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October 15, 2015

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APPLICATION NUMBER: 14/509,976
FILING DATE: October 08, 2014
RELATED PCT APPLICATION NUMBER: PCT/US15/54102

THE COUNTRY CODE AND NUMBER OF YOUR PRIORITY APPLICATION, TO BE USED FOR FILING ABROAD UNDER THE PARIS CONVENTION, IS US14/509,976

Certified by

[Signature]

Under Secretary of Commerce
for Intellectual Property
and Director of the United States
Patent and Trademark Office
**TRANSMITTAL FOR POWER OF ATTORNEY TO ONE OR MORE REGISTERED PRACTITIONERS**

**NOTE:** This form is to be submitted with the Power of Attorney by Applicant form (PTO/AIA/82A) to identify the application to which the Power of Attorney is directed, in accordance with 37 CFR 1.5, unless the application number and filing date are identified in the Power of Attorney by Applicant form. If neither form PTO/AIA/82A nor form PTO/AIA/82B identifies the application to which the Power of Attorney is directed, the Power of Attorney will not be recognized in the application.

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<td>First Named Inventor</td>
<td>Huimin Guo</td>
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<tr>
<td>Title</td>
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**SIGNATURE of Applicant or Patent Practitioner**

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<td>/Matt Hall/</td>
<td>October 8, 2014</td>
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<td>Name</td>
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**NOTE:** This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications. If more than one applicant, use multiple forms.

This collection of information is required by 37 CFR 1.131, 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.

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

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

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(Note: The boxes above may be left blank if information is provided on form PTO/AIA/82A.)

☐ I hereby appoint the Patent Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above.

OR

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

Please recognize or change the correspondence address for the application identified in the attached transmittal letter or the boxes above to:

☐ The address associated with the above-mentioned Customer Number

OR

☐ The address associated with Customer Number:

OR

 Firm or Individual Name

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I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

☐ Inventor or Joint Inventor (title not required below)

☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)

☐ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signa’s title if applicant is a juristic entity)

☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signa’s title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Name: Huihua Guo

Signature: [Signature]

Date (Optional):

Title:

NOTE: Signature – This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☐ Total of forms are submitted.

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(Note: The boxes above may be left blank if information is provided on form PTO/AIA/82A.)

☐ I hereby appoint the Patent Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above: 120937

☐ OR

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

Please recognize or change the correspondence address for the application identified in the attached transmittal letter or the boxes above to:

☐ The address associated with the above-mentioned Customer Number

☐ OR

☐ The address associated with Customer Number: [Blank]

☐ OR

Firm or Individual Name [Blank]

Address [Blank]

City [Blank]  State [Blank]  Zip [Blank]

Country [Blank]

Telephone [Blank]  Email [Blank]

I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

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SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature [Signature]

Name Ibrahim Eden

Title [Blank]

Date (Optional) 3/3/2014

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☐ Total of [Blank] forms are submitted.

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120937

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☐ The address associated with Customer Number:

OR

Firm or Individual Name

Address

City State Zip

Country

Telephone Email

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SIGNATURE of Applicant for Patent

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Name Vaibhav Thukral

Title SDE LEAD

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☐ Total of forms are submitted.

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POWER OF ATTORNEY BY APPLICANT

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☐️ The address associated with Customer Number: 

OR

Firm or Individual Name

Address

City State Zip

Country

Telephone Email

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SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature: 

Date (Optional): 1/22/2014

Name: David Zadarski, 

Title: 

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

Total of forms are submitted.

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

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## Payment information:

| **Submitted with Payment**  | yes          |
| **Payment Type**            | Deposit Account |
| **Payment was successfully received in RAM** | $1600 |
| **RAM confirmation Number** | 5664         |
| **Deposit Account**         | 503397       |

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- Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees)
- Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)
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**Warnings:**

- The page size in the PDF is too large. The pages should be 8.5 x 11 or A4. If this PDF is submitted, the pages will be resized upon entry into the Image File Wrapper and may affect subsequent processing.
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.
### Application Data Sheet 37 CFR 1.76

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<th>Title of Invention</th>
<th>GAZE TRACKING THROUGH EYEWEAR</th>
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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 1.78. 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:

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**Mailing Address of Inventor:**

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Inventor 4

Legal Name

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<td>David</td>
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Residence Information (Select One)

- [ ] US Residency
- [ ] Non US Residency
- [ ] Active US Military Service

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Postal Code 98005

Country US

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

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 120937

Email Address

Application Information:

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**Application Data Sheet 37 CFR 1.76**

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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).

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**Publication Information:**

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

**Representative Information:**

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

- Please Select One: ☐ Customer Number ☐ US Patent Practitioner ☐ Limited Recognition (37 CFR 11.9)
  Customer Number: 120937

**Domestic Benefit/National Stage Information:**

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

When referring to the current application, please leave the application number blank.

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

**Foreign Priority Information:**
Application Data Sheet 37 CFR 1.76

Title of Invention | GAZE TRACKING THROUGH EYEWEAR

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

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

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

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

This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.

NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Authorization to Permit Access:

☑ Authorization to Permit Access to the Instant Application by the Participating Offices
**Application Data Sheet 37 CFR 1.76**

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

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

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

**Applicant Information:**

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

**Applicant 1**

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 assignee 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.

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

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### Application Data Sheet 37 CFR 1.76

| Title of Invention | GAZE TRACKING THROUGH EYEWEAR |

### Mailing Address Information:

| Address 1 |  |
| Address 2 |  |
| City | State/Province |
| Country | Postal Code |
| 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.

