US012387366B2

(12) **United States Patent**
Simmons et al.

(10) **Patent No.: US 12,387,366 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **IMAGE BASED DETECTION OF FIT FOR A HEAD MOUNTED WEARABLE COMPUTING DEVICE**

(71) Applicant: **GOOGLE LLC**, Mountain View, CA (US)

(72) Inventors: **Rees Anwyl Samuel Simmons**, Waterloo (CA); **Idris Syed Aleem**, Kitchener (CA); **Sushant Umesh Kulkarni**, Waterloo (CA); **Mayank Bhargava**, Kitchener (CA); **Ahmed Gawish**, Waterloo (CA)

(73) Assignee: **GOOGLE LLC**, Mountain View, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 836 days.

(21) Appl. No.: **17/444,963**

(22) Filed: **Aug. 12, 2021**

(65) **Prior Publication Data**

US 2023/0046950 A1 Feb. 16, 2023

(51) **Int. Cl.**
G06T 7/73 (2017.01)
G02B 27/01 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G06T 7/73*** (2017.01); ***G02B 27/017*** (2013.01); ***G02B 27/0176*** (2013.01);
(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2013/0322683 A1 * 12/2013 Jacobs G02B 27/0149 382/103
2014/0218679 A1 8/2014 Haddadi
(Continued)

FOREIGN PATENT DOCUMENTS

EP 3339943 A1 * 6/2018
JP 2006155638 A 6/2006
(Continued)

OTHER PUBLICATIONS

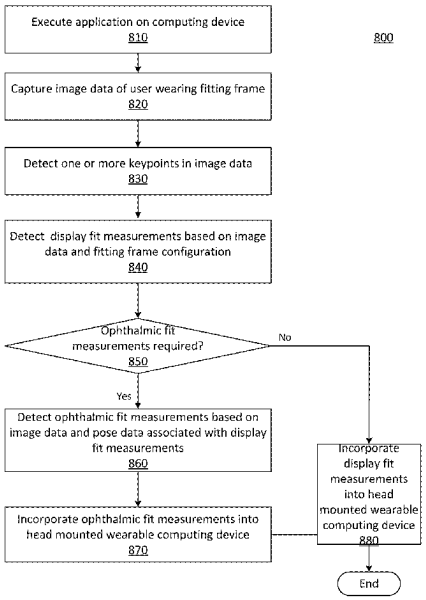
International Search Report and Written Opinion for PCT Application No. PCT/US2022/073931, mailed on Nov. 15, 2022, 10 pages.

Primary Examiner — Delomia L Gilliard
(74) *Attorney, Agent, or Firm* — Brake Hughes Bellermann LLP

(57) **ABSTRACT**

A system and method of detecting display fit measurements and/or ophthalmic measurements for a head mounted wearable computing device including a display device is provided. An image of a fitting frame worn by a user of the computing device is captured by the user, through an application running on the computing device. One or more keypoints and/or features and/or landmarks are detected in the image including the fitting frame. A three-dimensional pose of the fitting frame is determined based on the detected keypoints and/or features and/or landmarks, and configuration information associated with the fitting frame. The display device of the head mounted wearable computing device can then be configured based on the three-dimensional pose of the fitting frame as captured in the image.

17 Claims, 17 Drawing Sheets



(51) **Int. Cl.**
G02C 7/02 (2006.01)
G02C 13/00 (2006.01)
G06V 40/16 (2022.01)

(52) **U.S. Cl.**
CPC ***G02C 7/027*** (2013.01); ***G02C 13/003*** (2013.01); ***G06V 40/165*** (2022.01); *G02B 27/0149* (2013.01); *G02B 2027/0154* (2013.01); *G02B 2027/0178* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2015/0055086	A1*	2/2015	Fonte	H04L 65/403 700/98
2016/0124246	A1	5/2016	Rego et al.	
2019/0146246	A1	5/2019	Fonte et al.	
2020/0103675	A1*	4/2020	Schwarz	G06F 30/27

