other type of communication topology used for accessing, e.g., different memories in pulse-based system.

[0043] As used herein, the terms "computer", "computing device", and "computerized device ", include, but are not limited to, personal computers (PCs) and minicomputers, whether desktop, laptop, or otherwise, mainframe computers, workstations, servers, personal digital assistants (PDAs), handheld computers, embedded computers, programmable logic device, personal communicators, tablet or "phablet" computers, portable navigation aids, J2ME equipped devices, smart TVs, cellular telephones, smart phones, personal integrated communication or entertainment devices, or literally any other device capable of executing a set of instructions and processing an incoming data signal.

[0044] As used herein, the term "computer program" or "software" is meant to include any sequence or human or machine cognizable steps which perform a function. Such program may be rendered in virtually any programming language or environment including, for example, C/C++, C#, Fortran, COBOL, MATLAB™, PASCAL, Python, assembly language, markup languages (e.g., HTML, SGML, XML, VoXML), and the like, as well as object-oriented environments such as the Common Object Request Broker Architecture (CORBA), Java™ (including J2ME, Java Beans), Binary Runtime Environment (e.g., BREW), and other languages.

[0045] As used herein, the terms "connection", "link", "synaptic channel", "transmission

channel", "delay line", are meant generally to denote a causal link between any two or more entities (whether physical or logical/virtual), which enables information exchange between the entities.

[0046] As used herein the term feature may refer to a representation of an object edge, determined by change in color, luminance, brightness, transparency, texture, and/or curvature. The object features may comprise, *inter alia*, individual edges, intersections of edges (such as corners), orifices, and/or curvature

[0047] As used herein, the term "memory" includes any type of integrated circuit or other storage device adapted for storing digital data including, without limitation, ROM. PROM, EEPROM, DRAM, Mobile DRAM, SDRAM, DDR/2 SDRAM, EDO/FPMS, RLDRAM, SRAM, "flash" memory (e.g., NAND/NOR), memristor memory, and PSRAM.

[0048] As used herein, the terms "processor", "microprocessor" and "digital processor" are meant generally to include all types of digital processing devices including, without limitation, digital signal processors (DSPs), reduced instruction set computers (RISC), general-purpose (CISC) processors, microprocessors, gate arrays (e.g., field programmable gate arrays (FPGAs)), PLDs, reconfigurable computer fabrics (RCFs), array processors, secure microprocessors, and application-specific integrated circuits (ASICs). Such digital processors may be contained on a single unitary IC die, or distributed across multiple components.

[0049] As used herein, the term "network interface" refers to any signal, data, or software interface with a component, network or process including, without limitation, those of the FireWire (e.g., FW400, FW800, and/or other FireWire implementation.), USB (e.g., USB2), Ethernet (e.g., 10/100, 10/100/1000, Gigabit Ethernet, 10-Gig-E), MoCA, Coaxsys (e.g., TVnet™), radio frequency tuner (e.g., in-band or OOB, cable modem), Wi-Fi (802.11), WiMAX (802.16), PAN (e.g., 802.15), cellular (e.g., 3G, LTE/LTE-A/TD-LTE, GSM, and/or other cellular interface implementation) or IrDA families.

[0050] As used herein, the term "Wi-Fi" refers to, without limitation, any of the variants of IEEE-Std. 802.11 or related standards including 802.11 a/b/g/n/s/v and 802.11-2012.

[0051] As used herein, the term "wireless" means any wireless signal, data, communication, or other interface including without limitation Wi-Fi, Bluetooth, 3G (3GPP/3GPP2), HSDPA/HSUPA, TDMA, CDMA (e.g., IS-95A, WCDMA, and/or other wireless interface implementation.), FHSS, DSSS, GSM, PAN/802.15, WiMAX (802.16),

802.20, narrowband/FDMA, OFDM, PCS/DCS, LTE/LTE-A/TD-LTE, analog cellular, CDPD, RFID or NFC (e.g., EPC Global Gen. 2, ISO 14443, ISO 18000-3), satellite systems, millimeter wave or microwave systems, acoustic, and infrared (e.g., IrDA).

[0052] The present disclosure provides, among other things, apparatus and methods for detecting objects at a given distance from a moving device (such as e.g., a robotic device) in real time.

[0053] An optical distance/detection apparatus may comprise sensory apparatus, such as a camera comprising an imaging sensor with a lens configured to project a representation of a visual scene onto the imaging sensor. For a given lens, objects at different distances in front the lens may appear to focused at different ranges behind the lens. The lens may be characterized by a range of sharp focus (also referred to as depth of field). For a given range between the image sensor and the lens, one or more objects present within the range of focus may produce in-focus images. Objects disposed outside the range of focus may produce smeared (or out of focus) images. In-focus representations of objects may be characterized by a greater contrast parameter compared to out-of-focus representations. One or more images provided by the detection apparatus may be analyzed in order to determine image contrast parameter of a given image. Based on one or more criteria (e.g., the image contrast breaching a threshold), an object detection indication may be produced by the apparatus.

[0054] When operated from a moving vehicle or device (e.g., a car, an aerial vehicle) the image on the detector may gradually get sharper as the vehicle approaches an object. Upon breaching a given contrast (given sharpness) threshold, the detection apparatus may produce an indication conveying presence of an object within the range of focus in front of the lens.

[0055] FIG. 1 depicts a top view of mobile robotic apparatus comprising an optical object detection device configured for object detection in accordance with some implementations. The apparatus 100 may comprise for instance a robotic car, an unmanned aerial vehicle, and/or other apparatus configured to move in space in one or more dimensions. The apparatus 100 may comprise the optical object detection device 106. The apparatus 100 may navigate in a direction 104. One or more objects may be present in front of the apparatus 100, e.g., a ball 112 and a box 122, disposed at distance 110, 120, respectively, from the apparatus 100. The object detection device 106 may be configured to detect the presence of one or more objects (e.g., 112, 122) during, for example trajectory navigation by the apparatus 100 using the methodology of the

disclosure.

[0056] FIG. 2 illustrates a configuration of an optical apparatus used for object detection, according to one or more implementations. The apparatus 300 of FIG. 2, may comprise a lens 302 characterized by a focal length 332. A portion of the space to the left of the lens 302 in FIG. 2 may be referred to as the front (e.g., object space). A lens may be characterized by a relative aperture (also referred to as the f-number and/or focal number and defined as a ratio of lens focal length (e.g., element 332 in FIG. 2) to the diameter of the lens entrance pupil).

[0057] The apparatus 300 may comprise an image sensor disposed behind the lens 304. In some implementations, the sensor may be located at a fixed distance from the lens, e.g., in the focal plane 334 of the lens 302.

[0058] The lens 302 may be characterized by an area of acceptable contrast which also may be referred to as a circle of confusion (CoC). In optics, a circle of confusion may correspond to a region in a plane of the detector formed by a cone of light rays from a lens that may not coming to a perfect focus when imaging a point source. The area of acceptable contrast may also be termed to as disk of confusion, circle of indistinctness, blur circle, or region. The area of acceptable contrast of the lens 302 (denoted by bold segment in FIG. 2) of extent 304 may correspond to an extent of acceptably sharp focus 324 in front of the lens 302. In some implementations, the dimension (e.g., vertical in FIG. 2) of the acceptable contrast 304 may be configured based on, for example, one or more criteria such as an acceptable difference in brightness between (i) pixels corresponding to the light rays falling onto the detector within the area 304, and (ii) pixels corresponding the light rays falling onto the focal plane outside the area 304. The magnitude of the pixel brightness difference may be configured in accordance with parameters of a particular application (e.g., object distance, size, shape, image resolution, acquisition time and/or other parameters). In some implementations of object detection from an aerial vehicle for example, the magnitude of the pixel brightness difference may be selected between 10% and 20%.

[0059] In some implementations of still or video image processing, dimension of the circle of confusion may be determined based on a size of the largest blur spot that may still be perceived by the processing apparatus as a point. In some photography implementations wherein the detector may comprise a human eye, a person with a good vision may be able to distinguish an image resolution of 5 line pairs per millimeter (lp/mm) at 0.25 m, which corresponds to CoC

of 0.2 mm.

[0060] In one or more implementations of computerized detectors, the DOF dimension may be determined as

$$R \sim 1/dc,\ dc \sim d/dr/Rv \qquad \text{(Eqn. 1)}$$

where:

d is the viewing distance, dr is the minimum detectable resolution at a reference viewing distance, Rv – is the reference viewing distance.

[0061] For a given detector size and/or location, and sharpness threshold, the dimension 304 of the area of acceptable contrast may increase with an increasing f-number of the lens 302. By way of an illustration, the circle of confusion of a lens with f-number of 1.4 (f/1.4) will be twice that of the f/2.8 lens. Dimension of the area of acceptably sharp focus 324 in FIG. 2 (also referred to as the depth of field (DOF)) may be inversely proportional to the dimension 304 of the area of acceptable contrast and the lens f-number. In the above example, the DOF of the f/1.4 lens will be half that of the f/2.8 lens.

[0062] A plurality of objects (denoted by circles 312, 314, 316, 318 in FIG. 2) may be present in front of the lens 302. Axial extents denoted by arrows 322 and 326 in FIG. 2 may be referred to as out-of-focus portions, while the extent 324 may be referred to as the in-focus portion of the space in front of the lens. Objects that may be present within the DOF (e.g., the objects 314, 316 shown by solid circles in FIG. 2) produce in-focus image representations in the focal plane 334. Objects that may be present outside the DOF (e.g., the objects 312, 318 shown by open circles in FIG. 2) produce out-of-focus image representations in the focal plane 334. By way of an illustration, the object 312 may produce an out of focus image at the detector plane 334, the object 314 may produce an in-focus image at the detector plane 334.

[0063] In some implementations, a lens with a lower relative aperture (smaller f number) may be capable of producing a shallower depth of field (e.g., 324 in FIG. 2). An optical detection apparatus characterized by a shallow depth of field may reduce uncertainty associated with detecting objects using image contrast methodology described herein. A detection system 300

characterized by a shallower area of acceptably sharp focus may be used to achieve reliable detection (e.g., characterized by a lower rate of false positives) compared to a detection system characterized by a deeper area of acceptably sharp focus. In some implementations of object detection from a moving platform and/or detection of moving objects, a detection system characterized by the shallower DOF may be operated at an increased temporal resolution (compared to the deeper DOF system) in order to detect objects that may pass through the area of acceptably sharp focus.

[0064] In some implementations, e.g., such as illustrated in FIG. 1, the apparatus 200 may be disposed on a moving platform. As the platform approaches an object (e.g., 122 in FIG. 1) being present in the out-of focus area 322, the object, when at location 312 in FIG. 2, may produce an out of focus representation in the image. When the object becomes located within the apparatus 300 DOF (e.g., the location 314, and/or 316 of the extent 324 or there between), it may produce an in-focus representation. The in-focus representation may be characterized by one or more changes, such as e.g., an increased contrast as compared to the output focus representations. In such a case, analysis of the image contrast may be utilized in order to determine the presence of one or more objects in the image, e.g., as described below with respect to FIGS. 6-8B.

[0065] In some implementations, the contrast determination process may comprise one or more computer-implemented mathematical operations, including down-sampling the image produced by the detector; performing a high-pass filter operation on the acquired image; and/or determining a deviation parameter of pixels within the high–pass filtered image relative a reference value. FIG. 3 depicting an exemplary distance detection apparatus 400 comprising a three-dimensional image detector, according to one or more implementations. The apparatus 400 may comprise for instance a lens 402, and a three dimensional image sensor 410. The image sensor may comprise a charge-coupled device (CCD), CMOS device, an active-pixel sensor (APS), photodiode array, and/or other sensor technology. The image sensor may be configured to provide two-dimensional (e.g. X-Y) matrices of a pixel intensity values refreshed at, e.g., a 25 Hz or other suitable frame rate. In one or more implementations, the image sensor may operate at a single wavelength, or at multiple wavelengths. It will be appreciated that while many applications of the apparatus 400 may be configured to operate within the visual band of wavelengths, the present disclosure contemplates use of other wavelengths of electromagnetic

energy including, without limitation, those in IR, microwave, x-ray, and/or gamma-ray bands, or combinations of the foregoing. A given pixel may be characterized by one or more values, e.g., corresponding to individual wavelengths (R, G, B), and/or exposure. Individual values may be characterized by bit depth (e.g., comprising 8, 12, 16, or other number of bits). It will be appreciated by those skilled in the art when given this disclosure that the above-referenced image parameters are merely exemplary, and many other image representations (e.g., bitmap, luminance-chrominance (YUV, YCbCr), grayscale, and/or other image representations) are equally applicable to and useful with the various aspects of the present disclosure. Furthermore, data frames corresponding to other (non-visual) signal modalities such as infrared (IR), ultraviolet (UV) images may be compatible with the processing methodology of the disclosure, or yet other configurations.

[0066] The image sensor 410 may comprise one or more sensing layers arranged along dimension shown by arrow 404. Individual layers (not shown) may comprise a plurality of photo sensitive elements (photosites) configured to produce arrays of pixels. Individual sensing layers may be configured partially translucent so as to permit light delivered by the lens 402 propagation through a prior layer (with respect to the lens) to subsequent layer(s). Axial displacement of individual layers (e.g., along dimension 404) may produce an axial distribution of focal planes./ Light rays propagating through the lens 402 at different angles may be focused at different locations, as shown by broken lines 406, 408 in FIG. 3. Spatial separation of multiples focal planes may enable detection of objects disposed within the extent 412 in front of the lens. Objects disposed at different ranges 414 from the lens within the extent 410 may produce in focus images at a respective focal plane of the image sensor 410. In some implementations, the apparatus 400 may be used to provide distance to the detected object.

[0067] FIG. 4A illustrates an object detection apparatus comprising a slanted linear image detector, according to one or more implementations. The apparatus 420 of FIG. 4A may comprise a lens 402, and one or more image sensors 422, 424. Individual image sensors 422, 424 may comprise a linear array of photosites disposed at an angle with respect to the plane of the lens 402. Configuring the image sensor 422, 424 at an angle with respect to the lens 402 may enable the apparatus 420 to produce one or more areas of focus 426, 428. Areas of focus may be characterized by an axial horizontal extent, e.g., element 429 of the area 426 in FIG. 4A. Slanted areas of focus may correspond to multiple in-focus extents to the left of the lens 402, e.g. shown

by arrows 423, 425. Objects occurring within the one or more extents 423, 425 may produce an in-focus representation on the respective sensor. Use of one or more slanted image sensors may enable the apparatus 420 to detect objects at multiple locations that differ by distance from the lens plane and the cross axis position. In some implementations, detection of objects at multiple distances may enable a robotic vehicle to determine as to whether obtain information if its approaching an object (or if it is approached by an object) and undertake a relevant action (e.g. avoid an obstacle and/or move away from a trajectory of another object). In one or more implementations, the detection apparatus 420 may be employed to determine shape and/or aspect ratio of an object. By way of an illustration, number and/or location of activated slant sensors (e.g., 422, 424) of the slant array may convey information about object's location, orientation and/or shape.

[0068] FIG. 4B illustrates an object detection apparatus comprising a horizontal linear image detector, according to one or more implementations. The apparatus 430 of FIG. 4B may comprise a lens 402, and an image sensor 432 comprising a linear array of photosites disposed along axial direction of the lens 402. Disposing the image sensor 432 at a right angle with respect to the lens 402 plane may enable the apparatus 430 to produce in-focus images when an object may be present within the in-focus range 433 in front of the lens 402. When one or more objects may occur within the range 433 at different ranges from the lens, distance to individual objects may be resolved by, in one implementation, analyzing in-focus representations corresponding to light rays 436, 438 in FIG. 4B.

[0069] FIG. 4C illustrates a distance detection apparatus comprising an image sensor comprising detectors of multiple wavelengths, according to one or more implementations. The apparatus 440 of FIG. 4C may comprise a lens 402, and an image sensor 441. The image sensor 441 may comprise a linear array of photosites disposed along focal plane direction (vertical in FIG. 4C) of the lens 402. The photosite array may comprise elements configured to respond to light waves of different wavelength. The sensor 441 shown in FIG. 4C comprises three element types depicted by open, solid, and hashed rectangles denoted 444, 446, 442, respectively. Individual photosites of a given type (e.g., 444, 446, 442 in FIG. 4C) may be configured in an array, thus producing multiple image sensors disposed within the focal plane of the lens 402.

[0070] Due to light dispersion within the lens, light traveling along different paths may focus in different areas behind the lens. Conversely, objects disposed at different distances from



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the lens may produce in-focus representations at image sensors responding to different light wavelengths. By way of an illustration, light from objects within the distance range 453 may travel along ray paths 454 and produce in focus image on photosite type 444 array. Light from objects within the distance range 455 may travel along ray paths 456 and produce in focus image on photosite type 446 array. Light from objects within the distance range 457 may travel along ray paths 452 and produce in focus image on photosite type 442 array. Accordingly, the optical apparatus comprising one or more image sensors operating at multiple wavelengths may be capable of providing distance information for objects located at different distance from the lens. Although chromatic aberration is known in the arts, most modern lenses are constructed such as to remove or minimize effects of chromatic aberration. Such achromatic and/or apochromatic lenses may be quite costly, heavy, and/or large compared to simpler lenses with chromatic aberration. The methodology of the present disclosure may enable use of simpler, less costly, and/or more compact lens designs for detecting objects compared to existing approaches.

[0071] FIG. 4D illustrates an extended range distance detection apparatus comprising multiple detectors, according to one or more implementations.

[0072] The apparatus 480 of FIG. 4B may comprise a lens 402, and multiple image sensors 482, 484, 486. Individual image sensors 482, 484, 486 may be configured to respond to light of one or more wavelengths. Individual image sensors 482, 484, 486 may be disposed at different optical distances from the lens 402. In some implementations, such as shown in FIG. 4D, one or more light deflection components may be used in order to divert a portion of light gathered by the lens into two or more portions. In one or more implementations, the components 488, 490 may comprise a beam splitter, a polarizing prism, and/or a thin half-silvered mirror (pellicle mirror).

[0073] By way of an illustration, a portion of the light from the lens 402 may be diverted by semi-permeable mirror 488 along direction shown by arrow 496 towards the sensor 486 while a portion 492 of light may be passed through towards the sensor 482. All or a portion of the light from the lens 402 may be diverted by the semi-permeable mirror 490 along direction shown by arrow 494 towards the sensor 484. A portion 492 of the incident light may be passed through towards the sensor 482. Cumulative path lengths for light sensed by elements 482, 484, 486 may also be configured different from one another. Accordingly, the light traveling along paths denoted by arrows 481, 483, 485 may correspond to depth of field regions 493, 495, 497 in front

of the lens 402 in FIG. 4D. Optical apparatus comprising multiple image sensors characterized by different light path lengths may be capable of providing detection information for objects located at different distance from the lens.