#### 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 "Assignee Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

Remove

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

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#### 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.
**Application Data Sheet 37 CFR 1.76**

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

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

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.
Privacy Act Statement

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

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

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

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

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

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

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

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

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

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

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.
DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention
GAZE TRACKING THROUGH EYEWEAR
(Docket No. WHG14309)

As the below named inventor, I hereby declare that:

This declaration is directed to:  
☐ The attached application, or
☐ United States application or PCT international application number
________________________________________
filed on ____________________________________.

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

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

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

WARNING:

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

LEGAL NAME OF INVENTOR

Inventor: Huimin Guo

Signature: ________________  Date (Optional): ___09/08/2014____

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

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GAZE TRACKING THROUGH EYEWEAR
(Docket No. WHG14309)

As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

☐ United States application or PCT international application number _______________

filed on ____________________.

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

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

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

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LEGAL NAME OF INVENTOR

Inventor: Ibrahim Eden

Signature: __________________________ Date (Optional): 9/22/2014

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

**Title of Invention**
GAZE TRACKING THROUGH EYEWEAR (Docket No. WHG14309)

As the below named inventor, I hereby declare that:

This declaration is directed to:
- [ ] The attached application, or
- [ ] United States application or PCT international application number __________ filed on __________

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

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

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

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**LEGAL NAME OF INVENTOR**

Inventor: Vaibhav Thukral
Signature: ___________________________
Date (Optional): 10/7/14

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

Title of Invention
GAZE TRACKING THROUGH EYEWEAR (Docket No. WHG14309)

As the below named inventor, I hereby declare that:

This declaration is directed to:
☐ The attached application, or
☐ United States application or PCT international application number __________________________

filed on __________________________

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

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

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LEGAL NAME OF INVENTOR

Inventor: David Zachris Nister

Signature: __________________________

Date (Optional): 9/11/14

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ABSTRACT

A method to furnish input representing gaze direction in a computer system operatively coupled to a vision system. In this method, a first image of an eye at a first level of illumination is acquired by a camera of the vision system. The first image is obtained from the camera, and a second image of the eye corresponding to a second, different level of illumination is also obtained. Brightness of corresponding pixels of the first and second images is compared in order to distinguish a reflection of the illumination by the eye from a reflection of the illumination by eyewear. The input is then furnished based on the reflection of the illumination by the eye.
CLAIMS:

1. Enacted in a computer system operatively coupled to a vision system, a method to furnish input representing gaze direction, the method comprising:
from a camera of the vision system, obtaining a first image of an eye acquired at a first level of illumination;
obtaining a second image of the eye acquired at a second, different level of illumination;
comparing brightness of corresponding pixels of the first and second images to distinguish a reflection of the illumination by the eye from a reflection of the illumination by eyewear; and
furnishing the input based on the reflection of the illumination by the eye.

2. The method of claim 1, wherein the reflection of the illumination by the eye includes a reflection from a retina of the eye, the reflection passing back through a pupil of the eye and causing the pupil to appear bright relative to a surrounding iris in the first image.

3. The method of claim 1, wherein the reflection by the eye includes a reflection by an iris of the eye, causing a pupil of the eye to appear dark relative to the iris in the first image.
4. The method of claim 1, further comprising computing the input based on a location, in the first image, of the reflection of the illumination by the eye, while excluding those pixels associated with the reflection of the illumination by the eyewear.

5. The method of claim 4, further comprising correcting the input based on a kinematic model to account for movement of the eye between obtaining the first and second images.

6. The method of claim 1, wherein obtaining the second image of the eye includes multiplying a brightness of each unsaturated pixel of the first image by a multiplication factor to obtain a corresponding pixel of the second image.

7. The method of claim 1, wherein the input furnished includes an azimuth angle and an elevation angle defining a direction of sight through the eye.

8. The method of claim 1, further comprising:

associating the corresponding pixels of the first and second images with the reflection of the illumination by the eye if the brightness of such pixels differs by more than a threshold amount; and

associating the corresponding pixels of the first and second images with the reflection of the illumination by the eyewear if the brightness of such pixels differs by less than a threshold amount.
9. The method of claim 1, further comprising associating the corresponding pixels of the first and second images with the reflection of the illumination by the eyewear if both pixels are saturated.

10. The method of claim 1, wherein the first level of illumination is selected based on ability to stimulate and distinguish a bright-pupil response from the eye.

11. The method of claim 1, wherein the first level of illumination is selected based on ambient light conditions.

12. The method of claim 1, wherein the first and second images are selected from three or more images of the eye acquired by the camera at mutually different levels of illumination.

13. The method of claim 1, wherein comparing the brightness of the corresponding pixels includes using a machine-learned algorithm to distinguish the reflection of the illumination by the eye from the reflection of the illumination by the eyewear.

14. The method of claim 1, wherein the eye is a first of two eyes, and wherein the first and second images are images of the first eye, the method further comprising:
from a camera of the vision system, obtaining a first image of a second eye acquired at the first level of illumination;

obtaining a second image of the second eye corresponding to the second level of illumination;
comparing brightness of corresponding pixels of the first and second images of the second 
eye to distinguish a reflection of the illumination by the second eye from a reflection 
of the illumination by eyewear; and

furnishing the input based on the reflection of the illumination by the second eye and 
independent of the reflection of the illumination by the eyewear, such input including 
a determined focal point of the first and second eyes.