FOREIGN PATENT DOCUMENTS

JP	2012239566	A	12/2012
JP	2016537716	A	12/2016

* cited by examiner

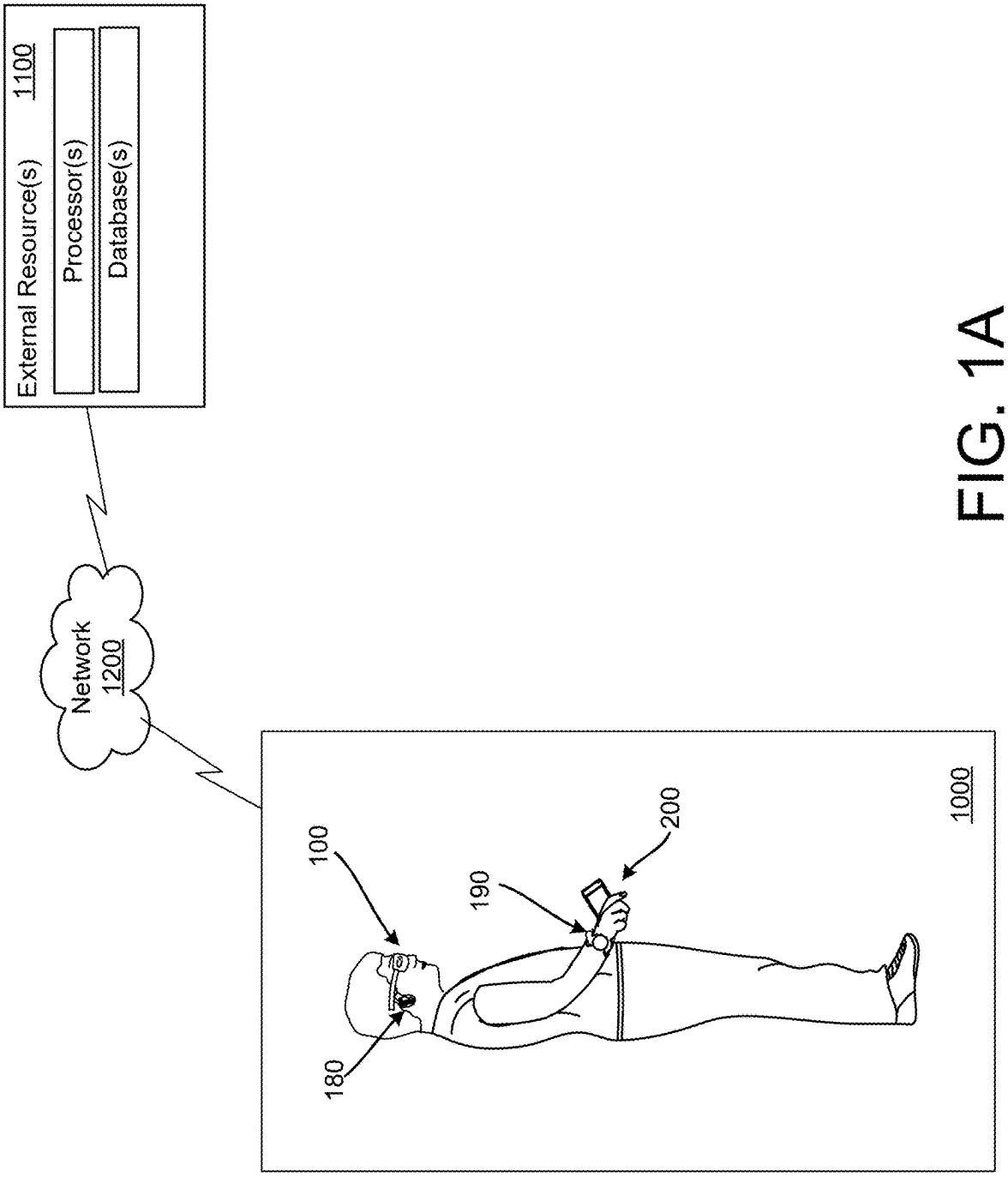

External Resource(s) 1100
Processor(s)
Database(s)
Network 1200
1000
100
190
200
180