[0074] FIG. 5A is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations. The apparatus 500 of FIG. 5A may comprise one or more sensors 504 configured to produce one or more pixels corresponding to sensory input 502. In one or more implementations, the sensory input may comprise light gathered by a lens. In one or more implementations of optical distance detection, the sensor component 504 may comprise one or more image sensor components, such as e.g., those described above with respect to FIGS. 3-4D.

[0075] The sensor 504 may provide output 506 comprising one or more pixels. In some implementations, the output 506 may comprise an array of pixels characterized by one or more channels (e.g., R,G,B) and a bit depth (e.g., 8/12/16 bits).

[0076] The output 506 may be high-pass (HP) filtered by the filter component 520. In some implementations, the filter component 520 may be configured to downsample the input 506. The filter component 520 operation may comprise a convolution operation with a Laplacian and/or another sharpening kernel, a difference of Gaussian operation configured to reduce low frequency energy, a combination thereof, and/or other operations configured to reduce low frequency energy content. In some implementations, the filter component 520 may be configured as described below with respect to FIGS. 6A.

[0077] In some implementations, the output 506 might be cropped prior to further processing (e.g., filtering, and/or transformations). Multiple crops of an image in the output 506 (performed with different cropping setting) may be used. In some implementations crops of the high-passed image may be utilized. In some implementations, the output 506 may be processed using a band-pass filter operation. The band pass filter may comprise a high-pass filtering operation, subsampling, and/or a blurring filter operation. The blurring filter operation on an image may comprise a convolution of a smoothing kernel (e.g., Gaussian, box, circular, and/or other kernel whose Fourier transform has most of energy in a low part of spectrum) with the image.

[0078] Filtered output 508 may be provided to a processing component 522 configured to execute a detection process. The detection process may comprise determination of a parameter,

quantity, or other value, such as e.g., a contrast parameter. In one or more implementations, the contrast parameter may be configured based on a maximum absolute deviation (MAD) of pixels within the filtered image from a reference value. The reference value may comprise a fixed pre-computed value, an image mean, image median, and/or a value determined using statistics of multiple images. In some implementations, the contrast parameter for a plurality of images value may be low-pass filtered using a running mean, an exponential filter, and/or other filter approach configured to reduce inter-image variability of the detection process, or accomplish some other desirable operation to enhance detection. The averaging window may be configured in accord with requirements of a given application. By way of an illustration, a detection apparatus configured to detect objects in a video acquired at 25 fps from a robotic rover device may utilize averaging window between 2 and 50 frames. It will be appreciated by those skilled in the arts that averaging parameters may be configured based on requirements of an applications, e.g., vehicle speed, motion of objects, object size, and/or other parameters. For autonomous ground vehicle navigation the averaging window may be selected smaller than 2 seconds.

[0079] The contrast parameter may be evaluated in light of one or more detection or triggering criteria; e.g., compared to a threshold, and/or analysis of a value produced by the contrast determination process. Responsive to the contrast parameter for a given image breaching the threshold (e.g., 604, 624 in FIGS. 6A-6B, below), the processing component 522 may produce output 510 indicative of a presence of an object in the sensory input 500. In one or more implementations, the threshold value may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. By way of an illustration, the threshold may be configured to provide greater sensitivity at dusk/dawn, and reduce sensitivity during the day and/or increase sensitivity in high light conditions, while reducing sensitivity in low light conditions.

[0080] FIG. 5B illustrates an exemplary object detection apparatus, according to one or more implementations. The apparatus 530 of FIG. 5B may comprise one or more sensors 504 configured to produce output 536 comprising one or more pixels corresponding to sensory input 502. In one or more implementations, the sensory input may comprise light gathered by a lens. In one or more implementations of optical distance detection, the sensor component 504 may comprise one or more image sensor components described above with respect to FIGS. 3-4D. The output 536 may comprise an array of pixels characterized by one or more channels (e.g.,

R,G,B) and a bit depth (e.g., 8/12/16 bits).

[0081] The output 536 may be processed by a processing component 538. In some implementations, the component 538 may be configured to assess spatial and/or temporal characteristics of the camera component output 536. In some implementations, the assessment process may comprise determination of a two-dimensional image spectrum using, e.g., a discrete Fourier transform described below with respect to FIG. 6B. The resultant spectrum may be analyzed to evaluate high-frequency (small scale) energy content. In some implementations, the high frequency energy content determination may comprise a determination of energy parameter (Ehi) associated with energy content in the image spectrum at spatial scales that are lower than 0.5-2/3 of the Nyquist frequency (3-10) pixels.

[0082] Responsive to a determination that the high frequency (small spatial scale) energy content in the image meets one or more criteria (e.g., breaches a threshold), the processing component 538 may produce output 540 indicative of a presence of an object in the sensory input 502. In one or more implementations, the threshold value may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[0083] In one or more implementations, the object detection may be effectuated based on a comparison of the Ehi parameter to another energy parameter (El) associated with energy content in the image spectrum at spatial scales that exceed a prescribed number of pixels.

[0084] In one or more implementations, processing components 520, 522, 524, 538 may be embodied within one or more integrated circuits, one or more computerized devices, and/or implemented using machine executable instructions (e.g., a software library) executed by one or more processors and/or ASICs.

[0085] FIGS. 6A-8B illustrate operation of object detection system of the disclosure configured in accordance with one or more implementations.

[0086] One or more images may an acquired using, e.g. a camera component 504 shown and described with respect to FIG. 5A mounted on a vehicle (e.g., a robotic vehicle 100 such as that shown in FIG. 1). The vehicle may approach an object (e.g., a flower). FIGS. 7A-7B present two exemplary images acquired with a camera apparatus comprising a lens (e.g., 302 in FIG. 2) characterized by an exemplary f/1.8 aperture and 35 mm focal length, and an imaging sensor (e.g., 304 in FIG. 2) characterized by dimensions of 23.1 mm by 15.4 mm. The image sensor may comprise an array of photosites and be characterized by a physical resolution (e.g.,

6,016 x 4,000) of photosites. The image sensor may produce an image comprising an array of pixels. Individual pixels may correspond to signal associated with a given photosite (raw resolution) or a group of photosites (subsampled image). Images provided by the sensor may be down-sampled to e.g., 320 pixels×180 pixels rectangle and converted to greyscale 8-bit representation. Various other resolutions, bit depths and/or image representations may be utilized. The pixels dimension may determine the smallest resolvable spatial scale (e.g., smallest change) in the image. For example, smaller pixels may enable resolving of smaller scales (higher detail) in the image.

[0087] Image 700 in FIG. 7A represents the down-sampled image comprising an out of-focus representation of the object (e.g., the flower), denoted by arrow 702. Image 720 in FIG. 7B represents the down-sampled image comprising an in-focus representation 722 of the flower.

[0088] The images may be high-pass processed by a filtering operation. The filtering operation may comprise determination of a Gaussian blurred image using a Gaussian kernel. In the implementation illustrated in FIGS. 6A-7B the Gaussian kernel standard deviation is selected equal to 5 pixels in vertical and horizontal dimensions. It may be appreciated by those skilled in the relevant arts that the image acquisition and/or processing parameters (e.g., bit depth, down-sampled image size, Gaussian kernel, and/or other parameters) may be configured in accordance with application requirements; e.g., expected object size, processing and/or energy capacity available for object detection, image sensor size, resolution, frame rate, noise floor, and/or other parameters.

[0089] In one or more implementations, the high-passed image Ih may be obtained by subtracting Gaussian blurred image Ig from the original image I, as follows:

$$Ih = I + m - Ig \qquad \text{(Eqn.2)}$$

where m denotes an offset value. In some implementations (e.g., such as illustrated in FIGS. 6A, 7A-7B), the offset m may be selected equal to a middle value of the grayscale brightness level (e.g., 128).

[0090] Panels 710, 740 FIGS. 7A-7B, respectively, depict output of the filtering operation of Eqn.. As may be observed in FIG. 7A, image of panel 710 (corresponding to the out



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of focus image of panel 700) is substantially void of high frequency content (e.g., the location 712 corresponding to the representation of the flower does not contain readily discernable feature(s)). As may be observed in FIG. 7B, the image of panel 740 (corresponding to the in-focus image of panel 720) comprises a plurality of high frequency features (e.g., the flower representation the location 732 may be readily discerned from the grey background).

[0091] In order to obtain a quantitative measure of an object presence in a given image (e.g., 720 in FIG. 7B), the corresponding high–pass filtered image (e.g., 740 in FIG. 7B) may be analyzed. The analysis may comprise for instance determination of deviation of pixel values from the mean intensity value within the image (e.g., 128 in some implementations of 8-bit greyscale images). In some implementations, the analysis may comprise determination of a contrast parameter configured based on a maximum of absolute deviation of a pixel value within the image from the image median value. In some implementations, the contrast parameter may be low-pass filtered using a running mean, an exponential filter, and/or other filter approach configured to reduce frame-to-frame variability. The exemplary filtered contrast parameter data shown by curve 602 in FIG. 6A were obtained using a running mean window of 25 frames in width, although it is appreciated that other values may readily be used consistent with the present disclosure. Temporal filtering may be employed in order to reduce number of false positives generated e.g. by thermal noise on the detector, camera shake, and/or other sources of noise.

[0092] The contrast parameter for a given image may be evaluated in light of one or more criteria (e.g., compared to a threshold) in order to determine presence of an object in the associated image. FIG. 6A illustrates contrast parameter values (curve 602) obtained for a plurality of images and the corresponding detection output (curve comprising portions 614, 616, 618. Data shown by curve 602 may correspond to output 510 of the component 522 of the detection the apparatus 500 of FIG. 5A. Data shown by segments 614, 616, 618 may correspond to output 512 of the apparatus 500 of FIG. 5A.

[0093] Detection threshold used for determining the presence of an object is shown by broken line 604 in FIG. 6A. In one or more implementations, the threshold value 604 may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. Values of the curve 602 that fall in the range 608 below the threshold 604 may cause a negative detection signal (e.g., equal to zero as shown by the segments 614, 618 in FIG. 6A). Values of the curve 602 that fall in the range 606 at and/or above the threshold 604



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may cause a positive detection signal (e.g., equal to one as shown by segment 616 in FIG. 6A).

[0094] FIGS. 6B and 8A-8B illustrate object detection using of spectral approach to image contrast analysis (by, e.g., the apparatus 530 of FIG. 5B), according to one or more implementations.

[0095] The input image (e.g., image 700, 720) may be transformed using a Fourier transformation, e.g., discrete Fourier transform (DFT), cosine Fourier transform, a Fast Fourier transform (FFT) or other spatial scale transformation. FIG. 8A illustrates a power spectrum of the de-focused image shown in panel 700 of FIG. 7A. FIG. 8B illustrates a power spectrum of the in-focus image shown in panel 720 of FIG. 7B.

[0096] The image spectra may be partitioned into a low-frequency portion and a high frequency portion. In some implementations, e.g., such as illustrated in FIG. 6B, the spectral partitioning may be configured based on an elliptical or circular curve area around the origin (e.g., zero frequency point). In some implementations, e.g., shown in FIG. 6B, the data were obtained using an ellipse with (x,y) axes selected at (37, 65) units of cycles along corresponding axis. Low frequency energy portion Elo may be obtained by determining a sum of power spectral values within the ellipse area. The high frequency energy portion Ehi may be obtained by determining a sum of power spectral values outside the ellipse area.

[0097] Detection of an object in a given image may comprise determination of a contrast parameter for a given image. In some implementations, the contrast parameter may be configured based on a comparison of the high frequency energy portion and the low frequency energy portion. In some implementations, the contrast parameter (C) may be determined based on a ratio or other relationship of the high frequency energy portion and the low frequency energy portion, such as the exemplary relationship of Eqn. 2 below.

$$C = Ehi/Elo \qquad \text{(Eqn. 2)}$$

[0098] The contrast parameter for a given image may be compared to a threshold in order to determine presence of an object in the associated image. FIG. 6B presents the contrast parameter (curve 622) for a series of images acquired by an optical object detection device disposed on a moving platform. The thick segments 634, 636, 638 in FIG. 6B depicts the



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detection output corresponding detection output. Data shown by segments 634, 636, 638 may correspond to output 540 of the component 538 of the detection the apparatus 530 of FIG. 5B.

[0099] The detection threshold used for determining the presence of an object is shown by the broken line 624 in FIG. 6B. In one or more implementations, the threshold value 624 may be selected (e.g., equal one in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. Values of the contrast parameter of curve 622 that fall in the range 628 below the threshold 624 may cause a negative detection signal (e.g., equal to zero as shown by the segments 634, 638 in FIG. 6B). Values of the curve 622 that fall in the range 626 at and/or above the threshold 624 may cause a positive detection signal (e.g., equal to one as shown by segment 636 in FIG. 6B).

[00100] FIG. 9 illustrates a computerized apparatus for implementing, *inter alia*, object detection in accordance with one or more implementations. The apparatus 900 may comprise a processing module 916 configured to receive sensory input from sensory block 920 (e.g., camera 106 in FIG. 1). The processing module 916 may be configured to implement signal processing functionality (e.g., object detection).

[00101] The apparatus 900 may comprise memory 914 configured to store executable instructions (e.g., operating system and/or application code, raw and/or processed data such as raw image fames, image spectrum, and/or contrast parameter, information related to one or more detected objects, and/or other information).

[00102] In some implementations, the processing module 916 may interface with one or more of the mechanical 918, sensory 920, electrical 922, power components 924, communications interface 926, and/or other components via driver interfaces, software abstraction layers, and/or other interfacing techniques. Thus, additional processing and memory capacity may be used to support these processes. However, it will be appreciated that these components may be fully controlled by the processing module. The memory and processing capacity may aid in processing code management for the apparatus 900 (e.g. loading, replacement, initial startup and/or other operations). Consistent with the present disclosure, the various components of the device may be remotely disposed from one another, and/or aggregated. For example, the instructions operating the detection process may be executed on a server apparatus that may control the mechanical components via a network or a radio connection. In some implementations, multiple mechanical, sensory, electrical units, and/or



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other components may be controlled by a single robotic controller via network/radio connectivity.

[00103] The mechanical components 918 may include virtually any type of device capable of motion and/or performance of a desired function or task. Examples of such devices may include one or more of motors, servos, pumps, hydraulics, pneumatics, stepper motors, rotational plates, micro-electro-mechanical devices (MEMS), electroactive polymers, shape memory alloy (SMA) activation, and/or other devices. The sensor devices may interface with the processing module, and/or enable physical interaction and/or manipulation of the device.

[00104] The sensory component may be configured to provide sensory input to the processing component. In some implementations, the sensory input may comprise camera output images.

[00105] The electrical components 922 may include virtually any electrical device for interaction and manipulation of the outside world. Examples of such electrical devices may include one or more of light/radiation generating devices (e.g. LEDs, IR sources, light bulbs, and/or other devices), audio devices, monitors/displays, switches, heaters, coolers, ultrasound transducers, lasers, and/or other electrical devices. These devices may enable a wide array of applications for the apparatus 900 in industrial, hobbyist, building management, medical device, military/intelligence, and/or other fields.

[00106] The communications interface may include one or more connections to external computerized devices to allow for, *inter alia*, management of the apparatus 900. The connections may include one or more of the wireless or wireline interfaces discussed above, and may include customized or proprietary connections for specific applications. The communications interface may be configured to receive sensory input from an external camera, a user interface (e.g., a headset microphone, a button, a touchpad, and/or other user interface), and/or provide sensory output (e.g., voice commands to a headset, visual feedback, and/or other sensory output).

[00107] The power system 924 may be tailored to the needs of the application of the device. For example, for a small hobbyist robot or aid device, a wireless power solution (e.g. battery, solar cell, inductive (contactless) power source, rectification, and/or other wireless power solution) may be appropriate. However, for building management applications, battery backup/direct wall power may be superior, in some implementations. In addition, in some

implementations, the power system may be adaptable with respect to the training of the apparatus 900. Thus, the apparatus 900 may improve its efficiency (to include power consumption efficiency) through learned management techniques specifically tailored to the tasks performed by the apparatus 900.

[00108] FIGS. 10-12 illustrate methods 1000, 1100, 1130, 1200 for determining and using object information from images. The operations of methods 1000, 1100, 1130, 1200 presented below are intended to be illustrative. In some implementations, methods 1000, 1100, 1130, 1200 may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. Additionally, the order in which the operations of method 1000, 1100, 1130, 1200 are illustrated in FIGS. 10-12 and described below is not intended to be limiting.

[00109] In some implementations, methods 1000, 1100, 1130, 1200 may be implemented in one or more processing devices (e.g., a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information). The one or more processing devices may include one or more devices executing some or all of the operations of methods 1000, 1100, 1130, 1200 in response to instructions stored electronically on an electronic storage medium. The one or more processing devices may include one or more devices configured through hardware, firmware, and/or software to be specifically designed for execution of one or more of the operations of methods 1000, 1100, 1200, 1300.

[00110] FIG. 10 illustrates a method of determining presence of an object in an image using image contrast information in accordance with one or more implementations.

[00111] At operation 1002 of method 1000, one or more input images may be acquired. In one or more implementations, individual images may be provided by an optical apparatus (e.g., 200 of FIG. 2) comprising a lens and an image sensor (e.g., CCD, CMOS device, and/or APS, photodiode arrays, and/or other image sensors). In some implementations, the input images may comprise a pixel stream downloaded from a file, such as a stream of two-dimensional matrices of red green blue RGB values (e.g., refreshed at a 25 Hz or other suitable frame rate). It will be appreciated by those skilled in the art when given this disclosure that the above-referenced image parameters are merely exemplary, and many other image representations (e.g., bitmap, luminance-chrominance YUV, YCbCr, grayscale, and/other image representations)

may be applicable to and useful with the various implementations. The images may form real-time (live) video.

[00112] At operation 1004, image contrast parameter may be determined. In one or more implementations, the contrast parameter determination may be effectuated by a processing apparatus (e.g., the apparatus described with respect to FIGS 5A-5B) using an image-domain based approach (e.g., such as described with respect to FIG. 6A), an image spectrum domain based approach (e.g., such as described with respect to FIG. 6B and/or Eqn. 2), and/or other applicable methodologies. In some implementations, (e.g., such as described with respect to FIG. 6A, the contrast parameter for a given image may be obtained using a smoothing operation (e.g., based on a block averaging filter, exponential filter, and/or other operation configured to reduce variability of the contrast parameter from one image to another).

[00113] At operation 1006, a determination may be made as to whether the parameter(s) of interest meet the relevant criterion or criteria (e.g., the contrast parameter is within detection range). In some implementations, the determination of operation 1006 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIGS 6A-6B. In one or more implementations, the threshold value may be selected (e.g., equal one in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00114] Responsive to a determination at operation 1006 that the contrast parameter is within the detection range (e.g., breached the threshold), the method 1000 may proceed to operation 1008 wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller.