15. A system comprising:

an illumination system configured to illuminate an eye;

a camera configured to acquire one or more images of the eye; and 

operatively coupled to the camera and the illumination system, a processor and 
associated computer memory, the computer memory holding instructions executable 
by the processor to 

obtain a first image of the eye from the camera, the first image acquired by the 
camera while the illumination system provides a first level of illumination;

obtain a second image of the eye corresponding to a second, different level of 
illumination;

compare brightness of corresponding pixels of the first and second images to 
distinguish a reflection of the illumination by the eye from a reflection of the 
illumination by eyewear; and
furnish input to the computer system based on the reflection of the illumination by the eye and independent of the reflection of the illumination by the eyewear.

16. The system of claim 15, further comprising instructions executable to capture one or more of the first image of the eye and the second image of the eye in multiple exposures.

17. The system of claim 15, wherein the instructions are executable to acquire the first image of the eye and the second image of the eye successively before reading the first image of the eye and the second image of the eye from the camera.

18. The system of claim 15, wherein the lamp is configured to transition from providing the first level of illumination to providing the second level of illumination in thirty milliseconds or less.

19. Enacted in computer system operatively coupled to a vision system, a method to furnish input responsive to gaze direction, the method comprising:

obtaining, from a camera of the vision system, a first image of the eye acquired at a first level of illumination;

obtaining from the camera a second image of the eye acquired at a second, different level of illumination;
comparing brightness of corresponding pixels of the first and second images to distinguish
a reflection of the illumination by the eye from a reflection of the illumination by
eyewear; and

furnishing the input based on the reflection of the illumination by the eye and
independent of the reflection of the illumination by the eyewear.

20. The method of claim 19, wherein the first and second levels of illumination are
provided by a lamp of the vision system, the method further comprising:

adjusting the lamp to provide the first level of illumination prior to obtaining the first
image; and

adjusting the lamp to provide the second level of illumination prior to obtaining the
second image.
GAZE TRACKING THROUGH EYEWEAR

BACKGROUND

[0001] Recent hardware and software advances have enabled new modes of natural user input (NUI) for computer systems. Gesture recognition, voice recognition, and gaze tracking are example NUI modes, which enable a user to interact intuitively with computer systems for various purposes and in various environments.

SUMMARY

[0002] Embodiments are disclosed that relate to distinguishing reflections from an eye and reflections from eyewear in an eye tracking system. One disclosed embodiment provides a method to furnish input representing gaze direction in a computer system operatively coupled to a vision system. In this embodiment, a first image of an eye at a first level of illumination is acquired by a camera of the vision system. The first image is obtained from the camera, and a second image of the eye corresponding to a second, different level of illumination is also obtained. Brightness of corresponding pixels of the first and second images is compared in order to distinguish a reflection of the illumination by the eye from a reflection of the illumination by eyewear. The input is then furnished based on the reflection of the illumination by the eye.

[0003] This Summary is provided to introduce a selection of concepts in simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it
intended to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 shows aspects of an example environment in which a user’s gaze is tracked and used as input in a computer system.

[0005] FIG. 2 shows aspects of an example computer system with an NUI system operatively coupled to a vision system.

[0006] FIG. 3 shows aspects of an example vision system configured for gaze detection.

[0007] FIG. 4A shows an example image of a user’s eyes obtained at a HIGH level of illumination.

[0008] FIG. 4B shows an example image of a user’s eyes obtained at a LOW level of illumination.

[0009] FIG. 4C shows an example result of excluding, from the image of FIG. 4A, reflections from the user’s eyewear.

[0010] FIG. 5 shows aspects of additional example environments where a user’s gaze is tracked and used as input in a computer system.

[0011] FIG. 6 shows aspects of another example vision system configured for gaze detection.
FIG. 7 illustrates an example method to furnish input responsive to gaze direction in a computer system.

DETAILED DESCRIPTION

[0013] Gaze tracking is a form of NUI based on the direction of a user’s gaze. In this approach, an image of the user’s eye is acquired by a camera. Ocular features such as the pupil or limbus are located in the acquired image, and the gaze direction is computed based on the locations of such features. Gaze direction computed in this manner may be used to navigate a graphical user-interface, to launch a program, make a selection, move a character in a game, and so on. Although the desired ocular features may be identified in images of the naked eye, stray reflections from eyewear may be a source of interference. Such interference may reduce the accuracy of gaze-tracking input for users with eyewear. As used herein, the term ‘eyewear’ includes any type of appliance worn that places a see-through structure between the eye and at least a portion of a field of view of the eye. Examples include, but are not limited to, eyeglasses, sunglasses, visors, masks, goggles, contact lens systems and other on-eye devices, near-eye display systems that project virtual imagery in the wearer’s field of view, etc.

[0014] Examples are disclosed herein that may help to distinguish reflections of light from the naked eye and reflections of light from eyewear, and thus may facilitate eye tracking. FIG. 1 shows aspects of an example environment 10 in which a user’s gaze is tracked and used as input in a computer system. The illustrated environment is a living room or family room of a personal residence. However, the systems and methods
disclosed herein are equally applicable in other environments, such as workplace, retail and service environments. Environment 10 features a home-entertainment system 12 for the enjoyment of user 14. The home-entertainment system includes a large-format display 16 and loudspeakers 18, both operatively coupled to computer system 20. The nature of computer system 20 may differ in various implementations. In some examples, the computer system may be a video-game system or a multimedia system configured to play music and/or video. In other examples, the computer system may be a general-purpose computer system for internet access and productivity applications. Computer system 20 may be configured for any or all of the above purposes, and/or any other suitable purposes, without departing from the scope of this disclosure.