FIG. 1A

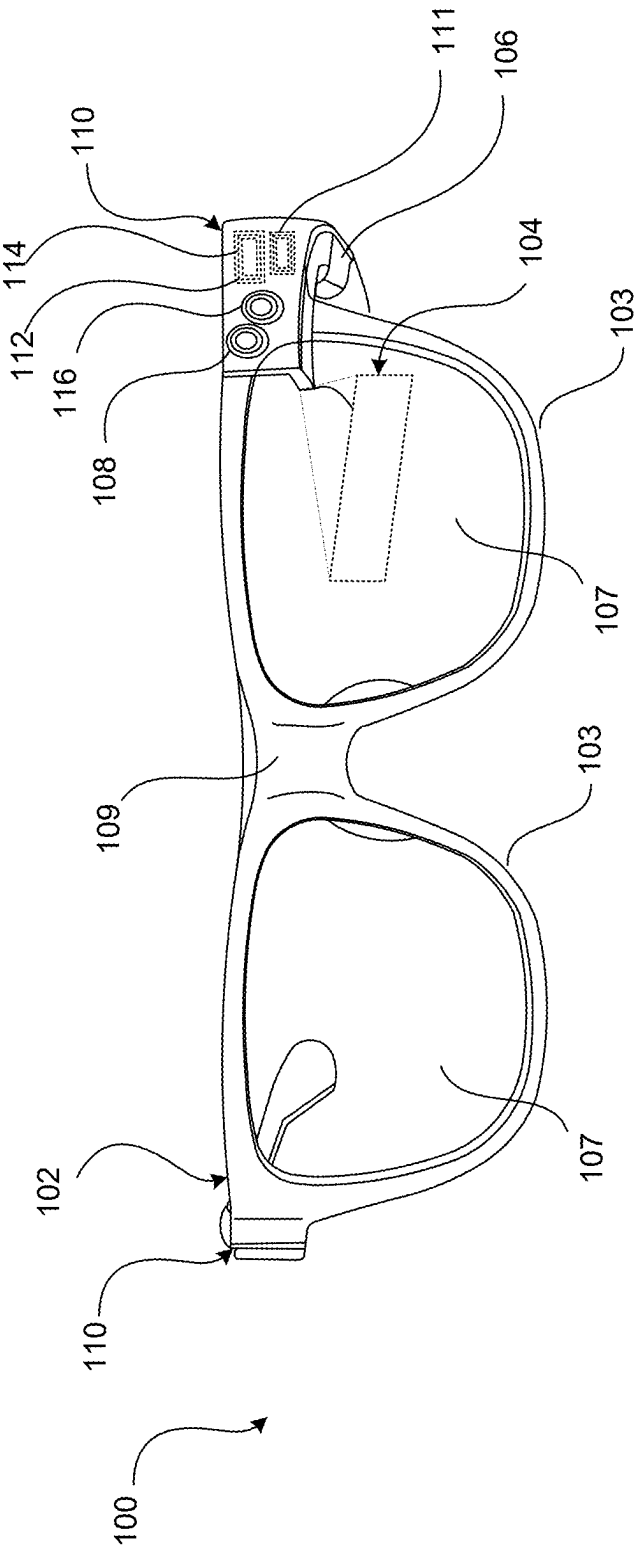


FIG. 1B

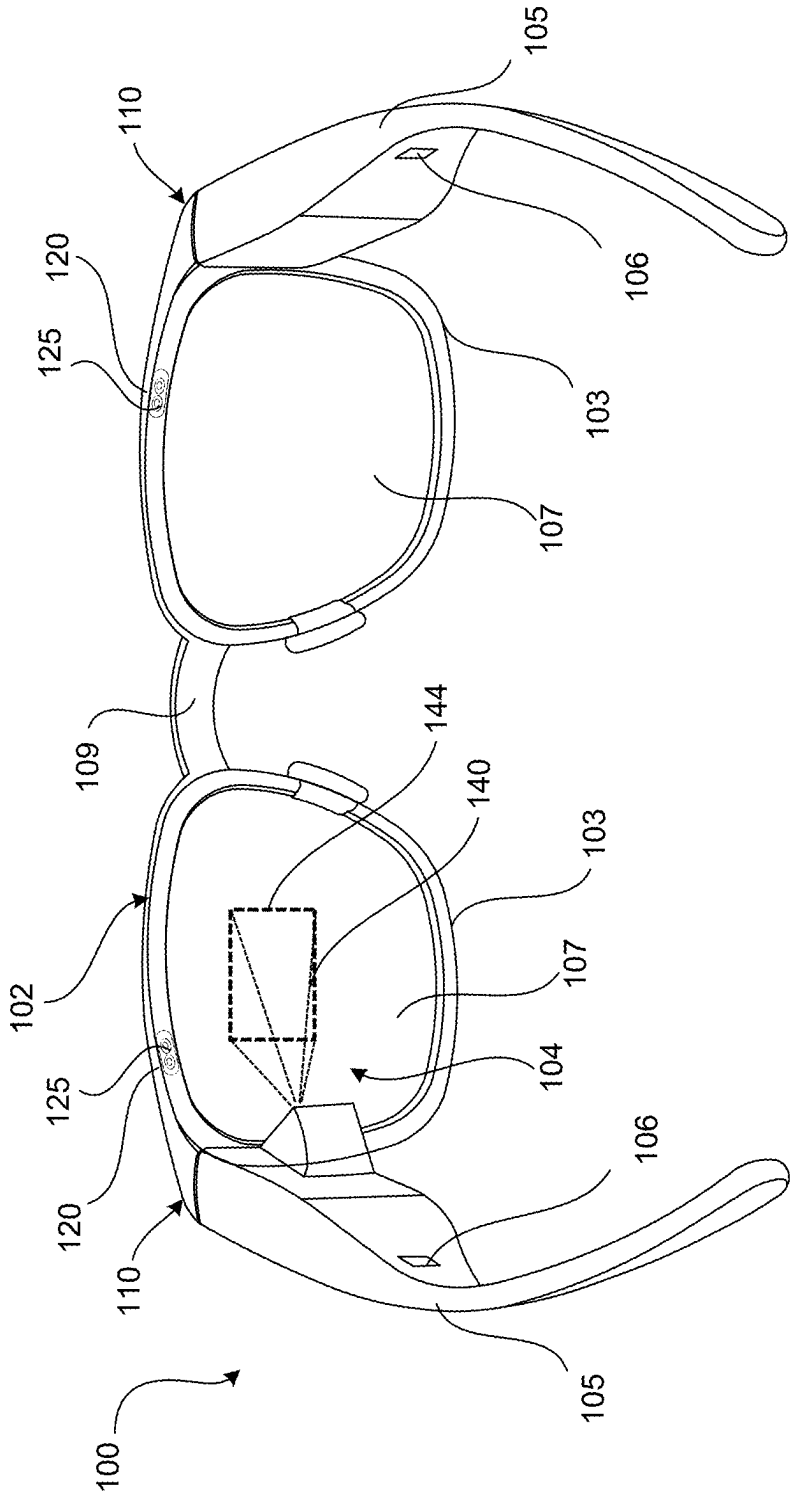

105
110
120
125
106
103
107
109
144
140
103
102
107
104
125
106
120
110
105
100

FIG. 1C

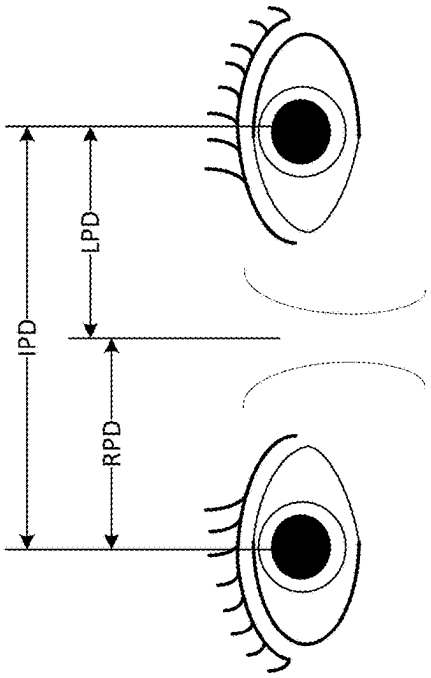


FIG. 2B

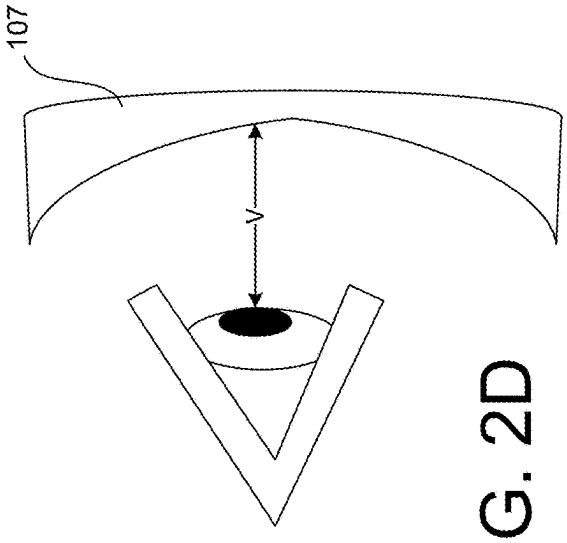


FIG. 2D

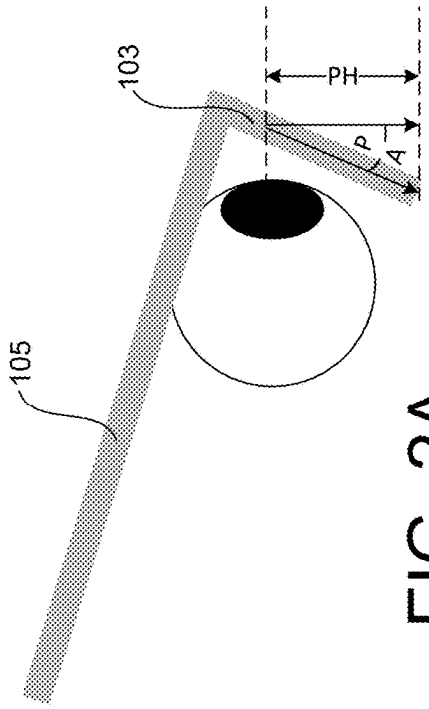


FIG. 2A

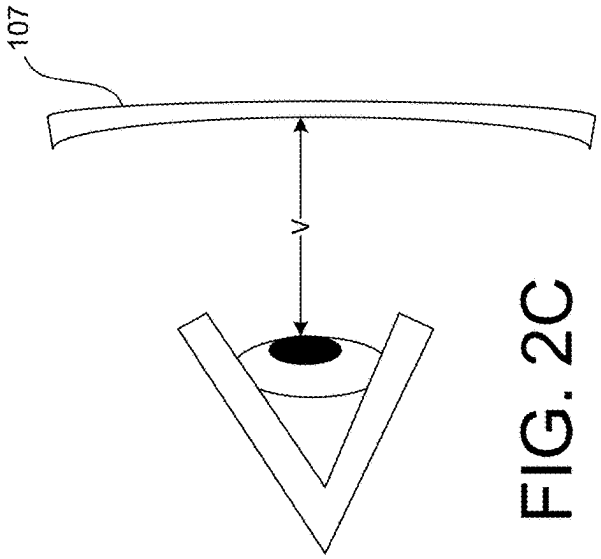


FIG. 2C

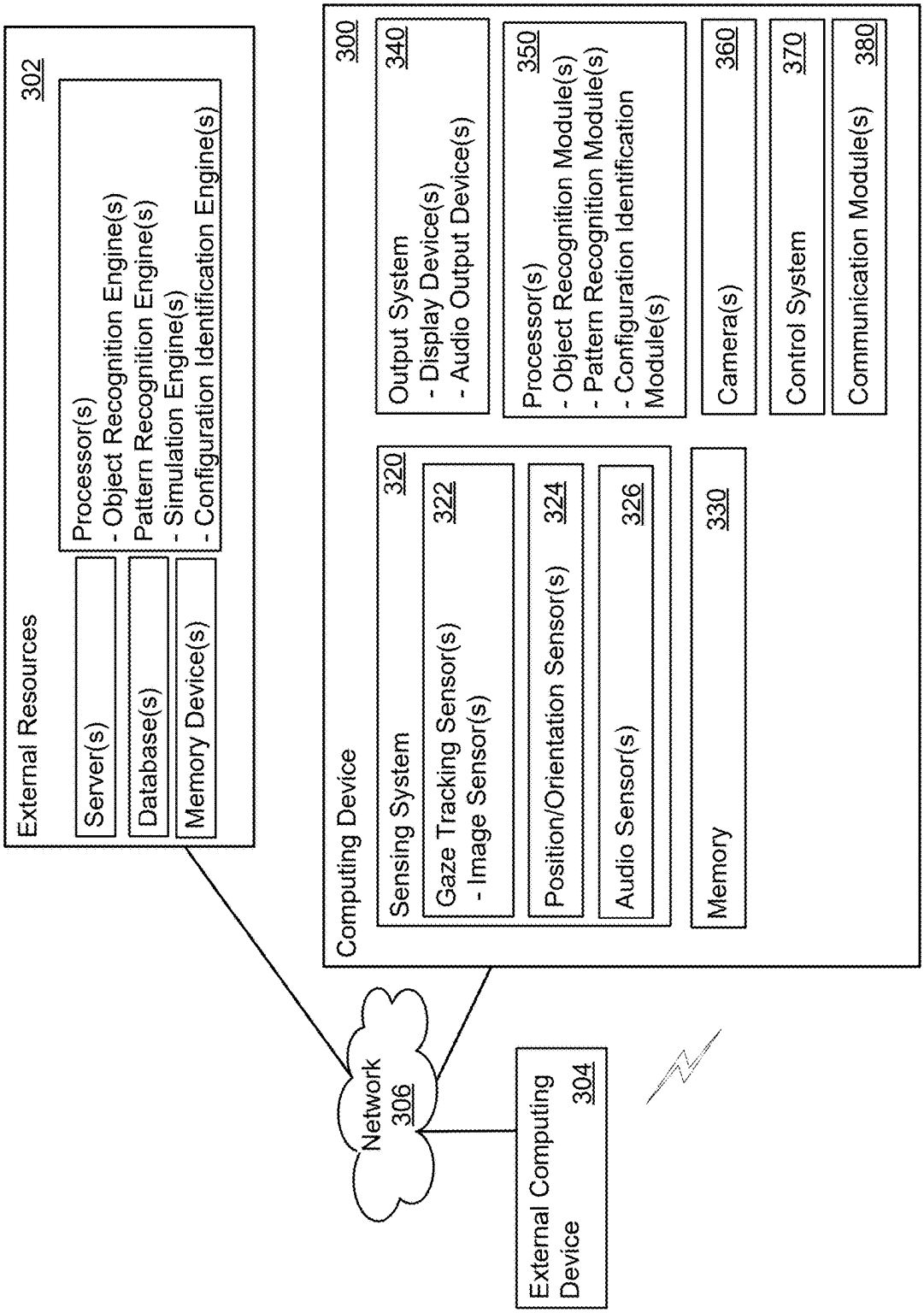

External Resources
302
Server(s)
Database(s)
Memory Device(s)
Processor(s)
- Object Recognition Engine(s)
Pattern Recognition Engine(s)
- Simulation Engine(s)
- Configuration Identification Engine(s)
Network
306
External Computing Device
304
Computing Device
300
Sensing System
320
Gaze Tracking Sensor(s)
322
- Image Sensor(s)
Position/Orientation Sensor(s)
324
Audio Sensor(s)
326
Memory
330
Output System
340
- Display Device(s)
- Audio Output Device(s)
Processor(s)
350
- Object Recognition Module(s)
- Pattern Recognition Module(s)
- Configuration Identification Module(s)
Camera(s)
360
Control System
370
Communication Module(s)
380