[00115] FIG. 11A illustrates a method of image analysis useful for object detection by an optical apparatus, in accordance with one or more implementations. The operations of method 1100 may be performed by an optical object detection apparatus (e.g., such as that of FIGS. 2-5A) disposed on, e.g., a mobile robotic device.

[00116] At operation 1102, an image may be obtained. In some implementations, the image may comprise a 2-array of pixels characterized by one or more channels (grayscale, RGB, and/or other representations) and/or pixel bit depth.



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[00117] At operation 1104, the obtained image may be evaluated. In some implementations, the image evaluation may be configured to determine a processing load of an image analysis apparatus (e.g., components of the apparatus 500, 530 of FIGS. 5A-5B, and/or 916 of FIG. 9, described above). The evaluation may comprise re-sampling (e.g., down sampling/up-sampling) the image to a given reference resolution. By way of an illustration, an image analysis component may comprise an ASIC configured to accept images of a given resolution (e.g., 320x180 pixels, 640x360 pixels, and/or other resolution). The operation 1104 may be configured to adapt the input image into a compatible resolution. In some implementations, the image evaluation operation may comprise modification of image bit depths (e.g., from 12 to 8 bits), and/or a channel combination operation e.g., configured to produce a grayscale image from RGB image.

[00118] At operation 1106 a high-passed version of the image produced by operation 1104 may be obtained. In one or more implementations, the high–pass filtered image version may be produced using a filter operation configured based on a convolution operation with a Laplacian, a difference of Gaussian operation, a combination thereof, and/or other operations. In some implementations, filter operation may be configured based on a hybrid kernel determined using a convolution of the Gaussian smoothing kernel with the Laplacian kernel. The hybrid kernel may be convolved with the image produced by operation 1104 in order to obtain the high-pass filtered image version. In some implementations of down-sampling and high-pass filtering, the image may be convolved with the processing kernel at a subset of locations in the image corresponding to the subsampling parameters, by applying the kernel on a grid of n pixels, where n is the down-sampling parameter.

[00119] At operation 1108, a contrast parameter of the high–pass filtered image may be determined. In one or more implementations, the contrast parameter determination may be effectuated by the processing component 522 of the apparatus 500 described with respect to FIG. 5A using an image-domain based approach. The contrast parameter determination using the image-domain based approach may comprise determination of a maximum absolute deviation of individual pixel values within the filtered image from a reference value. The reference value may comprise a fixed pre-computed value, an image mean, image median, and/or a value determined using statistics of multiple images. In some implementations, the contrast parameter for a plurality of images value may be low-pass filtered using a running mean, an exponential

filter, and/or other filter approach configured to reduce inter-image variability of the detection process.

[00120] At operation 1110, a determination may be made as to whether the contrast parameter may fall within detection range. In some implementations, the determination of operation 1110 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIG 6A. In one or more implementations, the threshold value may be selected (e.g., equal to 12% of the maximum deviation as in FIG. 6A) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00121] Responsive to a determination at operation 1110 that the contrast parameter may be within the detection range (e.g., breached the threshold), the method 1100 may proceed to operation 1112 wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller, an alert indication to a user, and/or to another entity.

[00122] FIG. 11B illustrates a method of image analysis useful for object detection by an optical apparatus, in accordance with one or more implementations. Operations of method 1130 may be performed by an optical object detection apparatus (e.g., of FIGS. 2-4D, 5B) disposed on a mobile robotic device.

[00123] At operation 1122 an image may be obtained. In some implementations, the image may comprise a 2-array of pixels characterized by one or more channels (grayscale, RGB, and/or other representations) and/or pixel bit depth.

[00124] At operation 1124, the image may be evaluated. In some implementations, the image evaluation may be configured to determine a processing load of an image analysis apparatus (e.g., components of the apparatus 530 of FIGS. 5B, and/or 916 of FIG. 9, described above). The evaluation may comprise re-sampling (e.g., down sampling/up-sampling) the image to a given reference resolution. By way of an illustration, an image analysis component may comprise an ASIC configured to accept images of a given resolution (e.g., 320x180 pixels, 640x360 pixels, and/or other resolution). The operation 1124 may be configured to adapt the input image into a compatible resolution. In some implementations, the image evaluation

operation may comprise modification of image bit depths (e.g., from 12 to 8 bits), and/or a channel combination operation e.g., configured to produce a grayscale image from RGB image.

[00125] At operation 1126, a spectrum of the image produced by operation 1124 may be obtained. In one or more implementations, the spectrum may be determined using a discrete Fourier transform, and/or other transformation.

[00126] At operation 1128, a contrast parameter of the image may be determined. In one or more implementations, the contrast parameter determination may be effectuated by the processing component 538 of the apparatus 530 described with respect to FIG. 5B using an image spectrum-domain based approach spectral domain based approach (e.g., such as described with respect to FIG. 6B and/or Eqn. 2). The contrast parameter determination using the image spectrum-domain based approach may comprise partitioning of the image spectrum into a low spatial frequency portion and a high spatial frequency portion. In some implementations, the spectrum partitioning may be configured by selecting a first area within e.g., circular, elliptical and/or other shape, around the origin (e.g., zero frequency), and a second area comprising the remaining portion of the spectrum (i.e., outside the ellipse/circle). The contrast image parameter may be determined for instance using a ratio of integral power within the first are to the integral power within the second area. In some implementations of a detection system with sensors elements disposed along multiple dimensions (e.g., as in FIG. 3, FIG. 4A, and/or FIG. 4D, image spectrum analysis may enable determination of objects of one or more orientation. For example, a given detector configuration may be more sensitive to objects of one orientation (e.g., vertical) and less sensitive to objects of another orientation (e.g., horizontal). In some implementations, an asymmetrical Laplacian kernel and/or Gabor type filter may be used to facilitate detection of objects at a target orientation.

[00127] At operation 1130, a determination may be made as to whether the contrast parameter may fall within detection range. In some implementations, the determination of operation 1130 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIG 6B. In one or more implementations, the threshold value may be selected (e.g., equal one as in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters, as previously described herein.

[00128] Responsive to a determination at operation 1130 that the contrast parameter is



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within the detection range (e.g., breached the threshold) the method 1120 may proceed to operation 1132, wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a wireless transmission, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller, an alert indication to a user, and/or to another entity.

[00129] FIG. 12 illustrates a method of executing an action by a robotic vehicle, the action execution configured based on an outcome of object detection methodology of the disclosure, in accordance with one or more implementations.

[00130] At operation 1202, a vehicle (e.g., the vehicle 100 of FIG. 1) may be operated, such as to for example navigate a trajectory. The trajectory navigation may be configured to for instance track and/or acquire video of a subject of interest (e.g., a user) from an aerial vehicle (e.g., a quad-copter), for example as described in U.S. Patent Application Serial Nos. 62/007,311, entitled "APPARATUS AND METHODS FOR TRACKING USING AERIAL VIDEO", filed on June 3, 2014 the foregoing being incorporated herein by reference in its entirety. In some implementations, the vehicle may comprise a robotic device equipped with a learning controller, e.g., such as described in U.S. Patent Application Serial No. 13/842,530, entitled "ADAPTIVE PREDICTOR APPARATUS AND METHODS", filed herewith on March 15, 2013, the foregoing being incorporated herein by reference in its entirety. In some implementations, the trajectory navigation may comprise one or more actions configured to enable landing of the aerial vehicle, e.g., as described in U.S. Patent Application Serial Nos. 14/285,466, entitled "APPARATUS AND METHODS FOR ROBOTIC OPERATION USING VIDEO IMAGERY", filed herewith on May 22, 2014, and/or 14/285,414, entitled "APPARATUS AND METHODS FOR DISTANCE ESTIMATION USING MULTIPLE IMAGE SENSORS", filed on May 22, 2014, each of the foregoing incorporated herein by reference in its entirety.

[00131] At operation 1204, an image of the surrounding may be obtained. In one or more implementation, the image may comprise representation of one or more objects in the surroundings (e.g., the objects 112, 122 in FIG. 1).

[00132] At operation 1206, the image may be analyzed using to obtain contrast parameter. In one or more implementations, the contrast parameter determination may be configured using

an image-domain approach (e.g., described above with respect to FIGS. 5A, 6A, 7A-7B, and/or 11A) or an image spectrum-domain approach (e.g., described above with respect to FIGS. 5B, 6B, 8A-8B, and/or 11B).

[00133] At operation 1208, a determination may be made as to whether an object may be present in the image obtained at operation 1204. In some implementations, the object presence may be determined based on a comparison of the contrast parameter to a threshold; e.g., as shown and described with respect to FIGS 6A-6B. In one or more implementations, the threshold value may be selected (e.g., equal one as in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00134] Responsive to a determination at operation 1208 that the object is present, the method 1200 may proceed to operation 1210, wherein the trajectory may be adapted. In some implementations, the object presence may correspond to a target being present in the surroundings and/or an obstacle present in the path of the vehicle. The trajectory adaptation may comprise alteration of vehicle course, speed, and/or other parameter. The trajectory adaptation may be configured based on one or more characteristics of the object (e.g., persistence over multiple frames, distance, location, and/or other parameters). In some implementations of target approach and/or obstacle avoidance by a robotic vehicle, when a target may be detected, the trajectory adaptation may be configured to reduce distance between the target and the vehicle (e.g., during landing, approaching a home base, a trash can, and/or other action). When an obstacle may be detected, the trajectory adaptation may be configured to maintain distance (e.g., stop), increase distance (e.g., go away), alter course (e.g., turn) in order to avoid collision. In some implementations, target/obstacle discrimination may be configured based on object color (e.g., approach red ball avoid all other objects); object reflectivity (approach bright objects), shape, orientation, and or other characteristics. In some implementations, object discrimination may be configured based on input from other sensors (e.g., RFID signal, radio beacon signal, acoustic pinger signal), location of the robotic device (e.g., when the vehicle is in the middle of a room all objects are treated as obstacles), and/or other approaches.

[00135] Although the above application of the object detection methodology is described for a vehicle navigation application, it will be appreciated by those skilled in the arts that various other implementations of the methodology of the present disclosure may be utilized. By way of an illustration, a security camera device may be used to observe and detect potential intruders

(e.g., based on sudden appearance of objects) and/or detect theft (e.g., based on a sudden disappearance of previously present objects)

[00136] Implementations of the principles of the disclosure may be further applicable to a wide assortment of applications including computer-human interaction (e.g., recognition of gestures, voice, posture, face, and/or other interactions), controlling processes (e.g., processes associated with an industrial robot, autonomous and other vehicles, and/or other processes), augmented reality applications, access control (e.g., opening a door based on a gesture, opening an access way based on detection of an authorized person), detecting events (e.g., for visual surveillance or people or animal counting, tracking).

[00137] A video processing system of the disclosure may be implemented in a variety of ways such as, for example, a software library, an IP core configured for implementation in a programmable logic device(e.g., FPGA), an ASIC, a remote server, comprising a computer readable apparatus storing computer executable instructions configured to perform feature detection. Myriad other applications exist that will be recognized by those of ordinary skill given the present disclosure.

[00138] Although the system(s) and/or method(s) of this disclosure have been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred implementations, it is to be understood that such detail is solely for that purpose and that the disclosure is not limited to the disclosed implementations, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. For example, it is to be understood that the present disclosure contemplates that, to the extent possible, one or more features of any implementation can be combined with one or more features of any other implementation.

WHAT IS CLAIMED IS:

1. – 23. (Canceled)

24. (New) A method of navigating a robotic apparatus comprising a controller, an actuator and a sensor, the method comprising:

obtaining at least one image associated with surroundings of the apparatus using the sensor;

analyzing the at least one image to detect a presence of an object in the at least one image;

determining that the detected object comprises one of either a target or an obstacle; and

causing the controller to selectively activate the actuator based on the determination.



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# OPTICAL DETECTION APPARATUS AND METHODS

Abstract of the Disclosure

An optical object detection apparatus and associated methods. The apparatus may comprise a lens (e.g., fixed-focal length wide aperture lens) and an image sensor. The fixed focal length of the lens may correspond to a depth of field area in front of the lens. When an object enters the depth of field area (e.g., sue to a relative motion between the object and the lens) the object representation on the image sensor plane may be in-focus. Objects outside the depth of field area may be out of focus. In-focus representations of objects may be characterized by a greater contrast parameter compared to out of focus representations. One or more images provided by the detection apparatus may be analyzed in order to determine useful information (e.g., an image contrast parameter) of a given image. Based on the image contrast meeting one or more criteria, a detection indication may be produced.



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# OPTICAL DETECTION APPARATUS AND METHODS

This application is a continuation of and claims the benefit of priority to U.S. Patent Application Serial No. 14/321,736 filed on July 1, 2014 of the same title, the contents of which being incorporated herein by reference in its entirety.

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## BACKGROUND

### Field of the Disclosure

[0002] The present disclosure relates to, *inter alia*, computerized apparatus and methods for detecting objects or targets using processing of optical data.

### Description of Related Art

[0003] Object detection may be required for target approach/obstacle avoidance by autonomous robotic devices. Small sized and/or low-cost robotic vehicles may comprise limited processing and/or energy resources (and/or weight budget) for object detection.

[0004] A variety of object detection apparatus (such as IR-based, ultrasonic, and lidar) currently exist, but suffer from various disabilities. Specifically, some existing infrared (IR) optical proximity sensing methods may prove unreliable, particularly when used outdoors and/or in presence of other sources of infrared radiation. Ultrasonic proximity sensors may become unreliable outdoors, particularly on e.g., unmanned aerial vehicles (UAV) comprising multiple motors that may produce acoustic noise. The ultrasonic sensor distance output may also be affected by wind and/or humidity. Lidar based systems are typically costly, heavy, and may require substantial computing resources for processing lidar data.

[0005] Therefore there exists a need for an improved object detection sensor apparatus, and associated methods. Specifically, in one application, the improved detection sensor apparatus

would be one or more of small sized, inexpensive, reliable, lightweight, power efficient, and/or capable of effective use outdoors.

## SUMMARY

[0006] The present disclosure satisfies the foregoing need for an improved object detection apparatus and associated methods.

[0007] Specifically, one aspect of the disclosure relates to a non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable to perform a method of detecting a distance to an object.

[0008] Another aspect of the disclosure relates to a non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable on a processing apparatus to detect an object in an image. In one implementation, the detection includes: producing a high-pass filtered version of the image, the high–pass filtered version comprising a plurality of pixels; for at least some of the plurality of pixels, determining a deviation parameter between the value of a given pixel and a reference value; and based on the deviation parameter meeting a criterion, providing an indication of the object being present in the image.

[0009] In one variant, the high–pass filtered version of the image is configured produced based at least on a first convolution operation between a kernel and the image, the kernel characterized by a kernel dimension; and the convolution operation is configured to reduce energy associated spatial scales in the image that are lower than the kernel dimension. The kernel is configured for example based at least on a second convolution operation of a first matrix, the first matrix configured based at least on a Laplacian operator, and a second matrix configured based at least on a Gaussian operator; and the image is characterized by image dimension, the image dimension exceeding the kernel dimension by at least 10ten times (10x).

[0010] In another variant, the criterion comprises meeting or exceeding a prescribed threshold.

[0011] In another aspect of the disclosure, an optical object detection apparatus is disclosed. In one implementation, the apparatus includes: a lens characterized by a depth of field range; an image sensor configured to provide an image comprising one or more pixels; and logic in communication with the image sensor. The logic is configured to in one variant: evaluate at

least a portion of the image to determine an image contrast parameter; and produce an object detection indication based on the contrast parameter breaching a threshold meeting one or more criteria, the object indication configured to convey presence of the object within the depth of field range.

[0012] In another variant, the image sensor comprises an array of photo-sensitive elements arranged in a plane disposed substantially parallel to the lens; and the image comprises an array of pixels, individual pixels being produced by individual ones of the photo-sensitive elements.

[0013] In another aspect, a method of navigating a trajectory by a robotic apparatus is disclosed. In one implementation, the apparatus includes a controller, an actuator and a sensor, and the method includes: obtaining at least one image associated with surroundings of the apparatus using the sensor; analyzing the at least one image to determine a contrast parameter of the image; detecting a presence of an object in the at least one image based at least in part on based on the contrast parameter meeting one or more criteria; and causing the controller to activate the actuator based on the detection of the presence of the object. In one variant, the actuator activation is configured consistent with a characteristic of the object.

[0014] In another variant, the robotic device comprises a vehicle; the object comprises one of a target or an obstacle; and the actuator activation is configured to cause the vehicle to perform at least one of a target approach or obstacle avoidance action.

[0015] In another implementation, the method includes: obtaining at least one image associated with surroundings of the apparatus using the sensor; analyzing the at least one image to detect a presence of an object in the at least one image; determining that the detected object comprises one of either a target or an obstacle; and causing the controller to selectively activate the actuator based on the determination.

In another aspect of the present disclosure, a method of navigating a robotic apparatus is disclosed. In one embodiment, the robotic apparatus includes a controller, an actuator and a sensor, and the method includes: obtaining, through a lens, at least one image associated with surroundings of the apparatus using the sensor, the sensor including a plurality of image detectors disposed at an angle with respect to a plane of the lens, each of the plurality of image detectors being associated with an extent located in the surroundings; analyzing the at least one image to detect a presence of one or more objects in the at least one image; during the navigating

of the robotic apparatus, detecting a distance to the one or more objects based on the presence of at least one of the one or more objects within the extent located in the surroundings; determining that the detected object includes one of either a target or an obstacle; and causing the controller to selectively activate the actuator based on the determination.

In another aspect of the present disclosure, an apparatus is disclosed. In one embodiment, the apparatus is configured to cause a robotic device to navigate a trajectory, and the apparatus includes a non-transitory computer-readable medium including a plurality of instructions configured to cause the apparatus to, when executed by a processor: obtain an image associated with surroundings of the apparatus using a sensor of the device, the sensor including multiple discrete image sensors behind a single lens associated therewith, each of the multiple discrete image sensors being associated with respective extents located in the surroundings of the apparatus; analyze the image to determine a contrast parameter of the image; detect a presence of an object in the image based at least in part on the contrast parameter meeting one or more criteria; and cause a controller of the device to activate an actuator of the device based on the detection of the presence of the object; wherein the actuator is configured to be activated based on a characteristic of the object; and wherein during the navigation of the trajectory by the robotic device, the apparatus is configured to determine (i) a first distance to the object when the presence of the object produces a first in-focus representation within a first extent of the respective extents and (ii) a second distance to the object when the presence of the object produces a second in-focus representation within a second extent of the respective extents.

[0016] These and other objects, features, and characteristics of the system and/or method disclosed herein, as well as the methods of operation and functions of the related elements of structure and the combination of parts and economies of manufacture, will become more apparent upon consideration of the following description and the appended claims with reference to the accompanying drawings, all of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the disclosure. As used in the specification and in the claims, the singular form of "a", "an", and "the" include plural referents unless the context clearly dictates otherwise.