[0015] Computer system 20 may be configured to accept various forms of input from one or more users 14. As such, user-input devices such as a keyboard, mouse, touchscreen, gamepad, or joystick controller may be operatively coupled to computer system 20. Computer system 20 may also be configured to accept natural user input (NUI) from one or more users. To mediate the NUI, the illustrated computer system includes an NUI system 22. The NUI system is configured to capture various aspects of the NUI and provide corresponding actionable input to other constructs within the computer system. To this end, the NUI system receives low-level input from various sensory components of the computer system, which include vision system 24 and an optional listening system 26.

[0016] Listening system 26, if included, may comprise one or more microphones to pick up vocalization and other audible input from user 14. Vision system 24 may be configured to detect various forms of user input, such as gaze vectors \( V \) and focal point \( P \), as well as
hand and body gestures, facial features, etc. In the illustrated example, the vision system and listening system share a common enclosure; in other examples, they may be separate. In still other examples, the vision, listening and NUI systems may be integrated within computer system 20. The computer system and its peripheral components may be coupled via a wired communication link, as shown in the drawing, or in any other suitable manner.

[0017] FIG. 2 is a high-level schematic diagram showing aspects of an example of computer system 20, NUI system 22, vision system 24, and listening system 26. The illustrated computer system includes operating system (OS) 28, which may be instantiated in software and/or firmware. The computer system also includes one or more applications 30, such as a video game application, digital-media player, internet browser, photo editor, word processor, and/or spreadsheet application, for example. Computer system 20, NUI system 22, vision system 24, and listening system 26 may include suitable data storage, instruction storage, and logic hardware as needed to support their respective functions, as further described hereinafter.

[0018] In the example of FIG. 2, vision system 24 includes one or more flat-image cameras 32, and may also include one or more depth cameras 34. Each depth camera, if included, may be configured to acquire a time-resolved sequence of depth maps of user 14 and other aspects of environment 10. The vision system also includes on- and off-axis lamps 36A and 36B, which illuminate user 14 and the environment 10, to support imaging by the flat-image and/or depth cameras. Each lamp and camera of the vision system is operatively coupled to microcontroller 38. The microcontroller may be configured to
control and triggers image acquisition by the cameras, and to control the illumination output of each lamp of the vision system.

[0019] Flat-image camera 32 detects light over a range of field angles and maps such angles onto a rectangular pixel array. In one example, the flat-image camera may detect light in a plurality of wavelength channels—e.g., red, green, blue, etc.—associated with a subset of the pixels of the array. Alternatively, a monochromatic flat-image camera may be used, to image visible, near-infrared (NIR), infrared (IR), and/or ultraviolet (UV) light in grayscale. Color or brightness values for all of the pixels exposed in the flat-image camera constitute collectively a digital image. In some examples, pixels of a flat-image camera may be registered to those of a depth camera.

[0020] As noted above, NUI system 22 processes low-level input (i.e., signal) from vision system 24 and optional listening system 26 to provide actionable, high-level input in computer system 20. For example, the NUI system may perform sound- or voice-recognition on audio signal from listening system 26. The voice recognition may generate corresponding text-based or other high-level commands to be received in OS 28 of the computer system. In the example shown in FIG. 2, the task of formulating a particular form of NUI from sensory data is assigned to particular NUI engines: speech-recognition engine 40, a gesture-recognition engine 42, face-recognition engine 44, and gaze-detection engine 46. Each of these engines may be configured to furnish its associated form of input to the OS and/or applications of the computer system.

[0021] Turning now to FIG. 3, each lamp 36 of vision system 24 may comprise a light-emitting diode (LED), diode laser, discharge lamp, and/or other suitable light source. In
environment 10, lamp 36A provides on-axis illumination of eye 48, and lamp 36B provides off-axis illumination. The terms ‘on-axis’ and ‘off-axis’ refer to the direction of illumination with respect to the optical axis A of flat-image camera 32.

[0022] On- and off-axis illumination may serve different purposes with respect to gaze tracking in environment 10. As shown in FIG. 3, off-axis illumination may create a specular glint 50 that reflects from cornea 52 of the user’s eye. Off-axis illumination may also be used to illuminate the eye for a ‘dark pupil’ effect, where pupil 54 appears darker than the surrounding iris 56. By contrast, on-axis illumination from an IR or NIR source may be used to create a ‘bright pupil’ effect, where the pupil appears brighter than the surrounding iris. More specifically, IR or NIR illumination from on-axis lamp 36A may illuminate the retroreflective tissue of the retina 58 of the eye, which reflects the illumination back through the pupil, forming a bright image 60 of the pupil, as imaged by flat-image camera 32. In some examples, the flat-image camera may include a wavelength filter blocking transmission outside of the IR or NIR band of on-axis lamp 36A, to improve bright-pupil contrast in the presence of strong ambient light. Although FIG. 3 shows the on- and off-axis lamps schematically as point sources, it will be understood that these lamps may take any suitable form. For example, in some examples, on-axis lamp 36A may be configured in the form of an ‘LED ring’ surrounding the aperture of flat-image camera 32. In other words, the on-axis lamp may include a plurality of LEDs encircling the optical axis of the flat-image camera.