FIG. 3

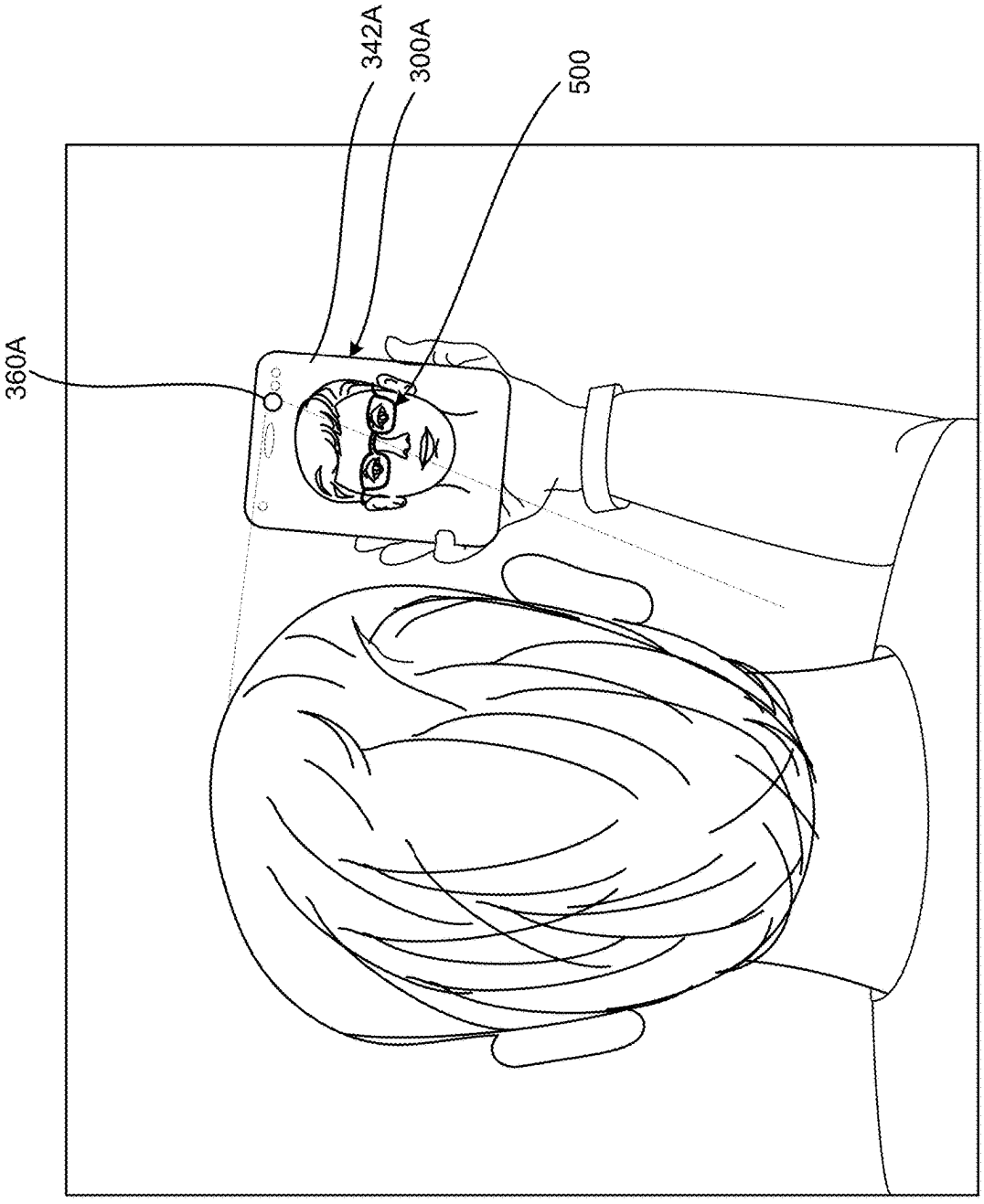


FIG. 4A

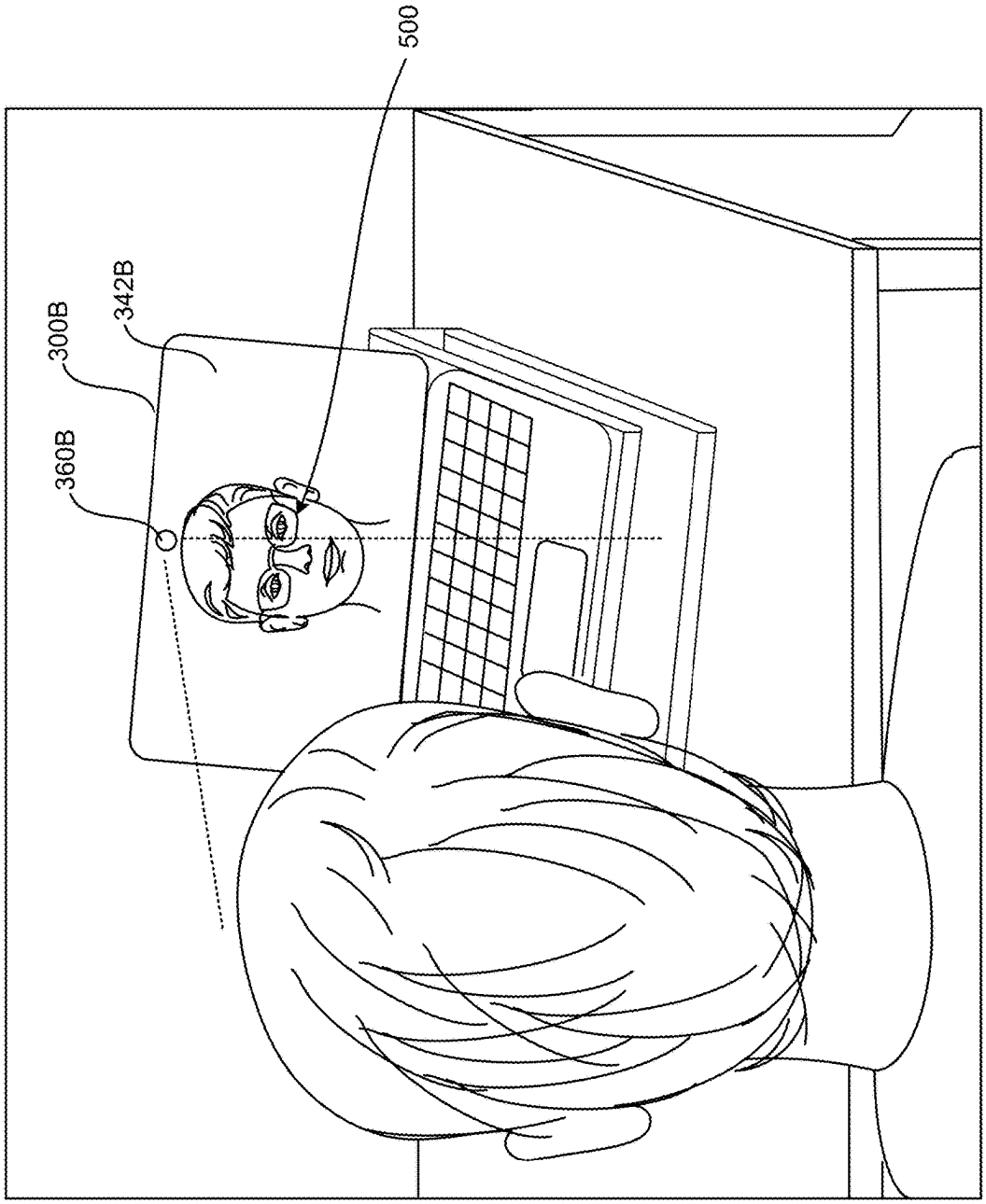


FIG. 4B

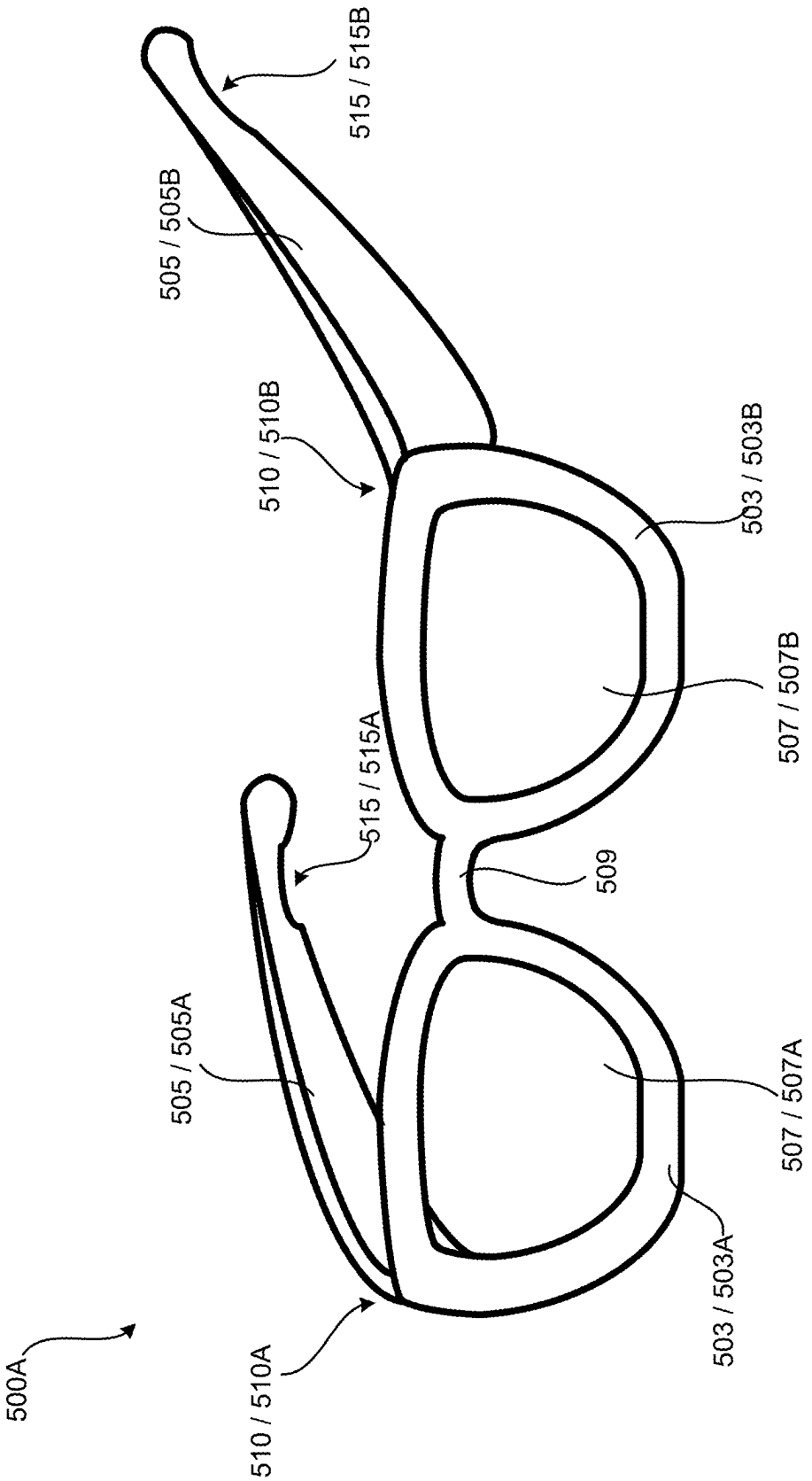