**Brief Description of the Drawings**

[0017] FIG. 1 is a graphical illustration depicting a top view of robotic apparatus configured for optical distance detection, in accordance with one or more implementations.

[0018] FIG. 2 is a diagram illustrating focal configuration of an optical apparatus used for distance detection, according to one or more implementations.

[0019] FIG. 3 is a graphical illustration depicting distance detection volume associated with a three-dimensional image detector, according to one or more implementations.

[0020] FIG. 4A is a graphical illustration depicting an object detection apparatus comprising a slanted linear image detector, according to one or more implementations.

[0021] FIG. 4B is a graphical illustration depicting an object detection apparatus comprising a horizontal linear image detector, according to one or more implementations.

[0022] FIG. 4C is a graphical illustration depicting a distance detection apparatus comprising detectors of multiple wavelengths, according to one or more implementations.

[0023] FIG. 4D is a graphical illustration depicting an extended range distance detection apparatus comprising multiple detectors, according to one or more implementations.

[0024] FIG. 5A is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations.

[0025] FIG. 5B is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations.

[0026] FIG. 6A is a plot illustrating output of an optical signal detection apparatus (e.g., the apparatus 500 of FIG. 5A), according to one or more implementations.

[0027] FIG. 6B is a plot illustrating output of an optical signal detection apparatus (e.g., the apparatus 530 of FIG. 5B), according to one or more implementations.

[0028] FIG. 7A is a plot illustrating de-focused images obtained with an optical distance detection system, according to one or more implementations.

[0029] FIG. 7B is a plot illustrating in-focus images obtained with an optical distance detection system, according to one or more implementations.

[0030] FIG. 8A is a plot illustrating a power spectrum of a de-focused image obtained with an optical distance detection system, according to one or more implementations.

[0031] FIG. 8B is a plot illustrating a power spectrum of an in-focus image obtained with an optical distance detection system, according to one or more implementations.

[0032] FIG. 9 is a functional block diagram illustrating a computerized apparatus for implementing, *inter alia*, object detection in accordance with one or more implementations.

[0033] FIG. 10 is a logical flow diagram illustrating a method of determining a salient feature using encoded video motion information, in accordance with one or more implementations.

[0034] FIG. 11A is a logical flow diagram illustrating a method of image processing useful for object detection by an optical apparatus, in accordance with one or more implementations.

[0035] FIG. 11B is a logical flow diagram illustrating a method of image processing useful for object detection by an optical apparatus, in accordance with one or more implementations.

[0036] FIG. 12 is a logical flow diagram illustrating a method of executing an action by a robotic vehicle, the action execution configured based on an outcome of object detection methodology of the disclosure, in accordance with one or more implementations.

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## DETAILED DESCRIPTION

[0038] Implementations of the present disclosure will now be described in detail with reference to the drawings, which are provided as illustrative examples so as to enable those skilled in the art to practice the present technology. Notably, the figures and examples below are not meant to limit the scope of the present disclosure to a single implementation, but other implementations are possible by way of interchange of or combination with some or all of the described or illustrated elements. Wherever convenient, the same reference numbers will be used throughout the drawings to refer to same or like parts.

[0039] Although the system(s) and/or method(s) of this disclosure have been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred implementations, it is to be understood that such detail is solely for that purpose and that the disclosure is not limited to the disclosed implementations, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit

and scope of the appended claims. For example, it is to be understood that the present disclosure contemplates that, to the extent possible, one or more features of any implementation may be combined with one or more features of any other implementation

[0040] In the present disclosure, an implementation showing a singular component should not be considered limiting; rather, the disclosure is intended to encompass other implementations including a plurality of the same component, and vice-versa, unless explicitly stated otherwise herein.

[0041] Further, the present disclosure encompasses present and future known equivalents to the components referred to herein by way of illustration.

[0042] As used herein, the term "bus" is meant generally to denote all types of interconnection or communication architecture that is used to access the synaptic and neuron memory. The "bus" could be optical, wireless, infrared or another type of communication medium. The exact topology of the bus could be for example standard "bus", hierarchical bus, network-on-chip, address-event-representation (AER) connection, or other type of communication topology used for accessing, e.g., different memories in pulse-based system.

[0043] As used herein, the terms "computer", "computing device", and "computerized device ", include, but are not limited to, personal computers (PCs) and minicomputers, whether desktop, laptop, or otherwise, mainframe computers, workstations, servers, personal digital assistants (PDAs), handheld computers, embedded computers, programmable logic device, personal communicators, tablet or "phablet" computers, portable navigation aids, J2ME equipped devices, smart TVs, cellular telephones, smart phones, personal integrated communication or entertainment devices, or literally any other device capable of executing a set of instructions and processing an incoming data signal.

[0044] As used herein, the term "computer program" or "software" is meant to include any sequence or human or machine cognizable steps which perform a function. Such program may be rendered in virtually any programming language or environment including, for example, C/C++, C#, Fortran, COBOL, MATLAB™, PASCAL, Python, assembly language, markup languages (e.g., HTML, SGML, XML, VoXML), and the like, as well as object-oriented environments such as the Common Object Request Broker Architecture (CORBA), Java™ (including J2ME, Java Beans), Binary Runtime Environment (e.g., BREW), and other languages.

[0045] As used herein, the terms "connection", "link", "synaptic channel", "transmission

channel", "delay line", are meant generally to denote a causal link between any two or more entities (whether physical or logical/virtual), which enables information exchange between the entities.

[0046] As used herein the term feature may refer to a representation of an object edge, determined by change in color, luminance, brightness, transparency, texture, and/or curvature. The object features may comprise, *inter alia*, individual edges, intersections of edges (such as corners), orifices, and/or curvature

[0047] As used herein, the term "memory" includes any type of integrated circuit or other storage device adapted for storing digital data including, without limitation, ROM. PROM, EEPROM, DRAM, Mobile DRAM, SDRAM, DDR/2 SDRAM, EDO/FPMS, RLDRAM, SRAM, "flash" memory (e.g., NAND/NOR), memristor memory, and PSRAM.

[0048] As used herein, the terms "processor", "microprocessor" and "digital processor" are meant generally to include all types of digital processing devices including, without limitation, digital signal processors (DSPs), reduced instruction set computers (RISC), general-purpose (CISC) processors, microprocessors, gate arrays (e.g., field programmable gate arrays (FPGAs)), PLDs, reconfigurable computer fabrics (RCFs), array processors, secure microprocessors, and application-specific integrated circuits (ASICs). Such digital processors may be contained on a single unitary IC die, or distributed across multiple components.

[0049] As used herein, the term "network interface" refers to any signal, data, or software interface with a component, network or process including, without limitation, those of the FireWire (e.g., FW400, FW800, and/or other FireWire implementation.), USB (e.g., USB2), Ethernet (e.g., 10/100, 10/100/1000, Gigabit Ethernet, 10-Gig-E), MoCA, Coaxsys (e.g., TVnet™), radio frequency tuner (e.g., in-band or OOB, cable modem), Wi-Fi (802.11), WiMAX (802.16), PAN (e.g., 802.15), cellular (e.g., 3G, LTE/LTE-A/TD-LTE, GSM, and/or other cellular interface implementation) or IrDA families.

[0050] As used herein, the term "Wi-Fi" refers to, without limitation, any of the variants of IEEE-Std. 802.11 or related standards including 802.11 a/b/g/n/s/v and 802.11-2012.

[0051] As used herein, the term "wireless" means any wireless signal, data, communication, or other interface including without limitation Wi-Fi, Bluetooth, 3G (3GPP/3GPP2), HSDPA/HSUPA, TDMA, CDMA (e.g., IS-95A, WCDMA, and/or other wireless interface implementation.), FHSS, DSSS, GSM, PAN/802.15, WiMAX (802.16),

802.20, narrowband/FDMA, OFDM, PCS/DCS, LTE/LTE-A/TD-LTE, analog cellular, CDPD, RFID or NFC (e.g., EPC Global Gen. 2, ISO 14443, ISO 18000-3), satellite systems, millimeter wave or microwave systems, acoustic, and infrared (e.g., IrDA).

[0052] The present disclosure provides, among other things, apparatus and methods for detecting objects at a given distance from a moving device (such as e.g., a robotic device) in real time.

[0053] An optical distance/detection apparatus may comprise sensory apparatus, such as a camera comprising an imaging sensor with a lens configured to project a representation of a visual scene onto the imaging sensor. For a given lens, objects at different distances in front the lens may appear to focused at different ranges behind the lens. The lens may be characterized by a range of sharp focus (also referred to as depth of field). For a given range between the image sensor and the lens, one or more objects present within the range of focus may produce in-focus images. Objects disposed outside the range of focus may produce smeared (or out of focus) images. In-focus representations of objects may be characterized by a greater contrast parameter compared to out-of-focus representations. One or more images provided by the detection apparatus may be analyzed in order to determine image contrast parameter of a given image. Based on one or more criteria (e.g., the image contrast breaching a threshold), an object detection indication may be produced by the apparatus.

[0054] When operated from a moving vehicle or device (e.g., a car, an aerial vehicle) the image on the detector may gradually get sharper as the vehicle approaches an object. Upon breaching a given contrast (given sharpness) threshold, the detection apparatus may produce an indication conveying presence of an object within the range of focus in front of the lens.

[0055] FIG. 1 depicts a top view of mobile robotic apparatus comprising an optical object detection device configured for object detection in accordance with some implementations. The apparatus 100 may comprise for instance a robotic car, an unmanned aerial vehicle, and/or other apparatus configured to move in space in one or more dimensions. The apparatus 100 may comprise the optical object detection device 106. The apparatus 100 may navigate in a direction 104. One or more objects may be present in front of the apparatus 100, e.g., a ball 112 and a box 122, disposed at distance 110, 120, respectively, from the apparatus 100. The object detection device 106 may be configured to detect the presence of one or more objects (e.g., 112, 122) during, for example trajectory navigation by the apparatus 100 using the methodology of the

disclosure.

[0056] FIG. 2 illustrates a configuration of an optical apparatus used for object detection, according to one or more implementations. The apparatus 300 of FIG. 2, may comprise a lens 302 characterized by a focal length 332. A portion of the space to the left of the lens 302 in FIG. 2 may be referred to as the front (e.g., object space). A lens may be characterized by a relative aperture (also referred to as the f-number and/or focal number and defined as a ratio of lens focal length (e.g., element 332 in FIG. 2) to the diameter of the lens entrance pupil).

[0057] The apparatus 300 may comprise an image sensor disposed behind the lens 304. In some implementations, the sensor may be located at a fixed distance from the lens, e.g., in the focal plane 334 of the lens 302.

[0058] The lens 302 may be characterized by an area of acceptable contrast which also may be referred to as a circle of confusion (CoC). In optics, a circle of confusion may correspond to a region in a plane of the detector formed by a cone of light rays from a lens that may not coming to a perfect focus when imaging a point source. The area of acceptable contrast may also be termed to as disk of confusion, circle of indistinctness, blur circle, or region. The area of acceptable contrast of the lens 302 (denoted by bold segment in FIG. 2) of extent 304 may correspond to an extent of acceptably sharp focus 324 in front of the lens 302. In some implementations, the dimension (e.g., vertical in FIG. 2) of the acceptable contrast 304 may be configured based on, for example, one or more criteria such as an acceptable difference in brightness between (i) pixels corresponding to the light rays falling onto the detector within the area 304, and (ii) pixels corresponding the light rays falling onto the focal plane outside the area 304. The magnitude of the pixel brightness difference may be configured in accordance with parameters of a particular application (e.g., object distance, size, shape, image resolution, acquisition time and/or other parameters). In some implementations of object detection from an aerial vehicle for example, the magnitude of the pixel brightness difference may be selected between 10% and 20%.

[0059] In some implementations of still or video image processing, dimension of the circle of confusion may be determined based on a size of the largest blur spot that may still be perceived by the processing apparatus as a point. In some photography implementations wherein the detector may comprise a human eye, a person with a good vision may be able to distinguish an image resolution of 5 line pairs per millimeter (lp/mm) at 0.25 m, which corresponds to CoC

of 0.2 mm.

[0060] In one or more implementations of computerized detectors, the DOF dimension may be determined as

$$R \sim 1/dc,\ dc \sim d/dr/Rv \qquad \text{(Eqn. 1)}$$

where:

d is the viewing distance, dr is the minimum detectable resolution at a reference viewing distance, Rv – is the reference viewing distance.

[0061] For a given detector size and/or location, and sharpness threshold, the dimension 304 of the area of acceptable contrast may increase with an increasing f-number of the lens 302. By way of an illustration, the circle of confusion of a lens with f-number of 1.4 (f/1.4) will be twice that of the f/2.8 lens. Dimension of the area of acceptably sharp focus 324 in FIG. 2 (also referred to as the depth of field (DOF)) may be inversely proportional to the dimension 304 of the area of acceptable contrast and the lens f-number. In the above example, the DOF of the f/1.4 lens will be half that of the f/2.8 lens.

[0062] A plurality of objects (denoted by circles 312, 314, 316, 318 in FIG. 2) may be present in front of the lens 302. Axial extents denoted by arrows 322 and 326 in FIG. 2 may be referred to as out-of-focus portions, while the extent 324 may be referred to as the in-focus portion of the space in front of the lens. Objects that may be present within the DOF (e.g., the objects 314, 316 shown by solid circles in FIG. 2) produce in-focus image representations in the focal plane 334. Objects that may be present outside the DOF (e.g., the objects 312, 318 shown by open circles in FIG. 2) produce out-of-focus image representations in the focal plane 334. By way of an illustration, the object 312 may produce an out of focus image at the detector plane 334, the object 314 may produce an in-focus image at the detector plane 334.

[0063] In some implementations, a lens with a lower relative aperture (smaller f number) may be capable of producing a shallower depth of field (e.g., 324 in FIG. 2). An optical detection apparatus characterized by a shallow depth of field may reduce uncertainty associated with detecting objects using image contrast methodology described herein. A detection system 300

characterized by a shallower area of acceptably sharp focus may be used to achieve reliable detection (e.g., characterized by a lower rate of false positives) compared to a detection system characterized by a deeper area of acceptably sharp focus. In some implementations of object detection from a moving platform and/or detection of moving objects, a detection system characterized by the shallower DOF may be operated at an increased temporal resolution (compared to the deeper DOF system) in order to detect objects that may pass through the area of acceptably sharp focus.

[0064] In some implementations, e.g., such as illustrated in FIG. 1, the apparatus 200 may be disposed on a moving platform. As the platform approaches an object (e.g., 122 in FIG. 1) being present in the out-of focus area 322, the object, when at location 312 in FIG. 2, may produce an out of focus representation in the image. When the object becomes located within the apparatus 300 DOF (e.g., the location 314, and/or 316 of the extent 324 or there between), it may produce an in-focus representation. The in-focus representation may be characterized by one or more changes, such as e.g., an increased contrast as compared to the output focus representations. In such a case, analysis of the image contrast may be utilized in order to determine the presence of one or more objects in the image, e.g., as described below with respect to FIGS. 6-8B.

[0065] In some implementations, the contrast determination process may comprise one or more computer-implemented mathematical operations, including down-sampling the image produced by the detector; performing a high-pass filter operation on the acquired image; and/or determining a deviation parameter of pixels within the high–pass filtered image relative a reference value. FIG. 3 depicting an exemplary distance detection apparatus 400 comprising a three-dimensional image detector, according to one or more implementations. The apparatus 400 may comprise for instance a lens 402, and a three dimensional image sensor 410. The image sensor may comprise a charge-coupled device (CCD), CMOS device, an active-pixel sensor (APS), photodiode array, and/or other sensor technology. The image sensor may be configured to provide two-dimensional (e.g. X-Y) matrices of a pixel intensity values refreshed at, e.g., a 25 Hz or other suitable frame rate. In one or more implementations, the image sensor may operate at a single wavelength, or at multiple wavelengths. It will be appreciated that while many applications of the apparatus 400 may be configured to operate within the visual band of wavelengths, the present disclosure contemplates use of other wavelengths of electromagnetic

energy including, without limitation, those in IR, microwave, x-ray, and/or gamma-ray bands, or combinations of the foregoing. A given pixel may be characterized by one or more values, e.g., corresponding to individual wavelengths (R, G, B), and/or exposure. Individual values may be characterized by bit depth (e.g., comprising 8, 12, 16, or other number of bits). It will be appreciated by those skilled in the art when given this disclosure that the above-referenced image parameters are merely exemplary, and many other image representations (e.g., bitmap, luminance-chrominance (YUV, YCbCr), grayscale, and/or other image representations) are equally applicable to and useful with the various aspects of the present disclosure. Furthermore, data frames corresponding to other (non-visual) signal modalities such as infrared (IR), ultraviolet (UV) images may be compatible with the processing methodology of the disclosure, or yet other configurations.

[0066] The image sensor 410 may comprise one or more sensing layers arranged along dimension shown by arrow 404. Individual layers (not shown) may comprise a plurality of photo sensitive elements (photosites) configured to produce arrays of pixels. Individual sensing layers may be configured partially translucent so as to permit light delivered by the lens 402 propagation through a prior layer (with respect to the lens) to subsequent layer(s). Axial displacement of individual layers (e.g., along dimension 404) may produce an axial distribution of focal planes./ Light rays propagating through the lens 402 at different angles may be focused at different locations, as shown by broken lines 406, 408 in FIG. 3. Spatial separation of multiples focal planes may enable detection of objects disposed within the extent 412 in front of the lens. Objects disposed at different ranges 414 from the lens within the extent 410 may produce in focus images at a respective focal plane of the image sensor 410. In some implementations, the apparatus 400 may be used to provide distance to the detected object.

[0067] FIG. 4A illustrates an object detection apparatus comprising a slanted linear image detector, according to one or more implementations. The apparatus 420 of FIG. 4A may comprise a lens 402, and one or more image sensors 422, 424. Individual image sensors 422, 424 may comprise a linear array of photosites disposed at an angle with respect to the plane of the lens 402. Configuring the image sensor 422, 424 at an angle with respect to the lens 402 may enable the apparatus 420 to produce one or more areas of focus 426, 428. Areas of focus may be characterized by an axial horizontal extent, e.g., element 429 of the area 426 in FIG. 4A. Slanted areas of focus may correspond to multiple in-focus extents to the left of the lens 402, e.g. shown

by arrows 423, 425. Objects occurring within the one or more extents 423, 425 may produce an in-focus representation on the respective sensor. Use of one or more slanted image sensors may enable the apparatus 420 to detect objects at multiple locations that differ by distance from the lens plane and the cross axis position. In some implementations, detection of objects at multiple distances may enable a robotic vehicle to determine as to whether obtain information if its approaching an object (or if it is approached by an object) and undertake a relevant action (e.g. avoid an obstacle and/or move away from a trajectory of another object). In one or more implementations, the detection apparatus 420 may be employed to determine shape and/or aspect ratio of an object. By way of an illustration, number and/or location of activated slant sensors (e.g., 422, 424) of the slant array may convey information about object's location, orientation and/or shape.