[0023] Gaze-detection engine 46 may be configured to process the image data from the flat-image camera to locate such features as the pupil center, pupil outline, and/or
corneal glints. The locations of such features in the image data may be used as input parameters in a model—e.g., a polynomial model—that relates feature position to the gaze vector $V$ of the eye. In examples where gaze is detected concurrently for both the right and left eyes, the point of intersection of the right and left gaze vectors may define the user’s focal point $P$ in three dimensions.

[0024] Returning briefly to FIG. 1, the drawing illustrates a scenario in which user 14 is navigating a UI presented on display 16 based on gaze direction. In this scenario, gaze-detection engine 46 has computed display screen coordinates ($X, Y$) corresponding to the point $P$ that the user is gazing at. By shifting his gaze to other points on the display screen, the user can navigate among the various UI elements 62 of an application or OS executing on computer system 20.

[0025] The gaze-detection approach introduced above may be further refined to improve accuracy in cases where user 14 may be wearing eyewear, such as sunglasses, corrective lenses, bifocals, sunglasses, visors, contact lenses, near-eye display systems, and/or other eyewear. Positioned close to the eye, such eyewear may reflect the illumination from lamps 36A and 36B of vision system 24. Such reflection creates noise in the image data acquired by the vision system. The increased noise may make it more difficult for gaze-detection engine 46 to unambiguously locate the pupil and/or corneal glints, which may increase the error in the determined gaze direction. More specifically, reflection from eyewear may appear similar to the bright-pupil images created with on-axis illumination, so that the gaze-detection engine mistakes them for bright pupils. This effect is shown in FIG. 4A, where bright pupils 54 appear together with numerous
reflections by the eyewear. A similar effect may occur when higher-angle illumination from off-axis lamp 36B is reflected by the eyeglasses and mistaken for a corneal glint. In general, when the reflection from the user’s eyeglasses are relatively small in diameter and bright, they may appear similar to a corneal glint to a gaze-detection engine.

[0026] One approach to disambiguate the desired ocular reflections from eyeglass reflections is to remove the latter by post-processing of the acquired images. Plausible discrimination criteria include intensity, size, or geometry (shape) of the candidate reflection. However, any post-processing approach may be sensitive to image-quality and other noise issues, and may require excessive compute time. Moreover, noise removal based on geometric discrimination of noise reflections may fail to generalize among the expected range of use scenarios—e.g., different styles of eyeglasses worn by the user, which may include different lens curvatures, frame shapes, etc.

[0027] Thus, the disclosed examples may disambiguate the desired ocular reflections from eyeglass reflections by utilizing a series of images of the user’s eye obtained at different illumination levels (i.e., intensities, powers). To this end, one, some, or all lamps 36 of vision system 24 may be configured to transition from providing a first level of illumination to providing a second, different level of illumination over a relatively short time interval, as further described below.

[0028] In one example, microcontroller 38 of vision system 24 may be configured to strobe on-axis lamp 36A and/or off-axis lamp 36B via pulse-width modulation (PWM). Two or more image frames are acquired at different brightness levels by assigning different PWM values to each frame. In other examples, the microcontroller may vary the
voltage or current provided to the lamps, change the number of lamp elements (e.g.,
LEDs) receiving power, or modulate an electrooptical attenuator to change the level of
illumination. Eye images at multiple brightness levels (HIGH + LOW, HIGH +
INTERMEDIATE + LOW, etc.) are captured over a very short interval—e.g., 60 milliseconds
(ms) or less, or 30 ms or less in some examples. The interval may be chosen, for example,
to limit an extent of motion blur caused by possible movement of the eye between
acquisition of the first and final images. During this interval, reflections from the ocular
features of interest, such as pupils and glints, may decrease proportionally in intensity
due to the decreasing illumination. However, the specular or near-specular reflections
from the user’s eyeglasses may saturate the receiving pixels of flat-image camera 32, even
at the LOW or INTERMEDIATE brightness levels. Accordingly, a proportional decrease in
brightness may not be observed for eyeglass reflections on transitioning from HIGH to
INTERMEDIATE or LOW brightness. The pixels that do not darken proportionately may be
removed from consideration in any suitable manner, to limit their impact on the
subsequent gaze-tracking computation.

[0029] A side-by-side comparison of FIGS. 4A and 4B further illustrates the above
approach. FIG. 4A shows an image acquired at HIGH brightness, and FIG. 4B shows an
image acquired at LOW brightness. It can be seen that the reflection from the user’s bright
pupils 54 is weaker in FIG. 4B than in FIG. 4A, but the reflection from the user’s eyeglasses
is just as intense.

[0030] Gaze-detection engine 46 may be configured to manage a buffer of two or more
images at different brightness levels, captured over a suitably short interval, such as 60
ms or less in some examples. The gaze-detection engine checks the brightness of the first (brighter) and second (darker) image, measuring every pixel. If a pixel has similar saturated brightness—e.g., differs by less than a threshold amount—or remains saturated in both images—the pixel then may, in some examples, be replaced with an average value of the brightness over the whole image (of FIG. 4A and 4B, respectively) while all the remaining pixels (those not affected by eyeglass reflections) may keep their original values. In other examples, the pixels may not be replaced, but may be tracked or compensated for in another manner.