500A
510 / 510A
505 / 505A
515 / 515A
509
510 / 510B
505 / 505B
515 / 515B
503 / 503A
507 / 507A
507 / 507B
503 / 503B

FIG. 5A

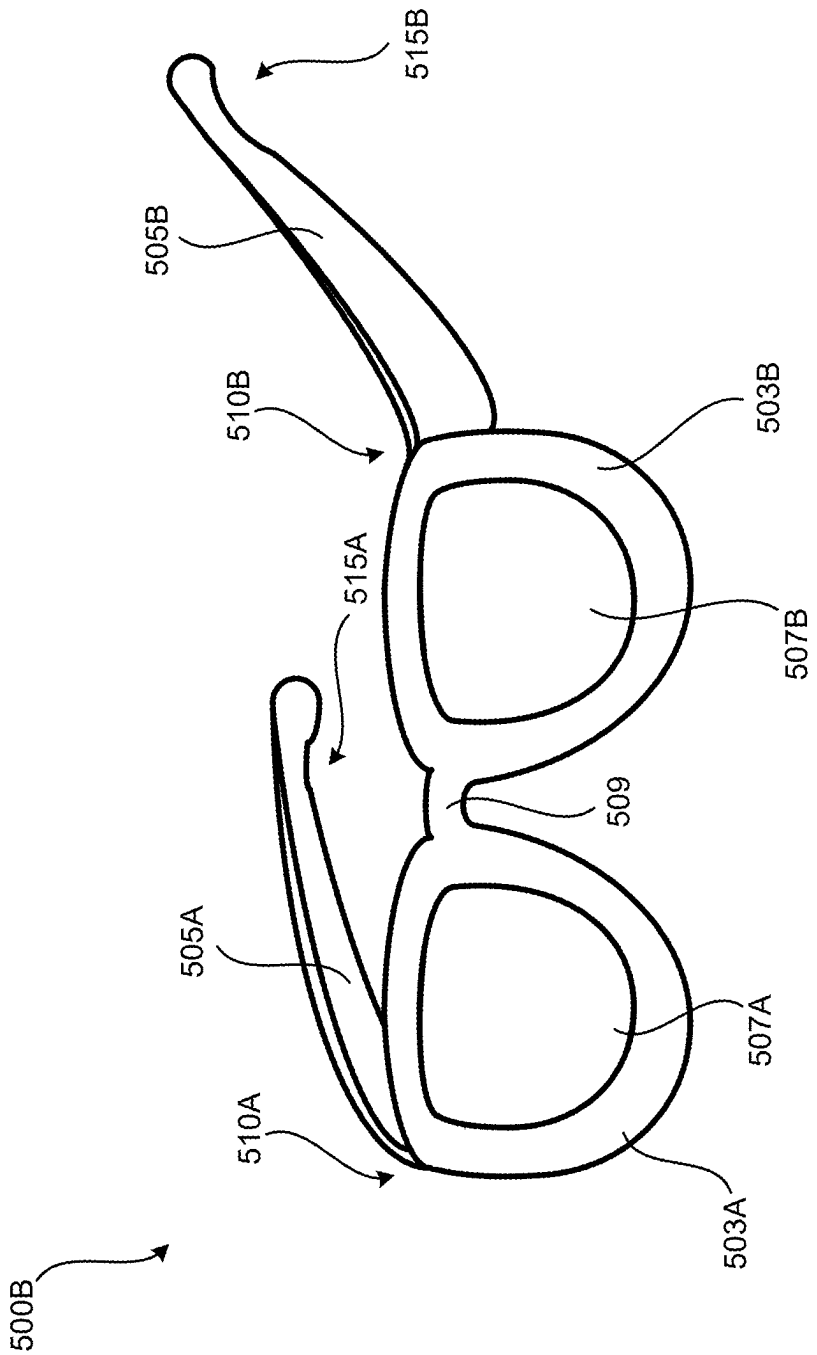


FIG. 5B

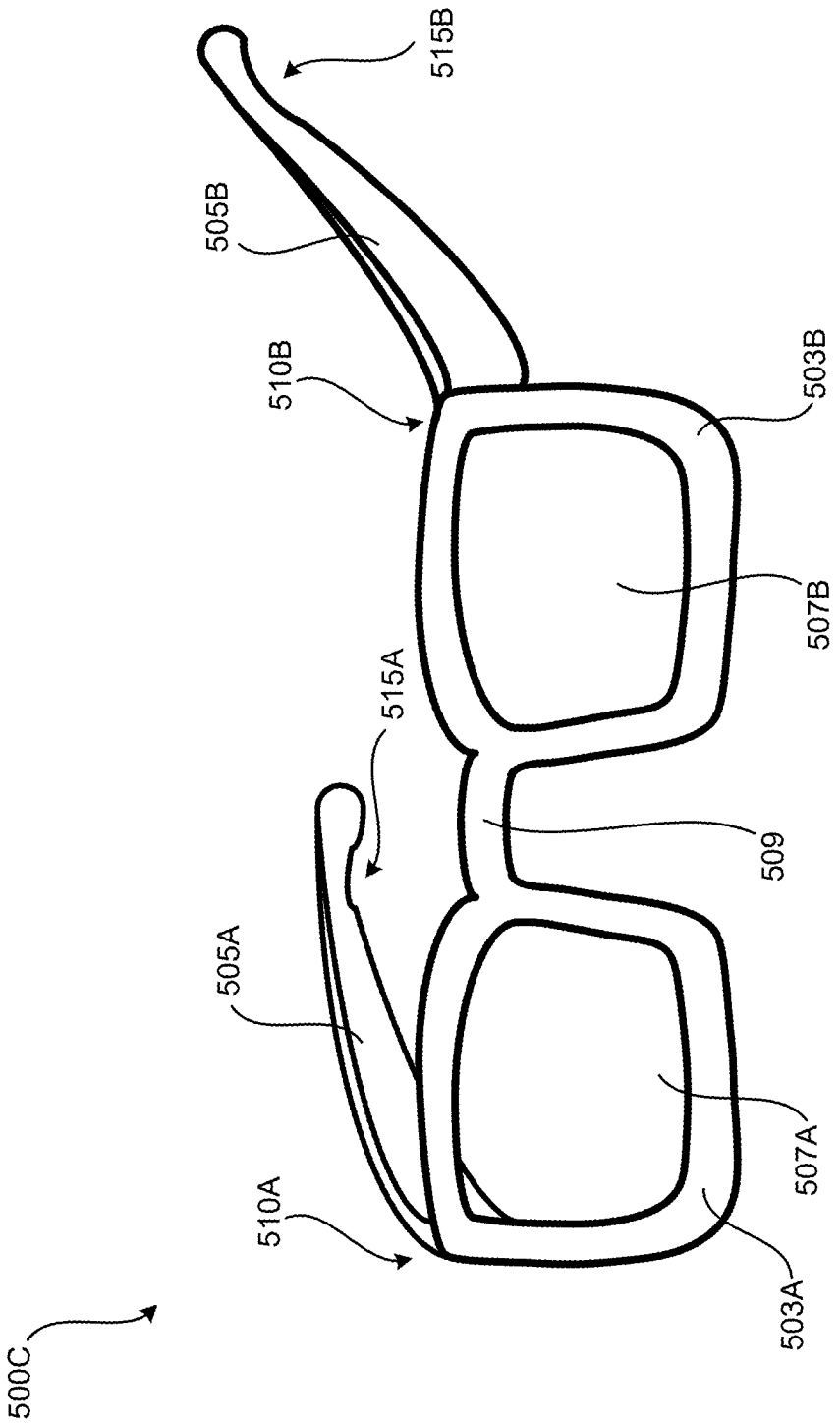


FIG. 5C

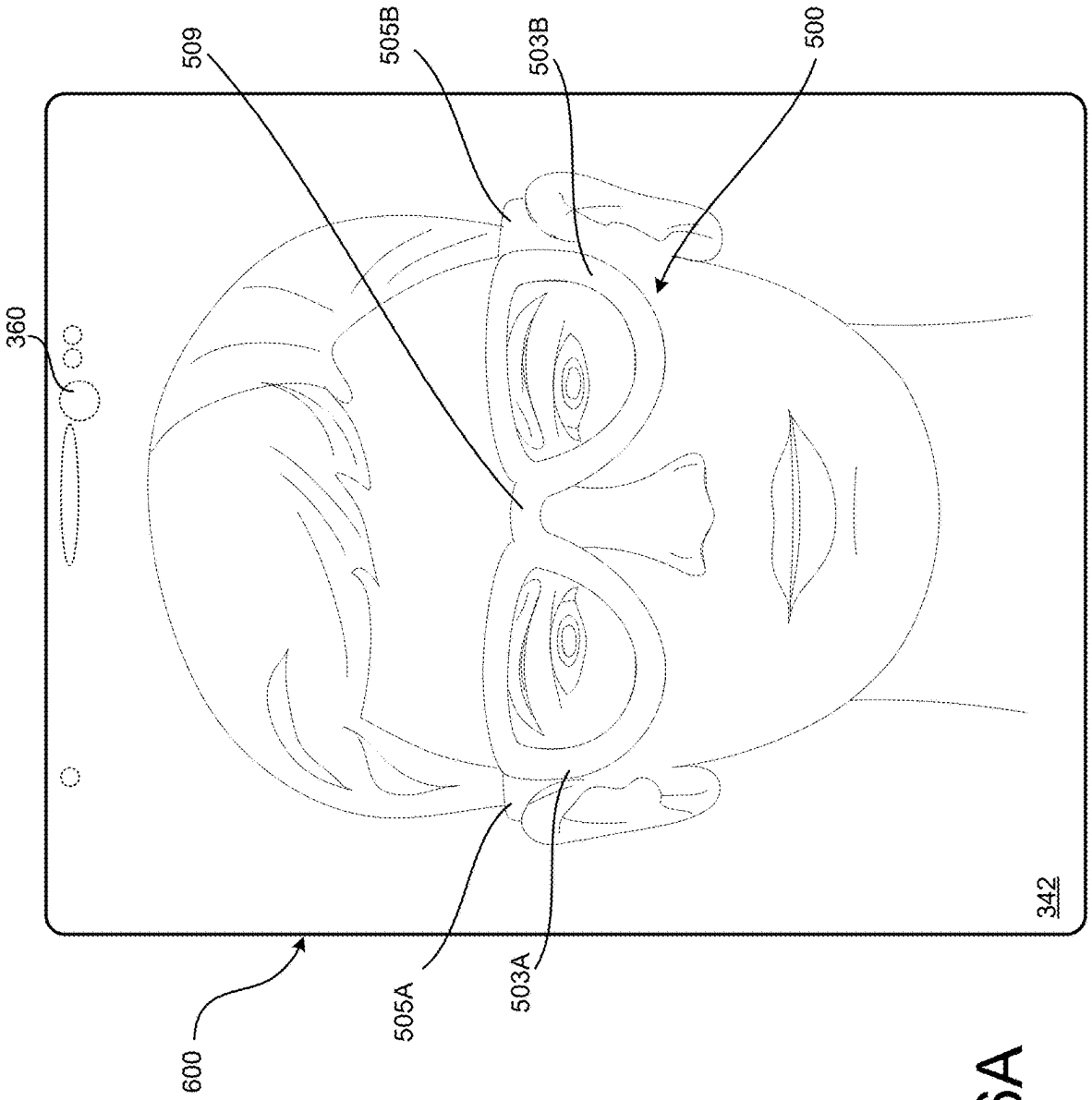


FIG. 6A