[0068] FIG. 4B illustrates an object detection apparatus comprising a horizontal linear image detector, according to one or more implementations. The apparatus 430 of FIG. 4B may comprise a lens 402, and an image sensor 432 comprising a linear array of photosites disposed along axial direction of the lens 402. Disposing the image sensor 432 at a right angle with respect to the lens 402 plane may enable the apparatus 430 to produce in-focus images when an object may be present within the in-focus range 433 in front of the lens 402. When one or more objects may occur within the range 433 at different ranges from the lens, distance to individual objects may be resolved by, in one implementation, analyzing in-focus representations corresponding to light rays 436, 438 in FIG. 4B.

[0069] FIG. 4C illustrates a distance detection apparatus comprising an image sensor comprising detectors of multiple wavelengths, according to one or more implementations. The apparatus 440 of FIG. 4C may comprise a lens 402, and an image sensor 441. The image sensor 441 may comprise a linear array of photosites disposed along focal plane direction (vertical in FIG. 4C) of the lens 402. The photosite array may comprise elements configured to respond to light waves of different wavelength. The sensor 441 shown in FIG. 4C comprises three element types depicted by open, solid, and hashed rectangles denoted 444, 446, 442, respectively. Individual photosites of a given type (e.g., 444, 446, 442 in FIG. 4C) may be configured in an array, thus producing multiple image sensors disposed within the focal plane of the lens 402.

[0070] Due to light dispersion within the lens, light traveling along different paths may focus in different areas behind the lens. Conversely, objects disposed at different distances from



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the lens may produce in-focus representations at image sensors responding to different light wavelengths. By way of an illustration, light from objects within the distance range 453 may travel along ray paths 454 and produce in focus image on photosite type 444 array. Light from objects within the distance range 455 may travel along ray paths 456 and produce in focus image on photosite type 446 array. Light from objects within the distance range 457 may travel along ray paths 452 and produce in focus image on photosite type 442 array. Accordingly, the optical apparatus comprising one or more image sensors operating at multiple wavelengths may be capable of providing distance information for objects located at different distance from the lens. Although chromatic aberration is known in the arts, most modern lenses are constructed such as to remove or minimize effects of chromatic aberration. Such achromatic and/or apochromatic lenses may be quite costly, heavy, and/or large compared to simpler lenses with chromatic aberration. The methodology of the present disclosure may enable use of simpler, less costly, and/or more compact lens designs for detecting objects compared to existing approaches.

[0071] FIG. 4D illustrates an extended range distance detection apparatus comprising multiple detectors, according to one or more implementations.

[0072] The apparatus 480 of FIG. 4B may comprise a lens 402, and multiple image sensors 482, 484, 486. Individual image sensors 482, 484, 486 may be configured to respond to light of one or more wavelengths. Individual image sensors 482, 484, 486 may be disposed at different optical distances from the lens 402. In some implementations, such as shown in FIG. 4D, one or more light deflection components may be used in order to divert a portion of light gathered by the lens into two or more portions. In one or more implementations, the components 488, 490 may comprise a beam splitter, a polarizing prism, and/or a thin half-silvered mirror (pellicle mirror).

[0073] By way of an illustration, a portion of the light from the lens 402 may be diverted by semi-permeable mirror 488 along direction shown by arrow 496 towards the sensor 486 while a portion 492 of light may be passed through towards the sensor 482. All or a portion of the light from the lens 402 may be diverted by the semi-permeable mirror 490 along direction shown by arrow 494 towards the sensor 484. A portion 492 of the incident light may be passed through towards the sensor 482. Cumulative path lengths for light sensed by elements 482, 484, 486 may also be configured different from one another. Accordingly, the light traveling along paths denoted by arrows 481, 483, 485 may correspond to depth of field regions 493, 495, 497 in front

of the lens 402 in FIG. 4D. Optical apparatus comprising multiple image sensors characterized by different light path lengths may be capable of providing detection information for objects located at different distance from the lens.

[0074] FIG. 5A is a block diagram depicting an exemplary object detection apparatus, according to one or more implementations. The apparatus 500 of FIG. 5A may comprise one or more sensors 504 configured to produce one or more pixels corresponding to sensory input 502. In one or more implementations, the sensory input may comprise light gathered by a lens. In one or more implementations of optical distance detection, the sensor component 504 may comprise one or more image sensor components, such as e.g., those described above with respect to FIGS. 3-4D.

[0075] The sensor 504 may provide output 506 comprising one or more pixels. In some implementations, the output 506 may comprise an array of pixels characterized by one or more channels (e.g., R,G,B) and a bit depth (e.g., 8/12/16 bits).

[0076] The output 506 may be high-pass (HP) filtered by the filter component 520. In some implementations, the filter component 520 may be configured to downsample the input 506. The filter component 520 operation may comprise a convolution operation with a Laplacian and/or another sharpening kernel, a difference of Gaussian operation configured to reduce low frequency energy, a combination thereof, and/or other operations configured to reduce low frequency energy content. In some implementations, the filter component 520 may be configured as described below with respect to FIGS. 6A.

[0077] In some implementations, the output 506 might be cropped prior to further processing (e.g., filtering, and/or transformations). Multiple crops of an image in the output 506 (performed with different cropping setting) may be used. In some implementations crops of the high-passed image may be utilized. In some implementations, the output 506 may be processed using a band-pass filter operation. The band pass filter may comprise a high-pass filtering operation, subsampling, and/or a blurring filter operation. The blurring filter operation on an image may comprise a convolution of a smoothing kernel (e.g., Gaussian, box, circular, and/or other kernel whose Fourier transform has most of energy in a low part of spectrum) with the image.

[0078] Filtered output 508 may be provided to a processing component 522 configured to execute a detection process. The detection process may comprise determination of a parameter,

quantity, or other value, such as e.g., a contrast parameter. In one or more implementations, the contrast parameter may be configured based on a maximum absolute deviation (MAD) of pixels within the filtered image from a reference value. The reference value may comprise a fixed pre-computed value, an image mean, image median, and/or a value determined using statistics of multiple images. In some implementations, the contrast parameter for a plurality of images value may be low-pass filtered using a running mean, an exponential filter, and/or other filter approach configured to reduce inter-image variability of the detection process, or accomplish some other desirable operation to enhance detection. The averaging window may be configured in accord with requirements of a given application. By way of an illustration, a detection apparatus configured to detect objects in a video acquired at 25 fps from a robotic rover device may utilize averaging window between 2 and 50 frames. It will be appreciated by those skilled in the arts that averaging parameters may be configured based on requirements of an applications, e.g., vehicle speed, motion of objects, object size, and/or other parameters. For autonomous ground vehicle navigation the averaging window may be selected smaller than 2 seconds.

[0079] The contrast parameter may be evaluated in light of one or more detection or triggering criteria; e.g., compared to a threshold, and/or analysis of a value produced by the contrast determination process. Responsive to the contrast parameter for a given image breaching the threshold (e.g., 604, 624 in FIGS. 6A-6B, below), the processing component 522 may produce output 510 indicative of a presence of an object in the sensory input 500. In one or more implementations, the threshold value may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. By way of an illustration, the threshold may be configured to provide greater sensitivity at dusk/dawn, and reduce sensitivity during the day and/or increase sensitivity in high light conditions, while reducing sensitivity in low light conditions.

[0080] FIG. 5B illustrates an exemplary object detection apparatus, according to one or more implementations. The apparatus 530 of FIG. 5B may comprise one or more sensors 504 configured to produce output 536 comprising one or more pixels corresponding to sensory input 502. In one or more implementations, the sensory input may comprise light gathered by a lens. In one or more implementations of optical distance detection, the sensor component 504 may comprise one or more image sensor components described above with respect to FIGS. 3-4D. The output 536 may comprise an array of pixels characterized by one or more channels (e.g.,

R,G,B) and a bit depth (e.g., 8/12/16 bits).

[0081] The output 536 may be processed by a processing component 538. In some implementations, the component 538 may be configured to assess spatial and/or temporal characteristics of the camera component output 536. In some implementations, the assessment process may comprise determination of a two-dimensional image spectrum using, e.g., a discrete Fourier transform described below with respect to FIG. 6B. The resultant spectrum may be analyzed to evaluate high-frequency (small scale) energy content. In some implementations, the high frequency energy content determination may comprise a determination of energy parameter (Ehi) associated with energy content in the image spectrum at spatial scales that are lower than 0.5-2/3 of the Nyquist frequency (3-10) pixels.

[0082] Responsive to a determination that the high frequency (small spatial scale) energy content in the image meets one or more criteria (e.g., breaches a threshold), the processing component 538 may produce output 540 indicative of a presence of an object in the sensory input 502. In one or more implementations, the threshold value may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[0083] In one or more implementations, the object detection may be effectuated based on a comparison of the Ehi parameter to another energy parameter (El) associated with energy content in the image spectrum at spatial scales that exceed a prescribed number of pixels.

[0084] In one or more implementations, processing components 520, 522, 524, 538 may be embodied within one or more integrated circuits, one or more computerized devices, and/or implemented using machine executable instructions (e.g., a software library) executed by one or more processors and/or ASICs.

[0085] FIGS. 6A-8B illustrate operation of object detection system of the disclosure configured in accordance with one or more implementations.

[0086] One or more images may an acquired using, e.g. a camera component 504 shown and described with respect to FIG. 5A mounted on a vehicle (e.g., a robotic vehicle 100 such as that shown in FIG. 1). The vehicle may approach an object (e.g., a flower). FIGS. 7A-7B present two exemplary images acquired with a camera apparatus comprising a lens (e.g., 302 in FIG. 2) characterized by an exemplary f/1.8 aperture and 35 mm focal length, and an imaging sensor (e.g., 304 in FIG. 2) characterized by dimensions of 23.1 mm by 15.4 mm. The image sensor may comprise an array of photosites and be characterized by a physical resolution (e.g.,

6,016 x 4,000) of photosites. The image sensor may produce an image comprising an array of pixels. Individual pixels may correspond to signal associated with a given photosite (raw resolution) or a group of photosites (subsampled image). Images provided by the sensor may be down-sampled to e.g., 320 pixels×180 pixels rectangle and converted to greyscale 8-bit representation. Various other resolutions, bit depths and/or image representations may be utilized. The pixels dimension may determine the smallest resolvable spatial scale (e.g., smallest change) in the image. For example, smaller pixels may enable resolving of smaller scales (higher detail) in the image.

[0087] Image 700 in FIG. 7A represents the down-sampled image comprising an out of-focus representation of the object (e.g., the flower), denoted by arrow 702. Image 720 in FIG. 7B represents the down-sampled image comprising an in-focus representation 722 of the flower.

[0088] The images may be high-pass processed by a filtering operation. The filtering operation may comprise determination of a Gaussian blurred image using a Gaussian kernel. In the implementation illustrated in FIGS. 6A-7B the Gaussian kernel standard deviation is selected equal to 5 pixels in vertical and horizontal dimensions. It may be appreciated by those skilled in the relevant arts that the image acquisition and/or processing parameters (e.g., bit depth, down-sampled image size, Gaussian kernel, and/or other parameters) may be configured in accordance with application requirements; e.g., expected object size, processing and/or energy capacity available for object detection, image sensor size, resolution, frame rate, noise floor, and/or other parameters.

[0089] In one or more implementations, the high-passed image Ih may be obtained by subtracting Gaussian blurred image Ig from the original image I, as follows:

$$Ih = I + m - Ig \qquad \text{(Eqn.2)}$$

where m denotes an offset value. In some implementations (e.g., such as illustrated in FIGS. 6A, 7A-7B), the offset m may be selected equal to a middle value of the grayscale brightness level (e.g., 128).

[0090] Panels 710, 740 FIGS. 7A-7B, respectively, depict output of the filtering operation of Eqn.. As may be observed in FIG. 7A, image of panel 710 (corresponding to the out



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of focus image of panel 700) is substantially void of high frequency content (e.g., the location 712 corresponding to the representation of the flower does not contain readily discernable feature(s)). As may be observed in FIG. 7B, the image of panel 740 (corresponding to the in-focus image of panel 720) comprises a plurality of high frequency features (e.g., the flower representation the location 732 may be readily discerned from the grey background).

[0091] In order to obtain a quantitative measure of an object presence in a given image (e.g., 720 in FIG. 7B), the corresponding high–pass filtered image (e.g., 740 in FIG. 7B) may be analyzed. The analysis may comprise for instance determination of deviation of pixel values from the mean intensity value within the image (e.g., 128 in some implementations of 8-bit greyscale images). In some implementations, the analysis may comprise determination of a contrast parameter configured based on a maximum of absolute deviation of a pixel value within the image from the image median value. In some implementations, the contrast parameter may be low-pass filtered using a running mean, an exponential filter, and/or other filter approach configured to reduce frame-to-frame variability. The exemplary filtered contrast parameter data shown by curve 602 in FIG. 6A were obtained using a running mean window of 25 frames in width, although it is appreciated that other values may readily be used consistent with the present disclosure. Temporal filtering may be employed in order to reduce number of false positives generated e.g. by thermal noise on the detector, camera shake, and/or other sources of noise.

[0092] The contrast parameter for a given image may be evaluated in light of one or more criteria (e.g., compared to a threshold) in order to determine presence of an object in the associated image. FIG. 6A illustrates contrast parameter values (curve 602) obtained for a plurality of images and the corresponding detection output (curve comprising portions 614, 616, 618. Data shown by curve 602 may correspond to output 510 of the component 522 of the detection the apparatus 500 of FIG. 5A. Data shown by segments 614, 616, 618 may correspond to output 512 of the apparatus 500 of FIG. 5A.

[0093] Detection threshold used for determining the presence of an object is shown by broken line 604 in FIG. 6A. In one or more implementations, the threshold value 604 may be selected and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. Values of the curve 602 that fall in the range 608 below the threshold 604 may cause a negative detection signal (e.g., equal to zero as shown by the segments 614, 618 in FIG. 6A). Values of the curve 602 that fall in the range 606 at and/or above the threshold 604

may cause a positive detection signal (e.g., equal to one as shown by segment 616 in FIG. 6A).

[0094] FIGS. 6B and 8A-8B illustrate object detection using of spectral approach to image contrast analysis (by, e.g., the apparatus 530 of FIG. 5B), according to one or more implementations.

[0095] The input image (e.g., image 700, 720) may be transformed using a Fourier transformation, e.g., discrete Fourier transform (DFT), cosine Fourier transform, a Fast Fourier transform (FFT) or other spatial scale transformation. FIG. 8A illustrates a power spectrum of the de-focused image shown in panel 700 of FIG. 7A. FIG. 8B illustrates a power spectrum of the in-focus image shown in panel 720 of FIG. 7B.

[0096] The image spectra may be partitioned into a low-frequency portion and a high frequency portion. In some implementations, e.g., such as illustrated in FIG. 6B, the spectral partitioning may be configured based on an elliptical or circular curve area around the origin (e.g., zero frequency point). In some implementations, e.g., shown in FIG. 6B, the data were obtained using an ellipse with (x,y) axes selected at (37, 65) units of cycles along corresponding axis. Low frequency energy portion Elo may be obtained by determining a sum of power spectral values within the ellipse area. The high frequency energy portion Ehi may be obtained by determining a sum of power spectral values outside the ellipse area.

[0097] Detection of an object in a given image may comprise determination of a contrast parameter for a given image. In some implementations, the contrast parameter may be configured based on a comparison of the high frequency energy portion and the low frequency energy portion. In some implementations, the contrast parameter (C) may be determined based on a ratio or other relationship of the high frequency energy portion and the low frequency energy portion, such as the exemplary relationship of Eqn. 2 below.

$$C = Ehi/Elo \qquad \text{(Eqn. 2)}$$

[0098] The contrast parameter for a given image may be compared to a threshold in order to determine presence of an object in the associated image. FIG. 6B presents the contrast parameter (curve 622) for a series of images acquired by an optical object detection device disposed on a moving platform. The thick segments 634, 636, 638 in FIG. 6B depicts the



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detection output corresponding detection output. Data shown by segments 634, 636, 638 may correspond to output 540 of the component 538 of the detection the apparatus 530 of FIG. 5B.

[0099] The detection threshold used for determining the presence of an object is shown by the broken line 624 in FIG. 6B. In one or more implementations, the threshold value 624 may be selected (e.g., equal one in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters. Values of the contrast parameter of curve 622 that fall in the range 628 below the threshold 624 may cause a negative detection signal (e.g., equal to zero as shown by the segments 634, 638 in FIG. 6B). Values of the curve 622 that fall in the range 626 at and/or above the threshold 624 may cause a positive detection signal (e.g., equal to one as shown by segment 636 in FIG. 6B).

[00100] FIG. 9 illustrates a computerized apparatus for implementing, *inter alia*, object detection in accordance with one or more implementations. The apparatus 900 may comprise a processing module 916 configured to receive sensory input from sensory block 920 (e.g., camera 106 in FIG. 1). The processing module 916 may be configured to implement signal processing functionality (e.g., object detection).

[00101] The apparatus 900 may comprise memory 914 configured to store executable instructions (e.g., operating system and/or application code, raw and/or processed data such as raw image fames, image spectrum, and/or contrast parameter, information related to one or more detected objects, and/or other information).

[00102] In some implementations, the processing module 916 may interface with one or more of the mechanical 918, sensory 920, electrical 922, power components 924, communications interface 926, and/or other components via driver interfaces, software abstraction layers, and/or other interfacing techniques. Thus, additional processing and memory capacity may be used to support these processes. However, it will be appreciated that these components may be fully controlled by the processing module. The memory and processing capacity may aid in processing code management for the apparatus 900 (e.g. loading, replacement, initial startup and/or other operations). Consistent with the present disclosure, the various components of the device may be remotely disposed from one another, and/or aggregated. For example, the instructions operating the detection process may be executed on a server apparatus that may control the mechanical components via a network or a radio connection. In some implementations, multiple mechanical, sensory, electrical units, and/or

other components may be controlled by a single robotic controller via network/radio connectivity.

[00103] The mechanical components 918 may include virtually any type of device capable of motion and/or performance of a desired function or task. Examples of such devices may include one or more of motors, servos, pumps, hydraulics, pneumatics, stepper motors, rotational plates, micro-electro-mechanical devices (MEMS), electroactive polymers, shape memory alloy (SMA) activation, and/or other devices. The sensor devices may interface with the processing module, and/or enable physical interaction and/or manipulation of the device.

[00104] The sensory component may be configured to provide sensory input to the processing component. In some implementations, the sensory input may comprise camera output images.