[0031] It will be noted that, as the image in FIG. 4A is brighter, the pupils have better contrast against the iris and are more easily detectable. In contrast, as FIG. 4B is darker, glints have better contrast against the pupils and are more easily detectable. The resulting processed images of FIG. 4A and FIG. 4B, after compensating for reflections of eyeglasses, are used as input for pupil detection and glint detection respectively. FIG. 4C shows a result of this procedure for applied to the HIGH and LOW intensity images of FIGS. 4A and 4B, where the white circles indicate the detected outlines of pupils 54.

[0032] The foregoing drawings and description should not be interpreted in a limiting sense, for numerous other examples and use scenarios are contemplated as well. In particular, numerous other environments and form factors, besides that of FIG. 1, lay within the spirit and scope of this disclosure. For example, as shown in FIG. 5, analogous gaze tracking may be enacted in a smart phone 66 or desktop computer 68 with an appropriate vision system 24A mounted beneath the display bezel. In other examples,
analagous gaze tracking may be enacted in a tablet or laptop computer with an integrated vision system.

[0033] In still other examples, the vision system may be integrated in active headwear or eyewear worn by the user (who also may be wearing conventional eyeglasses). Such headwear or eyewear may further support a stereoscopic, near-eye display system. FIG. 6 shows an optical system 70 of a near-eye display system with integrated gaze tracking. In this example, the user is wearing additional corrective lenses 71. Flat-image camera 32 images light from on-axis IR or NIR lamp 36A reflected off the wearer’s eye. An off-axis lamp 36B provides relatively high-angle illumination of the eye, to create a specular glint on the cornea of the eye, stimulate a dark-pupil effect, etc. Beam-turning optics integrated in optical system 70 enable the camera and the on-axis lamp to share a common optical axis A, despite their arrangement on the periphery of the optical system.

[0034] The approaches described herein may be extended to include other types of specular reflection than reflection from eyewear. In general, virtually any surface disposed between the user and the vision system may cause a bright, specular reflection that is distinguishable in the manner described herein. For example, specular reflection of vision-system illumination from a protective window (glass, acrylic, or polycarbonate sheet, hazmat shield, etc.) may be distinguished from an ocular reflection, for example, based on invariant detected brightness at two or more different illumination levels.

[0035] The configurations described above enable various methods for gaze detection to be enacted in a computer system operatively coupled to a vision system. Some such methods are now described with continued reference to the example configurations
described above. It will be understood, however, that the methods here described, and others within the scope of this disclosure, also may be enabled by different configurations.

[0036] FIG. 7 illustrates an example method 74 to furnish input responsive to gaze direction in a computer system operatively coupled to a vision system. At 76 of method 74, the output of an on-axis lamp of the vision system is adjusted to provide a first level of illumination to a user’s eye prior to acquisition of a first image of the eye, for example, using one or more of the methods described above. The first level of illumination could be a relatively HIGH level of illumination, in one example.

[0037] At 78 a first image of the eye is obtained from a camera of a vision system. The first image is acquired by the camera during an interval in which the first level of illumination is provided to the eye. At 80 a second image of the eye corresponding to a second, different level of illumination is obtained. The second level of illumination may be lower or higher than the first level of illumination, and the second image may be obtained in different ways, in various examples.

[0038] In one example, the output of the on-axis lamp may be again adjusted to provide the second level of illumination for acquisition of the second image by the camera. The second image is then obtained from the camera. In another example, the second image of the eye is obtained by multiplying a brightness of each unsaturated pixel of the first image by a multiplication factor to obtain a corresponding pixel of the second image.
The multiplication factor may be greater than one to construct an overall brighter second image, or less than one to construct an overall darker second image. In one variant, multiplied brightness values of the second image may be clipped to the maximum brightness valid for the type of image encoding used by the camera. Further, pixels already saturated in the first image may be multiplied by a different factor (e.g., a factor of one), or otherwise masked. In this way, saturated pixels (that may correspond to specular reflection from the user’s eyeglasses) are excluded from subsequent computations to determine the gaze direction.

The first and second images may be configured to reveal ocular reflections (e.g., bright pupils) at different, unsaturated brightness levels. This feature is used to distinguish the ocular features from eyeglass reflections (and, in some scenarios, from corneal glints due to off-axis illumination, which typically remain saturated, even at relatively low levels of illumination). However, it is not always possible to predict the appropriate first and second levels of illumination in advance of an unknown use scenario. For instance, different types of eyewear exhibit reflections of different reflectance. Further, the eyes of different individuals may require different levels of on-axis illumination to yield a bright-pupil response. Rather than apply the same two illumination levels for every user, gaze-detection engine 46 may be configured to analyze a series of three or more images acquired at different illumination levels, and then select appropriate first and second images to refine the first and second levels of illumination, as illustrated at 82 in FIG. 7. The images selected may be those, for example, which exhibit saturated eyeglass reflections, and strong but unsaturated (e.g., > 30% saturated
intensity, >50%, as examples) bright-pupil reflections. In this manner, the first and second levels of illumination, in method 74, may be selected based on ability to evoke and distinguish a bright pupil effect in the imaged eye, such levels differing for eyes of different users.

[0041] Another reason to provide a range of illumination levels across three or more acquired images may be to allow the system to respond to changing levels of ambient light in the wavelength band of the on-axis lamp. In this manner, the first and second levels of illumination may be selected based on ambient-light conditions. Providing a range of illumination levels also may help to distinguish the bright-pupil response from a corneal glint derived from off-axis illumination. Any suitable number of obtained images of the eye and corresponding illumination levels may be obtained, such as two, three, four, etc. This number may be dependent upon factors such as the frame rate utilized. In other words, faster image acquisition may enable a greater number of images to be acquired without experiencing the negative effect of motion blur due to eye movement.

[0042] Alternative modes of image / illumination-level selection may also be used at this stage of the method to address the challenges noted above. For example, once the appropriate illumination levels are revealed by analysis of the obtained images, this information may be fed back to earlier stages of the method to control which illumination levels are actually used when acquiring the first image, and obtaining the second image (whether by repeated image acquisition or by processing of the first image). This type of feedback may be used to reduce the number of redundant images obtained on each pass through the method, which may decrease the gaze-tracking latency. Even in cases where
two images are obtained, feedback based on analysis of the obtained images may be used to refine the HIGH and LOW levels of illumination used for subsequent first and second images.

[0043] Continuing in FIG. 7, at 84 of method 74, a reflection of the illumination by the user’s eye is distinguished from a reflection of the illumination by the user’s eyewear. As noted above, the desired reflection of the illumination by the eye may constitute a bright-pupil response—i.e., a retroreflection from the retina of the user’s eye, which passes back through the pupil and causes the pupil to appear bright relative to the surrounding iris. Alternatively, and equally important, the reflection by the eye may include a reflection by the iris itself, which causes the pupil to appear dark relative to the iris.

[0044] In one example embodiment, distinguishing eye from eyewear reflection may include comparing the brightness of corresponding pixels of the first and second images. In one example, corresponding pixels of the first and second images may be associated with the reflection of the illumination by the eye if the brightness of such pixels differs by more than a threshold amount (e.g., more than 5%, more than 10%, more than 10% of saturation, more than 10% of the maximum brightness, etc.). Conversely, the corresponding pixels may be associated with the reflection of the illumination by the eyewear if their brightness differs by less than a threshold amount (e.g., less than 5%, less than 1%, etc.). Such pixels may be masked from subsequent computation. In another example, corresponding pixels of the first and second images may be associated with reflection by the eyewear if both pixels are saturated. In yet another example, a machine-
learned algorithm may be used to distinguish the reflection of the illumination by the eye from the reflection of the illumination by the eyewear.

[0045] At 86 gaze-direction input is computed based on a location, in the first or second image, of the reflection of the illumination by the eye, while excluding those pixels associated with the reflection of the illumination by the eyewear. In one example, the computed input includes an azimuth angle $AA$ (in FIG. 3) and an elevation angle $EA$ defining a direction of sight through the eye. Any suitable reference frame may be used for defining such angles. In one example, the reference frame has its origin at the entry pupil of flat-image camera 34 and one axis aligned with optical axis A. Naturally, the foregoing acts of method 74 may be enacted on both of the user’s eyes, in a suitably configured vision system. When gaze vectors are available for both eyes, the coordinates of the user’s focal point $P$ may also be determined and included as input.

[0046] In some instances, on- or off-axis illumination of a user’s eyewear will create a reflection that overlaps a desired ocular feature in the first or second image. When this occurs, exclusion of the pixels associated with the eyewear reflection could mask the ocular feature, or some portion thereof, potentially causing an interruption in gaze detection for the affected eye. It will be understood, however, that even a prolonged interruption in the availability of gaze input may be less disruptive to the user experience than delivering inaccurate gaze input. This may be especially true in examples where gaze is detected independently for each eye.

[0047] At optional step 88, the computed gaze direction is corrected based on a kinematic model to account for motion blur—viz., movement of the eye during the short
time interval between obtaining the first and second images. The kinematic model may be an optical flow model, for example.

[0048] At 90, input including the detected gaze direction (and determined focal point, if available) is furnished to an appropriate consumer construct in the computer system—e.g., an OS or application of the computer system—based on the reflection of vision-system illumination by the eye. In view of the reflection discriminating effect of the disclosed method, the furnished input may be largely independent of reflection of the illumination by the user’s eyewear. It will be understood that the examples described herein may be implemented in various different ways. For example, an image of a user’s eye may be captured via at multiple exposures, such as by utilizing high dynamic range (HDR) imaging techniques, to achieve a greater dynamic range of luminosity in each image than with non-HDR techniques.

[0049] Further, some implementations may utilize an image sensing system configured to acquire two or more successive frames at some frame interval (e.g. every 30ms) that helps to avoid impacting a desired frame rate. As a non-limiting example, an illumination system comprising one or more lasers may be used for illumination such that the illumination is provided at a first intensity for a time period (e.g., 2ms) followed by a second, higher intensity for another time period (e.g., another 2 ms). During this illumination process, a first frame may be acquired in the first time period, and the second frame may be acquired during the second time period, such that both images of the eye are acquired before the image data is read. Any additional successive frames may be acquired in a similar manner. After the illumination process, the two or more image
frames acquired may be read for the remaining duration of the frame interval. Any suitable hardware configuration may be used to acquire images in this manner. For example, a system may take the form of two juxtaposed cameras, which may or may not be internally constructed to share the same die.

[0050] As evident from the foregoing description, the methods and processes described herein may be tied to a computer system of one or more computing machines. Such methods and processes may be implemented as a computer-application program or service, an application-programming interface (API), a library, and/or other computer-program product. The reader is again referred to FIG. 2, which shows a non-limiting example of a computer system 20 used to support the methods and processes described herein. The computer system includes a logic machine 92 and an instruction-storage machine 94. The computer system also includes a display 16, communication system 96, and various components not shown the drawing.