[00105] The electrical components 922 may include virtually any electrical device for interaction and manipulation of the outside world. Examples of such electrical devices may include one or more of light/radiation generating devices (e.g. LEDs, IR sources, light bulbs, and/or other devices), audio devices, monitors/displays, switches, heaters, coolers, ultrasound transducers, lasers, and/or other electrical devices. These devices may enable a wide array of applications for the apparatus 900 in industrial, hobbyist, building management, medical device, military/intelligence, and/or other fields.

[00106] The communications interface may include one or more connections to external computerized devices to allow for, *inter alia*, management of the apparatus 900. The connections may include one or more of the wireless or wireline interfaces discussed above, and may include customized or proprietary connections for specific applications. The communications interface may be configured to receive sensory input from an external camera, a user interface (e.g., a headset microphone, a button, a touchpad, and/or other user interface), and/or provide sensory output (e.g., voice commands to a headset, visual feedback, and/or other sensory output).

[00107] The power system 924 may be tailored to the needs of the application of the device. For example, for a small hobbyist robot or aid device, a wireless power solution (e.g. battery, solar cell, inductive (contactless) power source, rectification, and/or other wireless power solution) may be appropriate. However, for building management applications, battery backup/direct wall power may be superior, in some implementations. In addition, in some

implementations, the power system may be adaptable with respect to the training of the apparatus 900. Thus, the apparatus 900 may improve its efficiency (to include power consumption efficiency) through learned management techniques specifically tailored to the tasks performed by the apparatus 900.

[00108] FIGS. 10-12 illustrate methods 1000, 1100, 1130, 1200 for determining and using object information from images. The operations of methods 1000, 1100, 1130, 1200 presented below are intended to be illustrative. In some implementations, methods 1000, 1100, 1130, 1200 may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. Additionally, the order in which the operations of method 1000, 1100, 1130, 1200 are illustrated in FIGS. 10-12 and described below is not intended to be limiting.

[00109] In some implementations, methods 1000, 1100, 1130, 1200 may be implemented in one or more processing devices (e.g., a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information). The one or more processing devices may include one or more devices executing some or all of the operations of methods 1000, 1100, 1130, 1200 in response to instructions stored electronically on an electronic storage medium. The one or more processing devices may include one or more devices configured through hardware, firmware, and/or software to be specifically designed for execution of one or more of the operations of methods 1000, 1100, 1200, 1300.

[00110] FIG. 10 illustrates a method of determining presence of an object in an image using image contrast information in accordance with one or more implementations.

[00111] At operation 1002 of method 1000, one or more input images may be acquired. In one or more implementations, individual images may be provided by an optical apparatus (e.g., 200 of FIG. 2) comprising a lens and an image sensor (e.g., CCD, CMOS device, and/or APS, photodiode arrays, and/or other image sensors). In some implementations, the input images may comprise a pixel stream downloaded from a file, such as a stream of two-dimensional matrices of red green blue RGB values (e.g., refreshed at a 25 Hz or other suitable frame rate). It will be appreciated by those skilled in the art when given this disclosure that the above-referenced image parameters are merely exemplary, and many other image representations (e.g., bitmap, luminance-chrominance YUV, YCbCr, grayscale, and/other image representations)

may be applicable to and useful with the various implementations. The images may form real-time (live) video.

[00112] At operation 1004, image contrast parameter may be determined. In one or more implementations, the contrast parameter determination may be effectuated by a processing apparatus (e.g., the apparatus described with respect to FIGS 5A-5B) using an image-domain based approach (e.g., such as described with respect to FIG. 6A), an image spectrum domain based approach (e.g., such as described with respect to FIG. 6B and/or Eqn. 2), and/or other applicable methodologies. In some implementations, (e.g., such as described with respect to FIG. 6A, the contrast parameter for a given image may be obtained using a smoothing operation (e.g., based on a block averaging filter, exponential filter, and/or other operation configured to reduce variability of the contrast parameter from one image to another).

[00113] At operation 1006, a determination may be made as to whether the parameter(s) of interest meet the relevant criterion or criteria (e.g., the contrast parameter is within detection range). In some implementations, the determination of operation 1006 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIGS 6A-6B. In one or more implementations, the threshold value may be selected (e.g., equal one in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00114] Responsive to a determination at operation 1006 that the contrast parameter is within the detection range (e.g., breached the threshold), the method 1000 may proceed to operation 1008 wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller.

[00115] FIG. 11A illustrates a method of image analysis useful for object detection by an optical apparatus, in accordance with one or more implementations. The operations of method 1100 may be performed by an optical object detection apparatus (e.g., such as that of FIGS. 2-5A) disposed on, e.g., a mobile robotic device.

[00116] At operation 1102, an image may be obtained. In some implementations, the image may comprise a 2-array of pixels characterized by one or more channels (grayscale, RGB, and/or other representations) and/or pixel bit depth.

[00117] At operation 1104, the obtained image may be evaluated. In some implementations, the image evaluation may be configured to determine a processing load of an image analysis apparatus (e.g., components of the apparatus 500, 530 of FIGS. 5A-5B, and/or 916 of FIG. 9, described above). The evaluation may comprise re-sampling (e.g., down sampling/up-sampling) the image to a given reference resolution. By way of an illustration, an image analysis component may comprise an ASIC configured to accept images of a given resolution (e.g., 320x180 pixels, 640x360 pixels, and/or other resolution). The operation 1104 may be configured to adapt the input image into a compatible resolution. In some implementations, the image evaluation operation may comprise modification of image bit depths (e.g., from 12 to 8 bits), and/or a channel combination operation e.g., configured to produce a grayscale image from RGB image.

[00118] At operation 1106 a high-passed version of the image produced by operation 1104 may be obtained. In one or more implementations, the high–pass filtered image version may be produced using a filter operation configured based on a convolution operation with a Laplacian, a difference of Gaussian operation, a combination thereof, and/or other operations. In some implementations, filter operation may be configured based on a hybrid kernel determined using a convolution of the Gaussian smoothing kernel with the Laplacian kernel. The hybrid kernel may be convolved with the image produced by operation 1104 in order to obtain the high-pass filtered image version. In some implementations of down-sampling and high-pass filtering, the image may be convolved with the processing kernel at a subset of locations in the image corresponding to the subsampling parameters, by applying the kernel on a grid of n pixels, where n is the down-sampling parameter.

[00119] At operation 1108, a contrast parameter of the high–pass filtered image may be determined. In one or more implementations, the contrast parameter determination may be effectuated by the processing component 522 of the apparatus 500 described with respect to FIG. 5A using an image-domain based approach. The contrast parameter determination using the image-domain based approach may comprise determination of a maximum absolute deviation of individual pixel values within the filtered image from a reference value. The reference value may comprise a fixed pre-computed value, an image mean, image median, and/or a value determined using statistics of multiple images. In some implementations, the contrast parameter for a plurality of images value may be low-pass filtered using a running mean, an exponential

filter, and/or other filter approach configured to reduce inter-image variability of the detection process.

[00120] At operation 1110, a determination may be made as to whether the contrast parameter may fall within detection range. In some implementations, the determination of operation 1110 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIG 6A. In one or more implementations, the threshold value may be selected (e.g., equal to 12% of the maximum deviation as in FIG. 6A) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00121] Responsive to a determination at operation 1110 that the contrast parameter may be within the detection range (e.g., breached the threshold), the method 1100 may proceed to operation 1112 wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller, an alert indication to a user, and/or to another entity.

[00122] FIG. 11B illustrates a method of image analysis useful for object detection by an optical apparatus, in accordance with one or more implementations. Operations of method 1130 may be performed by an optical object detection apparatus (e.g., of FIGS. 2-4D, 5B) disposed on a mobile robotic device.

[00123] At operation 1122 an image may be obtained. In some implementations, the image may comprise a 2-array of pixels characterized by one or more channels (grayscale, RGB, and/or other representations) and/or pixel bit depth.

[00124] At operation 1124, the image may be evaluated. In some implementations, the image evaluation may be configured to determine a processing load of an image analysis apparatus (e.g., components of the apparatus 530 of FIGS. 5B, and/or 916 of FIG. 9, described above). The evaluation may comprise re-sampling (e.g., down sampling/up-sampling) the image to a given reference resolution. By way of an illustration, an image analysis component may comprise an ASIC configured to accept images of a given resolution (e.g., 320x180 pixels, 640x360 pixels, and/or other resolution). The operation 1124 may be configured to adapt the input image into a compatible resolution. In some implementations, the image evaluation

operation may comprise modification of image bit depths (e.g., from 12 to 8 bits), and/or a channel combination operation e.g., configured to produce a grayscale image from RGB image.

[00125] At operation 1126, a spectrum of the image produced by operation 1124 may be obtained. In one or more implementations, the spectrum may be determined using a discrete Fourier transform, and/or other transformation.

[00126] At operation 1128, a contrast parameter of the image may be determined. In one or more implementations, the contrast parameter determination may be effectuated by the processing component 538 of the apparatus 530 described with respect to FIG. 5B using an image spectrum-domain based approach spectral domain based approach (e.g., such as described with respect to FIG. 6B and/or Eqn. 2). The contrast parameter determination using the image spectrum-domain based approach may comprise partitioning of the image spectrum into a low spatial frequency portion and a high spatial frequency portion. In some implementations, the spectrum partitioning may be configured by selecting a first area within e.g., circular, elliptical and/or other shape, around the origin (e.g., zero frequency), and a second area comprising the remaining portion of the spectrum (i.e., outside the ellipse/circle). The contrast image parameter may be determined for instance using a ratio of integral power within the first are to the integral power within the second area. In some implementations of a detection system with sensors elements disposed along multiple dimensions (e.g., as in FIG. 3, FIG. 4A, and/or FIG. 4D, image spectrum analysis may enable determination of objects of one or more orientation. For example, a given detector configuration may be more sensitive to objects of one orientation (e.g., vertical) and less sensitive to objects of another orientation (e.g., horizontal). In some implementations, an asymmetrical Laplacian kernel and/or Gabor type filter may be used to facilitate detection of objects at a target orientation.

[00127] At operation 1130, a determination may be made as to whether the contrast parameter may fall within detection range. In some implementations, the determination of operation 1130 may be configured based on a comparison of the contrast parameter to a threshold, e.g., as shown and described with respect to FIG 6B. In one or more implementations, the threshold value may be selected (e.g., equal one as in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters, as previously described herein.

[00128] Responsive to a determination at operation 1130 that the contrast parameter is



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within the detection range (e.g., breached the threshold) the method 1120 may proceed to operation 1132, wherein an object detection indication may be produced. In some implementations, the object detection indication may comprise a message, a logic level transition, a pulse, a wireless transmission, a voltage, a register value and/or other means configured to communicate the detection indication to, e.g., a robotic controller, an alert indication to a user, and/or to another entity.

[00129] FIG. 12 illustrates a method of executing an action by a robotic vehicle, the action execution configured based on an outcome of object detection methodology of the disclosure, in accordance with one or more implementations.

[00130] At operation 1202, a vehicle (e.g., the vehicle 100 of FIG. 1) may be operated, such as to for example navigate a trajectory. The trajectory navigation may be configured to for instance track and/or acquire video of a subject of interest (e.g., a user) from an aerial vehicle (e.g., a quad-copter), for example as described in U.S. Patent Application Serial Nos. 62/007,311, entitled "APPARATUS AND METHODS FOR TRACKING USING AERIAL VIDEO", filed on June 3, 2014 the foregoing being incorporated herein by reference in its entirety. In some implementations, the vehicle may comprise a robotic device equipped with a learning controller, e.g., such as described in U.S. Patent Application Serial No. 13/842,530, entitled "ADAPTIVE PREDICTOR APPARATUS AND METHODS", filed herewith on March 15, 2013, the foregoing being incorporated herein by reference in its entirety. In some implementations, the trajectory navigation may comprise one or more actions configured to enable landing of the aerial vehicle, e.g., as described in U.S. Patent Application Serial Nos. 14/285,466, entitled "APPARATUS AND METHODS FOR ROBOTIC OPERATION USING VIDEO IMAGERY", filed herewith on May 22, 2014, and/or 14/285,414, entitled "APPARATUS AND METHODS FOR DISTANCE ESTIMATION USING MULTIPLE IMAGE SENSORS", filed on May 22, 2014, each of the foregoing incorporated herein by reference in its entirety.

[00131] At operation 1204, an image of the surrounding may be obtained. In one or more implementation, the image may comprise representation of one or more objects in the surroundings (e.g., the objects 112, 122 in FIG. 1).

[00132] At operation 1206, the image may be analyzed using to obtain contrast parameter. In one or more implementations, the contrast parameter determination may be configured using

an image-domain approach (e.g., described above with respect to FIGS. 5A, 6A, 7A-7B, and/or 11A) or an image spectrum-domain approach (e.g., described above with respect to FIGS. 5B, 6B, 8A-8B, and/or 11B).

[00133] At operation 1208, a determination may be made as to whether an object may be present in the image obtained at operation 1204. In some implementations, the object presence may be determined based on a comparison of the contrast parameter to a threshold; e.g., as shown and described with respect to FIGS 6A-6B. In one or more implementations, the threshold value may be selected (e.g., equal one as in FIG. 6B) and/or configured dynamically based on, e.g., ambient light conditions, time of day, and/or other parameters.

[00134] Responsive to a determination at operation 1208 that the object is present, the method 1200 may proceed to operation 1210, wherein the trajectory may be adapted. In some implementations, the object presence may correspond to a target being present in the surroundings and/or an obstacle present in the path of the vehicle. The trajectory adaptation may comprise alteration of vehicle course, speed, and/or other parameter. The trajectory adaptation may be configured based on one or more characteristics of the object (e.g., persistence over multiple frames, distance, location, and/or other parameters). In some implementations of target approach and/or obstacle avoidance by a robotic vehicle, when a target may be detected, the trajectory adaptation may be configured to reduce distance between the target and the vehicle (e.g., during landing, approaching a home base, a trash can, and/or other action). When an obstacle may be detected, the trajectory adaptation may be configured to maintain distance (e.g., stop), increase distance (e.g., go away), alter course (e.g., turn) in order to avoid collision. In some implementations, target/obstacle discrimination may be configured based on object color (e.g., approach red ball avoid all other objects); object reflectivity (approach bright objects), shape, orientation, and or other characteristics. In some implementations, object discrimination may be configured based on input from other sensors (e.g., RFID signal, radio beacon signal, acoustic pinger signal), location of the robotic device (e.g., when the vehicle is in the middle of a room all objects are treated as obstacles), and/or other approaches.

[00135] Although the above application of the object detection methodology is described for a vehicle navigation application, it will be appreciated by those skilled in the arts that various other implementations of the methodology of the present disclosure may be utilized. By way of an illustration, a security camera device may be used to observe and detect potential intruders

(e.g., based on sudden appearance of objects) and/or detect theft (e.g., based on a sudden disappearance of previously present objects)

[00136] Implementations of the principles of the disclosure may be further applicable to a wide assortment of applications including computer-human interaction (e.g., recognition of gestures, voice, posture, face, and/or other interactions), controlling processes (e.g., processes associated with an industrial robot, autonomous and other vehicles, and/or other processes), augmented reality applications, access control (e.g., opening a door based on a gesture, opening an access way based on detection of an authorized person), detecting events (e.g., for visual surveillance or people or animal counting, tracking).

[00137] A video processing system of the disclosure may be implemented in a variety of ways such as, for example, a software library, an IP core configured for implementation in a programmable logic device(e.g., FPGA), an ASIC, a remote server, comprising a computer readable apparatus storing computer executable instructions configured to perform feature detection. Myriad other applications exist that will be recognized by those of ordinary skill given the present disclosure.

[00138] Although the system(s) and/or method(s) of this disclosure have been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred implementations, it is to be understood that such detail is solely for that purpose and that the disclosure is not limited to the disclosed implementations, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. For example, it is to be understood that the present disclosure contemplates that, to the extent possible, one or more features of any implementation can be combined with one or more features of any other implementation.

WHAT IS CLAIMED IS:

~~1. A non-transitory computer-readable storage medium having instructions embodied thereon, the instructions being executable on a processing apparatus to detect an object in an image by at least:~~

~~producing a high-pass filtered version of the image, the high-pass filtered version comprising a plurality of pixels;~~

~~for at least some of the plurality of pixels, determining a deviation parameter between the value of a given pixel and a reference value; and~~

~~based on the deviation parameter meeting a criterion, providing an indication of the object being present in the image.~~

~~2. The non-transitory medium of Claim 1, wherein:~~

~~the high-pass filtered version of the image is produced based at least on a first convolution operation between a kernel and the image, the kernel characterized by a kernel dimension; and~~

~~the convolution operation is configured to reduce energy-associated spatial scales in the image that are lower than the kernel dimension.~~

~~3. The non-transitory medium of Claim 2, wherein:~~

~~the kernel is configured based at least on a second convolution operation of a first matrix, the first matrix configured based at least on a Laplacian operator, and a second matrix configured based at least on a Gaussian operator; and~~

~~the image is characterized by image dimension, the image dimension exceeding the kernel dimension by at least ten times (10x).~~

~~4. The non-transitory medium of Claim 2, wherein~~

~~the high-pass filtered version of the image is further produced based on a difference between the image and a smoothed version of the image,~~

~~the smoothed version of the image obtained using one or more smoothing operations applied to the image.~~

~~5. The non-transitory medium of Claim 2, wherein~~

~~the reference value comprises a mean or median brightness of the image; and~~

~~the deviation parameter comprises a maximum absolute value of a difference between a given pixel value and the reference value.~~

~~6. The non-transitory medium of Claim 2, wherein the contrast parameter is determined based at least on a temporal average of a plurality of contrast parameters, individual ones of the plurality of contrast parameters corresponding to a plurality of images.~~

~~7. The non-transitory medium of Claim 1, wherein the criterion comprises meeting or exceeding a prescribed threshold.~~

~~8. An optical object detection apparatus comprising:~~

~~a lens characterized by a depth of field range;~~

~~an image sensor configured to provide an image comprising one or more pixels; and~~

~~a logic in communication with the image sensor and configured to:~~

~~evaluate at least a portion of the image to determine an image contrast parameter; and~~

~~produce an object detection indication based on the contrast parameter meeting one or more criteria, the object indication configured to convey presence of the object within the depth of field range.~~

~~9. The apparatus of Claim 8, wherein:~~

~~the image sensor comprises an array of photo-sensitive elements arranged in a plane disposed substantially parallel to the lens; and~~

~~individual pixels being produced by individual ones of the photo-sensitive elements.~~

~~10. The apparatus of Claim 9, wherein:~~

~~the array of photo-sensitive elements comprises elements operable to respond to a first wavelength and a second wavelength of electromagnetic energy;~~

~~the elements operable for the first wavelength are configured to respond to a first object representation disposed at a first distance from the lens; and~~

~~the elements operable for the second wavelength are configured to respond to a second object representation disposed at a second distance from the lens, the second distance being smaller than the first distance.~~