[0051] Each logic machine 92 includes one or more physical logic devices configured to execute instructions. A logic machine may be configured to execute instructions that are part of one or more applications, services, programs, routines, libraries, objects, components, data structures, or other logical constructs. Such instructions may be implemented to perform a task, implement a data type, transform the state of one or more components, achieve a technical effect, or otherwise arrive at a desired result.

[0052] Each logic machine 92 may include one or more processors configured to execute software instructions. Additionally or alternatively, a logic machine may include one or more hardware or firmware logic machines configured to execute hardware or
firmware instructions. Processors of a logic machine may be single-core or multi-core, and the instructions executed thereon may be configured for sequential, parallel, and/or distributed processing. Individual components of a logic machine optionally may be distributed among two or more separate devices, which may be remotely located and/or configured for coordinated processing. Aspects of a logic machine may be virtualized and executed by remotely accessible, networked computing devices configured in a cloud-computing configuration.

[0053] Each data-storage machine 94 includes one or more physical, computer-memory devices configured to hold instructions executable by an associated logic machine 92 to implement the methods and processes described herein. When such methods and processes are implemented, the state of the data-storage machine may be transformed—e.g., to hold different data. A data-storage machine may include removable and/or built-in devices; it may include optical memory (e.g., CD, DVD, HD-DVD, Blu-Ray Disc, etc.), semiconductor memory (e.g., RAM, EPROM, EEPROM, etc.), and/or magnetic memory (e.g., hard-disk drive, floppy-disk drive, tape drive, MRAM, etc.), among others. A data-storage machine may include volatile, nonvolatile, dynamic, static, read/write, read-only, random-access, sequential-access, location-addressable, file-addressable, and/or content-addressable devices.

[0054] It will be appreciated that each data-storage machine 94 includes one or more physical devices. However, aspects of the instructions described herein alternatively may be propagated by a communication medium (e.g., an electromagnetic signal, an optical signal, etc.), as opposed to being stored via a storage medium.
Aspects of the logic machine(s) and data-storage machine(s) may be integrated together into one or more hardware-logic components. Such hardware-logic components may include field-programmable gate arrays (FPGAs), program- and application-specific integrated circuits (PASIC / ASICs), program- and application-specific standard products (PSSP / ASSPs), system-on-a-chip (SOC), and complex programmable logic devices (CPLDs), for example.

The term ‘engine’ may be used to describe an aspect of a computer system implemented to perform a particular function. In some cases, an engine may be instantiated via a logic machine executing instructions held by a data-storage machine. It will be understood that different engines may be instantiated from the same application, service, code block, object, library, routine, API, function, etc. Likewise, the same engine may be instantiated by different applications, services, code blocks, objects, routines, APIs, functions, etc. The term ‘engine’ may encompass individual or groups of executable files, data files, libraries, drivers, scripts, database records, etc.

Communication system 96 may be configured to communicatively couple the computer system to one or more other machines. The communication system may include wired and/or wireless communication devices compatible with one or more different communication protocols. As non-limiting examples, a communication system may be configured for communication via a wireless telephone network, or a wired or wireless local- or wide-area network. In some examples, a communication system may allow a computing machine to send and/or receive messages to and/or from other devices via a network such as the Internet.
0058] It will be understood that the configurations and/or approaches described herein are exemplary in nature, and that these specific examples or examples are not to be considered in a limiting sense, because numerous variations are possible. The specific routines or methods described herein may represent one or more of any number of processing strategies. As such, various acts illustrated and/or described may be performed in the sequence illustrated and/or described, in other sequences, in parallel, or omitted. Likewise, the order of the above-described processes may be changed.

[0059] The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various processes, systems and configurations, and other features, functions, acts, and/or properties disclosed herein, as well as any and all equivalents thereof.
FIG. 2
FIG. 6
ADJUST ILLUMINATION SOURCE TO PROVIDE FIRST LEVEL OF ILLUMINATION TO THE EYE

OBTAIN FROM CAMERA A FIRST IMAGE OF THE EYE ACQUIRED AT THE FIRST LEVEL OF ILLUMINATION

OBTAIN A SECOND IMAGE OF EYE CORRESPONDING TO A SECOND LEVEL OF ILLUMINATION

ADJUST ON-AXIS LAMP TO PROVIDE SECOND LEVEL OF ILLUMINATION

MULTIPLY BRIGHTNESS OF UNSATURATED PIXELS OF FIRST IMAGE TO OBTAIN SECOND IMAGE

OBTAIN THE SECOND IMAGE FROM THE CAMERA

PROCESS SERIES OF IMAGES TO REFINE FIRST AND SECOND LEVELS OF ILLUMINATION

DISTINGUISH EYE REFLECTION FROM EYEWEAR REFLECTION

COMPUTE GAZE DIRECTION BASED ON LOCATION OF EYE REFLECTION

CORRECT GAZE DIRECTION BASED ON KINEMATIC FLOW MODEL

FURNISH INPUT BASED ON GAZE DIRECTION

FIG. 7
SCORE Placeholder Sheet for IFW Content

Application Number: 14509976  Document Date: 10/08/2014

The presence of this form in the IFW record indicates that the following document type was received in electronic format on the date identified above. This content is stored in the SCORE database.

- Drawings – Other than Black and White Line Drawings

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