~~11. The apparatus of Claim 8, wherein the image sensor comprises two or more arrays~~

~~of photo-sensitive elements disposed in first and second plane, the first plane being parallel to the lens, the second plane being oblique to the lens.~~

~~12. The apparatus of Claim 8 wherein the image sensor comprises an array of photo-sensitive element s disposed in a plane inclined to the lens.~~

~~13. The apparatus of Claim 8, wherein the image sensor comprises an array of photo-sensitive elements disposed in a plane perpendicular to the lens plane.~~

~~14. The apparatus of Claim 8, wherein:~~

~~image sensor comprises an array of photo sensitive elements arranged in a plane parallel to the lens; and~~

~~the image is characterized by an image dimension, the image dimension corresponding to a first resolvable spatial scale;~~

~~individual pixels of the one or more pixels are characterized by a pixel dimension, the pixel dimension corresponding to a second resolvable spatial scale; and~~

~~the determination of the image contrast parameter comprises:~~

~~determination of a two dimensional distribution of energy content within a plurality of groups of pixels of the image, individual ones of the plurality of groups of pixels characterized by a scale of a plurality of spatial scales;~~

~~partition of the two dimensional distribution into a first portion and a second portion; and~~

~~evaluation of the first portion two dimensional distribution of energy content.~~

~~15. The apparatus of Claim 14, wherein:~~

~~the first resolvable spatial scale comprises a largest spatial scale in the image;~~

~~the first portion comprises an inner portion encompassing the largest spatial scale;~~

~~the two dimensional distribution of energy content comprises a plurality of components corresponding to individual ones of the plurality of spatial scales; and~~

~~evaluation of the inner portion comprises a comparison of a first sum of components within the inner portion to a second sum of components within the second portion of the two dimensional distribution.~~

~~16. The apparatus of Claim 14, wherein:~~

~~the determination of a two dimensional distribution of energy content is based at least in part on performance of a two dimensional Fourier transform operation on the image;~~

~~partition of the distribution is configured based on a curve in scale space characterized by a range from the first resolvable spatial scale; and~~

~~evaluation of the first portion comprises a determination of a ratio of a first sum of components within the first portion to a second sum of components within the second portion of the two dimensional distribution.~~

~~17. The apparatus of Claim 8, wherein the determination of the image contrast parameter comprises:~~

~~a determination of a high-pass filtered version of the image configured based on a convolution operation between a kernel and the image, the high passed version comprising a plurality of pixels; and~~

~~for a given pixel of the plurality of pixels, a determination of a deviation parameter between value of the given pixel and a reference value.~~

~~18. A method of navigating a trajectory by a robotic apparatus comprising a controller, an actuator and a sensor, the method comprising:~~

~~obtaining at least one image associated with surroundings of the apparatus using the sensor;~~

~~analyzing the at least one image to determine a contrast parameter of the image;~~

~~detecting a presence of an object in the at least one image based at least in part on the contrast parameter meeting one or more criteria; and~~

~~causing the controller to activate the actuator based on the detection of the presence of the object;~~

~~wherein the actuator activation is configured consistent with a characteristic of the object.~~

~~19. The method of Claim 18, wherein:~~

~~the robotic device comprises a vehicle;~~

~~the object comprises one of a target or an obstacle; and~~

~~the actuator activation is configured to cause the vehicle to perform at least one of a target approach or obstacle avoidance action.~~

~~20. The method of Claim 19, wherein:~~

~~the object characteristic comprises a distance of the camera to the object;~~

~~for the target approach action the actuator activation is configured to reduce the distance; and~~

~~for the obstacle avoidance action the actuator activation is configured to increase the distance.~~

~~21. The method of Claim 19, wherein:~~

~~the trajectory is characterized by motion direction;~~

~~the object characteristic comprises object location with respect to the camera;~~

~~for the target approach action the actuator activation is configured to adjust the motion towards the location; and~~

~~for the obstacle avoidance action the actuator activation is configured to adjust the motion away the location.~~

~~22. A method of navigating a robotic apparatus comprising a controller, an actuator and a sensor, the method comprising:~~

~~obtaining at least one image associated with surroundings of the apparatus using the sensor;~~

~~analyzing the at least one image to detect a presence of an object in the at least one image;~~

~~determining that the detected object comprises one of either a target or an obstacle; and~~

~~causing the controller to selectively activate the actuator based on the determination.~~

~~23. The method of Claim 21, wherein the selective activation comprises activation of one or more actions by the actuator which will cause the apparatus to either increase or decrease its proximity to the object.~~

24. (New) A method of navigating a robotic apparatus comprising a controller, an actuator and a sensor, the method comprising:

obtaining at least one image associated with surroundings of the apparatus using the sensor;

analyzing the at least one image to detect a presence of an object in the at least one image;

determining that the detected object comprises one of either a target or an obstacle; and

causing the controller to selectively activate the actuator based on the determination.

# OPTICAL DETECTION APPARATUS AND METHODS

Abstract of the Disclosure

An optical object detection apparatus and associated methods. The apparatus may comprise a lens (e.g., fixed-focal length wide aperture lens) and an image sensor. The fixed focal length of the lens may correspond to a depth of field area in front of the lens. When an object enters the depth of field area (e.g., sue to a relative motion between the object and the lens) the object representation on the image sensor plane may be in-focus. Objects outside the depth of field area may be out of focus. In-focus representations of objects may be characterized by a greater contrast parameter compared to out of focus representations. One or more images provided by the detection apparatus may be analyzed in order to determine useful information (e.g., an image contrast parameter) of a given image. Based on the image contrast meeting one or more criteria, a detection indication may be produced.

## *COMBINED DECLARATION AND ASSIGNMENT FOR PATENT APPLICATIONS*

Title of Invention: **OPTICAL DETECTION APPARATUS AND METHODS**

As a below named inventor (hereinafter designated as the undersigned), I hereby declare that:

This declaration is directed to the application attached hereto. If the application is not attached hereto, the application is as identified by the attorney docket number as set forth above and/or the following:

U.S. Application Serial No.: 14/321,736; or
PCT International Application No.: _____
Filed on: July 1, 2014.

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 information which is material to patentability as defined in Title 37, Code of Federal Regulations § 1.56.

WHEREAS, the undersigned has invented certain new and useful improvements described in the application identified.

WHEREAS, **BRAIN CORPORATION**, with its principal place of business at 3611 Valley Centre Drive, Suite 400, San Diego, CA 92130, its heirs, successors, legal representatives and assigns (hereinafter designated as the Assignee) is desirous of acquiring the entire right, title and interest in and to said invention and in and to any Letters Patent(s) that may be granted therefor in the United States of America and in any foreign countries.

NOW, THEREFORE, for good and valuable consideration, the receipt and sufficiency of which is hereby acknowledged, the undersigned has sold, assigned and transferred, and by these presents does (do) sell, assign and transfer unto said Assignee the full and exclusive right to the said invention in the United States of America, its territories, dependencies and possessions and the entire right, title and interest in and to any and all Letters Patent(s) which may be granted therefor in the United States of America, its territories, dependencies and possessions, and if the box above is designated, in any and all foreign countries; and to any and all divisions, reissues, re-examinations, continuations, conversions and extensions thereof, and provisional applications to which priority is claimed therefrom, for the full term or terms for which the same may be granted.

The undersigned agrees to execute all papers necessary in connection with this application and any continuing, divisional, conversion, re-exam, provisional, or reissue applications thereof and also to execute separate assignments in connection with such applications as the Assignee may deem necessary or expedient.

The undersigned agrees to execute all papers necessary in connection with any interference which may be declared concerning this application or continuation, division, conversion, re-exam, provisional, or reissue thereof or Letters Patent(s) or reissue patent issued thereon and to cooperate with the Assignee in every way possible in obtaining and producing evidence and proceeding with such interference.

## *COMBINED DECLARATION AND ASSIGNMENT FOR PATENT APPLICATIONS*

The undersigned agrees to execute all papers and documents and to perform any act which may be necessary in connection with claims or provisions of the International Convention for the Protection of Industrial Property or similar agreements.

The undersigned agrees to perform all affirmative acts which may be necessary to obtain a grant of (a) valid United States of America patent(s) or a grant of (a) valid United States of America and any foreign patent(s) to the Assignee and to vest all rights therein hereby conveyed to said Assignee as fully and entirely as the same would have been held by the undersigned if this Assignment and sale had not been made.

The undersigned hereby authorizes and requests the Patent and Trademark Office Officials in the United States of America and in any foreign countries to issue any and all Letters Patent(s) resulting from said application or any continuing, divisional conversion or reissue applications thereof to the said Assignee, as Assignee of the entire interest, and hereby covenants that he has the full right to convey the entire interest herein assigned, and that he has not executed, and will not execute, any agreement in conflict herewith.

The undersigned hereby grants the law firm of GAZDZINSKI & ASSOCIATES, PC, Customer No. **132059**, the power to insert any further identification which may be necessary or desirable in order to comply with the rules of the U.S. Patent and Trademark Office.

The undersigned hereby covenants that no assignment, sale, agreement or encumbrance has been or will be made or entered into which would conflict with this assignment.

The undersigned hereby acknowledges 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.

Executed by the undersigned on the date opposite the undersigned name.

LEGAL NAME OF INVENTOR

Inventor's Name: **FILIP PIEKNIEWSKI** Date: 03.28.2016

Signature: Pieknie

An application data sheet (PTO/AIA/14 or equivalent), including naming the entire inventive entity, must accompany this form. Use a separate form for each inventor; or check the box below and complete the attached page(s) to list additional inventors.

■ Additional inventors are being named on the one (1) supplemental sheet(s) attached hereto.

***SUPPLEMENTAL SHEET FOR COMBINED DECLARATION AND ASSIGNMENT***

LEGAL NAME OF JOINT INVENTOR, IF ANY

Inventor's Name: **VADIM POLONICHKO** Date:_____

Signature:_____

LEGAL NAME OF JOINT INVENTOR, IF ANY

Inventor's Name: **EUGENE IZHIKEVICH** Date: March 30, 2016

Signature: Eugene Izhikevich

*GAZDZINSKI & ASSOCIATES, PC*
*16644 West Bernardo Drive, Suite 201, San Diego, CA 92127*
*Telephone: (858) 675-1670 - Facsimile: (858) 675-1674 - Email: docket@gazpat.com*

Attorney's Docket No. BRAIN.052A/BC201416A

***SUPPLEMENTAL SHEET FOR COMBINED DECLARATION AND ASSIGNMENT***

LEGAL NAME OF JOINT INVENTOR, IF ANY

Inventor's Name: **VADIM POLONICHKO** Date: 26 March 2016

Signature: _____

LEGAL NAME OF JOINT INVENTOR, IF ANY

Inventor's Name: **EUGENE IZHIKEVICH** Date: _____

Signature: _____

*GAZDZINSKI & ASSOCIATES, PC*
*16644 West Bernardo Drive, Suite 201, San Diego, CA 92127*
*Telephone: (858) 675-1670 - Facsimile: (858) 675-1674 - Email: docket@gazpat.com*

PTO/AIA/96 (08-12)
Approved for use through 01/31/2013. OMB 0651-0031
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# STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: Filip Piekniewski, et al.

Application No./Patent No.: 15/845,891 Filed/Issue Date: December 18, 2017

Titled: OPTICAL DETECTION APPARATUS AND METHODS

Brain Corporation, a corporation

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose **one** of options 1, 2, 3 or 4 below):

1. ☑ The assignee of the entire right, title, and interest.

2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):

   ☐ The extent (by percentage) of its ownership interest is _____%. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

   ☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

   Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

   Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (*e.g.*, bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose **one** of options A or B below):

A. ☑ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel 036173, Frame 0091, or for which a copy thereof is attached.

B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

   1. From: _____ To: _____

      The document was recorded in the United States Patent and Trademark Office at

      Reel _____, Frame _____, or for which a copy thereof is attached.

   2. From: _____ To: _____

      The document was recorded in the United States Patent and Trademark Office at

      Reel _____, Frame _____, or for which a copy thereof is attached.



This collection of information is required by 37 CFR 3.73(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 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, 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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PTO/AIA/96 (08-12)
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## STATEMENT UNDER 37 CFR 3.73(c)

3. From: _____ To: _____

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6. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

☐ Additional documents in the chain of title are listed on a supplemental sheet(s).

☑ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

| /Peter J. Gutierrez, III/ | June 11, 2018 |
|---|---|
| Signature | Date |
| Peter J. Gutierrez, III | 56,732 |
| Printed or Typed Name | Title or Registration Number |

PTO/AIA/80 (07-12)
Approved for use through 11/30/2014. OMB 0651-0035
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# POWER OF ATTORNEY TO PROSECUTE APPLICATIONS BEFORE THE USPTO

I hereby revoke all previous powers of attorney given in the application identified in the attached statement under 37 CFR 3.73(c).

I hereby appoint:

☒ Practitioners associated with Customer Number: 132059

OR

☐ Practitioner(s) named below (if more than ten patent practitioners are to be named, then a customer number must be used):

| Name | Registration Number | Name | Registration Number |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

As attorney(s) or agent(s) to represent the undersigned before the United States Patent and Trademark Office (USPTO) in connection with any and all patent applications assigned only to the undersigned according to the USPTO assignment records or assignments documents attached to this form in accordance with 37 CFR 3.73(c).

Please change the correspondence address for the application identified in the attached statement under 37 CFR 3.73(c) to:

☑ The address associated with Customer Number: 132059

OR

☐

| | | | |
|---|---|---|---|
| Firm or Individual Name | | | |
| Address | | | |
| City | | State | Zip |
| Country | | | |
| Telephone | | Email | |

Assignee Name and Address: Brain Corporation
9401 Waples Street, Suite 100
San Diego, CA 92121

**A copy of this form, together with a statement under 37 CFR 3.73(c) (Form PTO/AIA/96 or equivalent) is required to be Filed in each application in which this form is used. The statement under 37 CFR 3.73(c) may be completed by one of The practitioners appointed in this form, and must identify the application in which this Power of Attorney is to be filed.**

**SIGNATURE of Assignee of Record**

The individual whose signature and title is supplied below is authorized to act on behalf of the assignee

| | | | |
|---|---|---|---|
| Signature | Eugene Izhikevich | Date | 9/2/2016 |
| Name | Dr. Eugene M. Izhikevich | Telephone | |
| Title | Co-founder, Chairman, and CEO of Brain Corporation | | |

This collection of information is required by 37 CFR 1.31, 1.32 and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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# Electronic Patent Application Fee Transmittal

| | |
|---|---|
| **Application Number:** | 15845891 |
| **Filing Date:** | 18-Dec-2017 |
| **Title of Invention:** | OPTICAL DETECTION APPARATUS AND METHODS |
| **First Named Inventor/Applicant Name:** | Filip Piekniewski |
| **Filer:** | Peter John Gutierrez III/Christine McGaw |
| **Attorney Docket Number:** | BRAIN.052C1/BC201416C1 |

Filed as Small Entity

**Filing Fees for Utility under 35 USC 111(a)**

| Description | Fee Code | Quantity | Amount | Sub-Total in USD($) |
|---|---|---|---|---|
| **Basic Filing:** | | | | |
| UTILITY FILING FEE (ELECTRONIC FILING) | 4011 | 1 | 75 | 75 |
| UTILITY SEARCH FEE | 2111 | 1 | 330 | 330 |
| UTILITY EXAMINATION FEE | 2311 | 1 | 380 | 380 |
| **Pages:** | | | | |
| **Claims:** | | | | |
| **Miscellaneous-Filing:** | | | | |
| LATE FILING FEE FOR OATH OR DECLARATION | 2051 | 1 | 80 | 80 |
| **Petition:** | | | | |

| Description | Fee Code | Quantity | Amount | Sub-Total in USD($) |
|---|---|---|---|---|
| **Patent-Appeals-and-Interference:** | | | | |
| **Post-Allowance-and-Post-Issuance:** | | | | |
| **Extension-of-Time:** | | | | |
| Extension - 3 months with $0 paid | 2253 | 1 | 700 | 700 |
| **Miscellaneous:** | | | | |
| | | **Total in USD ($)** | | **1565** |

# Electronic Acknowledgement Receipt

| | |
|---|---|
| **EFS ID:** | 32866491 |
| **Application Number:** | 15845891 |
| **International Application Number:** | |
| **Confirmation Number:** | 1010 |
| **Title of Invention:** | OPTICAL DETECTION APPARATUS AND METHODS |
| **First Named Inventor/Applicant Name:** | Filip Piekniewski |
| **Customer Number:** | 132059 |
| **Filer:** | Peter John Gutierrez III/Christine McGaw |
| **Filer Authorized By:** | Peter John Gutierrez III |
| **Attorney Docket Number:** | BRAIN.052C1/BC201416C1 |
| **Receipt Date:** | 11-JUN-2018 |
| **Filing Date:** | 18-DEC-2017 |
| **Time Stamp:** | 19:50:25 |
| **Application Type:** | Utility under 35 USC 111(a) |

## Payment information:

| | |
|---|---|
| Submitted with Payment | yes |
| Payment Type | DA |
| Payment was successfully received in RAM | $1565 |
| RAM confirmation Number | 061218INTEFSW00007426501423 |
| Deposit Account | 501423 |
| Authorized User | Chrissie McGaw |

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

37 CFR 1.16 (National application filing, search, and examination fees)

37 CFR 1.17 (Patent application and reexamination processing fees)

37 CFR 1.19 (Document supply fees)

37 CFR 1.20 (Post Issuance fees)

37 CFR 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 | Transmittal Letter | Transmittal.pdf | 93262<br>1bc579aed0e2468ada5f14e5bf94e8e06a696488 | no | 2 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| 2 | Applicant Response to Pre-Exam Formalities Notice | Notice.pdf | 106619<br>e84ed455c11ad084adc4d5639500b2046783bc02 | no | 2 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| 3 | Specification | Spec_Clean.pdf | 201384<br>391a533574a97e948ff0a13d06305f0997554643 | no | 33 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| 4 | Specification | Spec_MarkedUp.pdf | 213637<br>d73df8f0265e5446d41adbec64f803b1bfb8fe23 | no | 38 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| 5 | Oath or Declaration filed | DecAndAssign.pdf | 1237368<br>aa1c7a4b5d679ee5aa509c87201b50a292b3a5c7 | no | 4 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| 6 | Assignee showing of ownership per 37 CFR 3.73 | 373_Statement.pdf | 638002<br>d48f96ad3d4544b4a4bb828fc12d8881d6f4e1d5 | no | 2 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 7 | Power of Attorney | POA_Brain.pdf | 483945<br>da07d920c96cba156b8359a4bc79e8e1438f0573 | no | 1 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| 8 | Fee Worksheet (SB06) | fee-info.pdf | 39096<br>fa638d349914f21b98532a43b89a00ef7aed2701 | no | 2 |
| **Warnings:** | | | | | |
| **Information:** | | | | | |
| | | **Total Files Size (in bytes):** | 3013313 | | |

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

**New Applications Under 35 U.S.C. 111**

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

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

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

**New International Application Filed with the USPTO as a Receiving Office**

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

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

| | | |
|---|---|---|
| Applicant | : | Filip Piekniewski, et al. |
| Appl. No. | : | 15/845,891 |
| Filed | : | December 18, 2017 |
| For | : | **OPTICAL DETECTION APPARATUS AND METHODS** |
| Examiner | : | Unknown |
| Group Art Unit | : | Unknown |

**CUSTOMER NO. 132059**

**CERTIFICATE OF ELECTRONIC (EFS-WEB) TRANSMISSION**

I hereby certify that this correspondence is being transmitted via the Office electronic filing system in accordance with 37 C.F.R. § 1.8(a)(1)(i)(C) from the Pacific Time Zone of the United States on the local date shown below.

Date: June 11, 2018

By: /Peter J. Gutierrez, III/
Peter J. Gutierrez, III, Reg. No. 56,732

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

**RESPONSE TO NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION**

Dear Examiner:

Applicant hereby responds to the Notice to File Missing Parts of Nonprovisional Application mailed January 11, 2018, a response to which was due March 11, 2018.

Enclosed please find the following documents:

- ✓ Notice to File Missing Parts (2 pages);
- ✓ Substitute specification (clean version) in thirty-three (33) pages, including new Claim 24 (as submitted in the Preliminary Amendment filed December 18, 2017), and Abstract;
- ✓ Substitute specification (marked-up version) in thirty-eight (38) pages, including new Claim 24 (as submitted in the Preliminary Amendment filed December 18, 2017), and Abstract; and
- ✓ Declaration – USA Patent Application signed by the inventor(s) in compliance with 37 CFR 1.63 (4 pages);

- ✓ 3.73(c) Assignee Statement (2 pages); and
- ✓ Power of Attorney (1 page).
- ✓ A small entity status of this Application under 37 CFR 1.9 and 1.27 has been established by a verified statement previously submitted.
- ✓ Applicant hereby requests a THREE-MONTH extension of time in responding to the Patent Office communication mailed January 11, 2016.

**Applicant submits that the substitute specification (clean version) is in compliance with 37 CFR 1.52, 1.121(B)(3) and 1.125, and that the substitute specification (marked-up version) is in compliance with 37 CFR 1.125(c). Pursuant to 37 CFR 1.125(b), Applicant herein states that the materials included herewith contain no new matter.**

Please charge the amount of $1,565.00 and any other deficiency in fees owed to Deposit Account No. 501423.

Respectfully requested,

GAZDZINSKI & ASSOCIATES, PC

Dated: June 11, 2018

By:/Peter J. Gutierrez, III/

Peter J. Gutierrez, III
Registration No. 56,732
16644 West Bernardo Drive, Suite 201
San Diego, CA 92127
Telephone: (858) 675-1670
Facsimile: (858) 675-1674

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

| | | |
|---|---|---|
| Applicant | : | Filip Piekniewski et al. |
| Appl. No. | : | 15/845,891 |
| Filed | : | December 18, 2017 |
| For | : | **OPTICAL DETECTION APPARATUS AND METHODS** |
| Examiner | : | Unknown |
| Group Art Unit | : | Unknown |

**CUSTOMER NO. 132059**

**CERTIFICATE OF ELECTRONIC (EFS-WEB) TRANSMISSION**

I hereby certify that this correspondence is being transmitted via the Office electronic filing system in accordance with 37 C.F.R. § 1.8(a)(1)(i)(C) from the Pacific Time Zone of the United States on the local date shown below.

Date: June 12, 2018

By: /Peter J. Gutierrez, III/
Peter J. Gutierrez, III, Reg. No. 56,732

## SECOND PRELIMINARY AMENDMENT

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

Dear Sir:

Before a first action on the merits, please amend the above-referenced application as follows:

IN THE CLAIMS

Please cancel Claim 24 without prejudice, and add new Claims 25 – 38 as follows:

1. – 24. (Canceled)

25. (New) A method of navigating an apparatus comprising:

obtaining at least one image associated with surroundings of the apparatus using a sensor, the apparatus comprising a controller, an actuator and the sensor;

analyzing the at least one image to detect a presence of an object in the at least one image;

determining whether the object comprises one of either a target or an obstacle; and

causing the controller to selectively activate the actuator based on the determination.

26. (New) The method of Claim 25, further comprising:

activating the apparatus between a first mode and a second mode upon detection of the object, the object comprising at least one obstacle or target;

activating the first mode upon detection that the object is an obstacle, the first mode corresponds to increasing distance between the object and the apparatus; and

activating the second mode upon detection that the object is a target, the second mode corresponds to navigating the apparatus towards the object.

27. (New) The method of Claim 25, further comprising:

analyzing a plurality of static objects to calibrate the actuator and the sensor based on:

measuring a velocity vector of the apparatus based on images and data generated by the sensor;

calculating the discrepancy between an ideal velocity vector, the ideal velocity vector comprising movement of the apparatus and the measured velocity vector of the apparatus; and

adjusting subsequent actions of the apparatus based on the calculated discrepancy.

28. (New) The method of Claim 27, further comprising:

determining the velocity vector of the apparatus based on:

obtaining, via the sensor, a plurality of images, the plurality of images comprising images of a surrounding environment of the apparatus;

identifying a stationary object or fixed point within the plurality of images from the sensor;

analyzing a first image of the plurality of images to determine a first location of the stationary object at a first duration;

analyzing a second image of the plurality of images to determine a second location of the stationary object at a second duration; and

determining a velocity vector associated with the apparatus based on the difference of the first and second positions of the stationary object in the first and second images.

29. (New) The method of Claim 25, further comprising:

adapting movement of the apparatus based on the velocity vectors of surrounding objects and the apparatus, causing the controller to activate or deactivate the actuator.

30. (New) A non-transitory computer-readable storage medium having computer readable instructions stored thereon, that when executed by at least one processor configure the at least one processor to:

receive data from at least one sensor, the data comprising at least one image of an environment;

analyze an image, from data generated by the at least one sensor, to determine a contrast parameter criterion comprising a deviation parameter, a reference value, and/or threshold associated with object detection;

detect whether an object is present in the image from the contrast parameter meeting or exceeding a predetermined threshold; and

determine a location of the object from the contrast parameter meeting or exceeding the prescribed threshold at the location of the object.

31. (New) The non-transitory computer-readable storage medium of Claim 30, wherein the at least one processor is further configured to execute the computer readable instructions to:

receive data from the at least one sensor, the data comprising dynamic lighting parameters of the environment; and

adjust the prescribed contrast parameter threshold for object detection based on the data

from the at least one sensor.

32. (New) The non-transitory storage medium of Claim 30, wherein the at least one processor is further configured to execute the computer readable instructions to:

determine a contrast parameter criterion comprising a fixed or a dynamic value from statistics of multiple images gathered by the at least one sensor.

33. (New) The non-transitory storage medium of Claim 30, wherein the at least one processor is further configured to execute the computer readable instructions to:

partition a first image into at least two sub-images, the at least two sub-images comprise different energy spectra or regions of the first image; and

apply filtering operations to the at least one of the two sub-images prior to the determination of a contrast parameter criterion.

34. (New) The non-transitory storage medium of Claim 30, wherein the at least one processor is further configured to execute the computer readable instructions to:

apply an asymmetrical filter to the at least one image received from the at least one sensor to facilitate the detection of an object at a target orientation.

35. (New) A method for detection of objects near an apparatus, comprising:

gathering data from at least one sensor, the data comprising at least one image of an environment surrounding the apparatus;

analyzing the at least one image, to determine a contrast parameter comprising a deviation parameter, a reference value, and/or threshold associated with object detection;

determining a fixed or dynamic contrast parameter threshold based on dynamic properties of the environment; and

determining if an object is present in the image from the contrast parameter meeting or exceeding a prescribed threshold.

36. (New) The method of Claim 35, further comprising:

partitioning a first image, from the plurality of images, into at least two sub-images comprising two different energy spectra or regions of the first image; and

applying filtering and/or cropping operations to the at least one of the two sub-images prior to the determination of a contrast parameter criterion.

37. (New) The method of Claim 35, further comprising:

applying an asymmetrical filter to the data from the at least one sensor to facilitate detection of objects at a target orientation.

38. (New) The method of Claim 35, further comprising:

determining a velocity vector associated with an object based on:

obtaining a plurality of data, the data comprising images of a surrounding environment of the apparatus, from at least one sensor;

analyzing a first image of the plurality of images to determine a first location of the object taken at a first duration;

analyzing a second image of the plurality of images for a second location of the object taken at a second duration, the first location being different from the second location; and

determining a velocity vector of the object based on differences in position of the object in the first and second images.

39. (New) The method of Claim 38, further comprising:

detecting a plurality of distinguishable objects in the first and second images;

determining the locations of each of the plurality of objects in both the first and second images; and

determining velocity vectors associated with each of the plurality of objects.

REMARKS

Claim 24 was pending in the application. By this paper, Applicant has canceled Claim 24 without prejudice and added new Claims 25 – 39. Accordingly, Claims 25 – 39 are presented for examination herein.

*New Claim*

Applicant has hereby added new Claims 25 – 39. Support for newly added Claims 25 – 39 may be found at, *inter alia*, originally submitted Claims 1 – 23 of Applicant's specification as filed. Additional support for newly added Claims 25 – 39 may be found at, *inter alia*, paragraphs [0010], [0065], [0078], [0079], [0081], [0096] and [0126] of Applicant's specification as filed. Hence, no new matter has been added by virtue of these newly added claims.

*Other Remarks*

Applicant notes that any claim cancellations or additions made herein are made solely for the purposes of more clearly and particularly describing and claiming the invention. The Examiner should infer no (i) adoption of a position with respect to patentability, (ii) change in the Applicant's position with respect to any claim or subject matter of the invention, or (iii) acquiescence in any way to any position taken by the Examiner, based on such cancellations or additions.

Furthermore, any remarks made with respect to a given claim or claims are limited solely to such claim or claims.

If the Office has any questions or comments which may be resolved over the telephone, he is requested to call the undersigned at (858) 675-1670.

Respectfully submitted,

GAZDZINSKI & ASSOCIATES, PC

Dated: June 12, 2018

By: /Peter J. Gutierrez, III/

Peter J. Gutierrez, III
Registration No. 56,732
Attorney of Record
16644 West Bernardo Drive, Suite 201
San Diego, CA 92127
Telephone No.: (858) 675-1670
Facsimile No.: (858) 675-1674

# Electronic Acknowledgement Receipt

| | |
|---|---|
| **EFS ID:** | 32879375 |
| **Application Number:** | 15845891 |
| **International Application Number:** | |
| **Confirmation Number:** | 1010 |
| **Title of Invention:** | OPTICAL DETECTION APPARATUS AND METHODS |
| **First Named Inventor/Applicant Name:** | Filip Piekniewski |
| **Customer Number:** | 132059 |
| **Filer:** | Peter John Gutierrez III/Brandi Manzano |
| **Filer Authorized By:** | Peter John Gutierrez III |
| **Attorney Docket Number:** | BRAIN.052C1/BC201416C1 |
| **Receipt Date:** | 12-JUN-2018 |
| **Filing Date:** | 18-DEC-2017 |
| **Time Stamp:** | 19:01:18 |
| **Application Type:** | Utility under 35 USC 111(a) |

## Payment information:

| | |
|---|---|
| Submitted with Payment | no |

## File Listing:

| Document Number | Document Description | File Name | File Size(Bytes)/ Message Digest | Multi Part /.zip | Pages (if appl.) |
|---|---|---|---|---|---|
| 1 | Transmittal Letter | Transmittal.pdf | 87201<br>7ae254bf0585443abecd2b632884b7ac50b<br>c530f | no | 2 |

**Warnings:**

| Information: | | | | | |
|---|---|---|---|---|---|
| 2 | Preliminary Amendment | 2ndPrelimAmendment.pdf | 101496<br>1cd5105f4c561c97bb1a826507b7de4a0734c821 | no | 7 |
| Warnings: | | | | | |
| Information: | | | | | |
| | | | Total Files Size (in bytes): | 188697 | |

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

**New Applications Under 35 U.S.C. 111**

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

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

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

**New International Application Filed with the USPTO as a Receiving Office**

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

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

| | | |
|---|---|---|
| Applicant | : | Filip Piekniewski, et al. |
| Appl. No. | : | 15/845,891 |
| Filed | : | December 18, 2017 |
| For | : | **OPTICAL DETECTION APPARATUS AND METHODS** |
| Examiner | : | Unknown |
| Group Art Unit | : | Unknown |

**CUSTOMER NO. 132059**

**CERTIFICATE OF ELECTRONIC (EFS-WEB) TRANSMISSION**

I hereby certify that this correspondence is being transmitted via the Office electronic filing system in accordance with 37 C.F.R. § 1.8(a)(1)(i)(C) from the Pacific Time Zone of the United States on the local date shown below.

June 12, 2018
(Date)

/Peter J. Gutierrez, III/
Peter J. Gutierrez, III, Reg. No. 56,732

**MAIL STOP AMENDMENT**
**COMMISSIONER FOR PATENTS**
**P.O. BOX 1450**
**ALEXANDRIA, VA 22313-1450**

Sir:

Transmitted herewith in the above-entitled application are the following:

(X) Second Preliminary Amendment (7 pages).

(X) A small entity status of this application under 37 CFR 1.9 and 1.27 has been established by a verified statement previously submitted.

The fee has been calculated as shown below:

**CLAIMS AS FILED**

| | CLAIMS REMAINING AFTER AMENDMENT | | HIGHEST NO. PREVIOUSLY PAID FOR | PRESENT EXTRA | RATE | ADDITIONAL FEE |
|---|---|---|---|---|---|---|
| Total Claims | 15 | MINUS | 20 | = 0 X | $ 50 | = $0 |
| Independent Claims | 3 | MINUS | 3 | = 0 X | $230 | = $0 |
| If application has been amended to contain multiple dependent claim(s), then add | | | | | $410 | = $0 |
| Information Disclosure Statement | | | | | $120 | = $0 |
| (Select only one) | | | | one month | $100 | = $0 |
| Time Extension Fees: | | | | two months | $300 | = $0 |
| | | | | three months | $700 | = $0 |
| | | | | **TOTAL ADDITIONAL FEE FOR THIS AMENDMENT** | | **$0** |

(X) The Commissioner is hereby authorized to charge any additional fees under 37 CFR 1.16 and 1.17 which may be required to Deposit Account No. 501423

GAZDZINSKI & ASSOCIATES, PC

Dated: June 12, 2018

By: /Peter J. Gutierrez, III/
Peter J. Gutierrez, III
Registration No. 56,732
16644 West Bernardo Drive, Suite 201
San Diego, CA 92127
Telephone No. (858) 675-1670
Facsimile No. (858) 675-1674

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
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Alexandria, Virginia 22313-1450
www.uspto.gov

| APPLICATION NUMBER | FILING or 371(c) DATE | GRP ART UNIT | FIL FEE REC'D | ATTY.DOCKET.NO | TOT CLAIMS | IND CLAIMS |
|---|---|---|---|---|---|---|
| 15/845,891 | 12/18/2017 | 1722 | 865 | BRAIN.052C1/BC201416C1 | 1 | 1 |

**CONFIRMATION NO. 1010**

**UPDATED FILING RECEIPT**

132059
Gazdzinski & Associates, PC
16644 West Bernardo Drive
Suite 201
San Diego, CA 92127

OC000000100240524

Date Mailed: 06/15/2018

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

**Inventor(s)**

Filip Piekniewski, San Diego, CA;
Vadim Polonichko, San Diego, CA;
Eugene Izhikevich, San Diego, CA;

**Applicant(s)**

Brain Corporation, San Diego, CA;

**Power of Attorney:** The patent practitioners associated with Customer Number 132059

**Domestic Priority data as claimed by applicant**

This application is a CON of 14/321,736 07/01/2014 PAT 9848112

**Foreign Applications** for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
*Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.*

**Permission to Access Application via Priority Document Exchange:** Yes

**Permission to Access Search Results:** Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

**If Required, Foreign Filing License Granted:** 01/10/2018

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 15/845,891**

**Projected Publication Date:** 09/27/2018

**Non-Publication Request:** No

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

OPTICAL DETECTION APPARATUS AND METHODS

**Preliminary Class**

430

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

## PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

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

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

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

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

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

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## Title 35, United States Code, Section 184

## Title 37, Code of Federal Regulations, 5.11 & 5.15

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

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

**NOT GRANTED**

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## PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 15/845,891

### APPLICATION AS FILED - PART I

| FOR | (Column 1) NUMBER FILED | (Column 2) NUMBER EXTRA | 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 | 75 | | N/A | |
| SEARCH FEE (37 CFR 1.16(k), (i), or (m)) | N/A | N/A | N/A | 330 | | N/A | |
| EXAMINATION FEE (37 CFR 1.16(o), (p), or (q)) | N/A | N/A | N/A | 380 | | N/A | |
| TOTAL CLAIMS (37 CFR 1.16(i)) | 1 minus 20 = | * | x 50 = | 0.00 | OR | | |
| INDEPENDENT CLAIMS (37 CFR 1.16(h)) | 1 minus 3 = | * | x 230 = | 0.00 | | | |
| APPLICATION SIZE FEE (37 CFR 1.16(s)) | If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s). | | | 0.00 | | | |
| MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j)) | | | | 0.00 | | | |
| | | | TOTAL | 785 | | TOTAL | |

* If the difference in column 1 is less than zero, enter "0" in column 2.

### APPLICATION AS AMENDED - PART II

| | | (Column 1) CLAIMS REMAINING AFTER AMENDMENT | | (Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR | (Column 3) PRESENT EXTRA | SMALL ENTITY RATE($) | SMALL ENTITY ADDITIONAL FEE($) | OR | OTHER THAN SMALL ENTITY RATE($) | OTHER THAN SMALL ENTITY ADDITIONAL FEE($) |
|---|---|---|---|---|---|---|---|---|---|---|
| AMENDMENT A | 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 | |

| | | (Column 1) CLAIMS REMAINING AFTER AMENDMENT | | (Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR | (Column 3) PRESENT EXTRA | RATE($) | ADDITIONAL FEE($) | OR | RATE($) | ADDITIONAL FEE($) |
|---|---|---|---|---|---|---|---|---|---|---|
| AMENDMENT B | Total (37 CFR 1.16(i)) | * | Minus | ** | = | x = | | OR | x = | |
| | Independent (37 CFR 1.16(h)) | * | Minus | *** | = | x = | | OR | x = | |
| | Application Size Fee (37 CFR 1.16(s)) | | | | | | | | | |
| | FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j)) | | | | | | | OR | | |
| | | | | | | TOTAL ADD'L FEE | | OR | TOTAL ADD'L FEE | |

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.