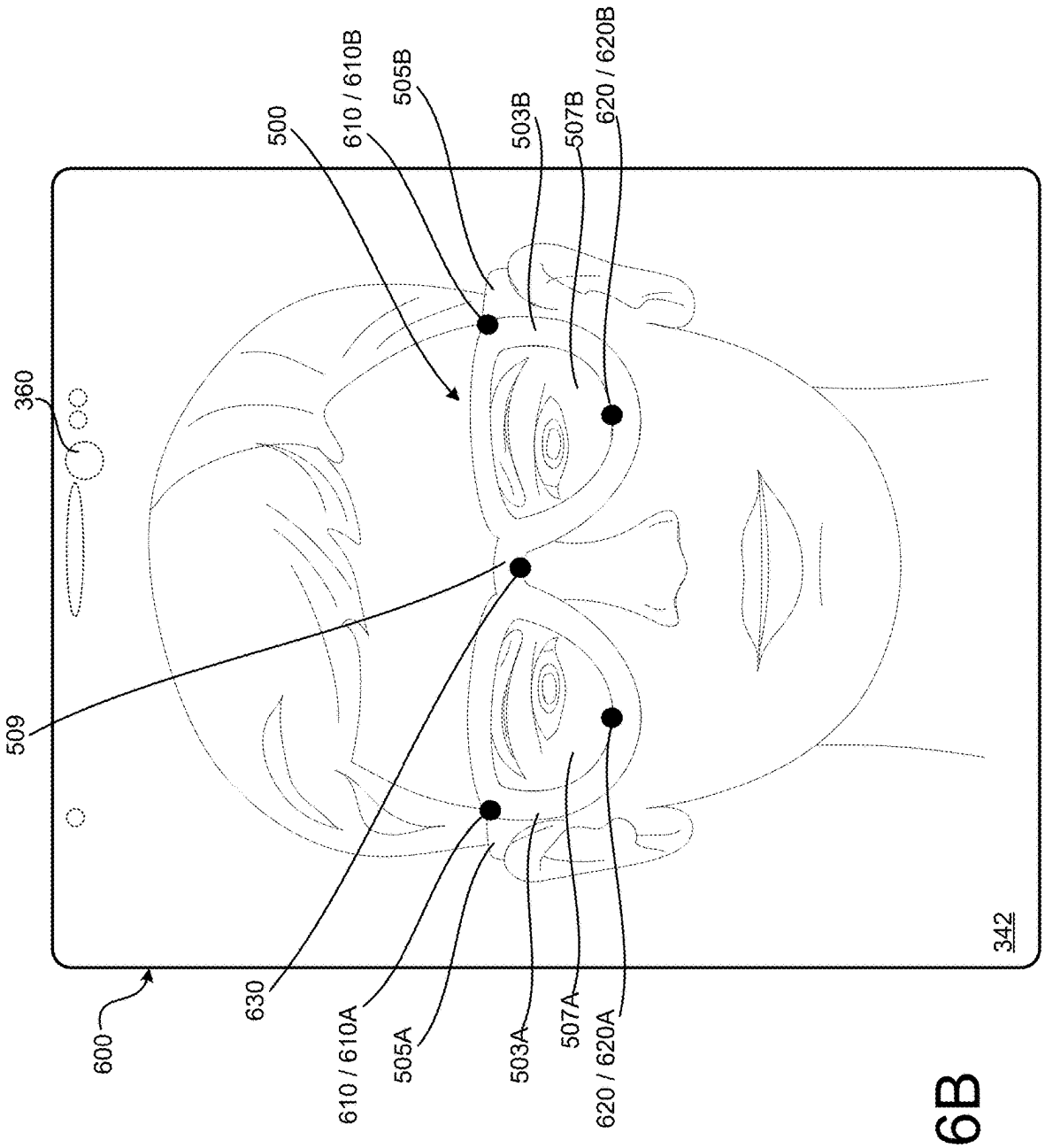

500
610 / 610B
505B
503B
507B
620 / 620B
360
509
630
610 / 610A
505A
503A
507A
620 / 620A
600
342

FIG. 6B

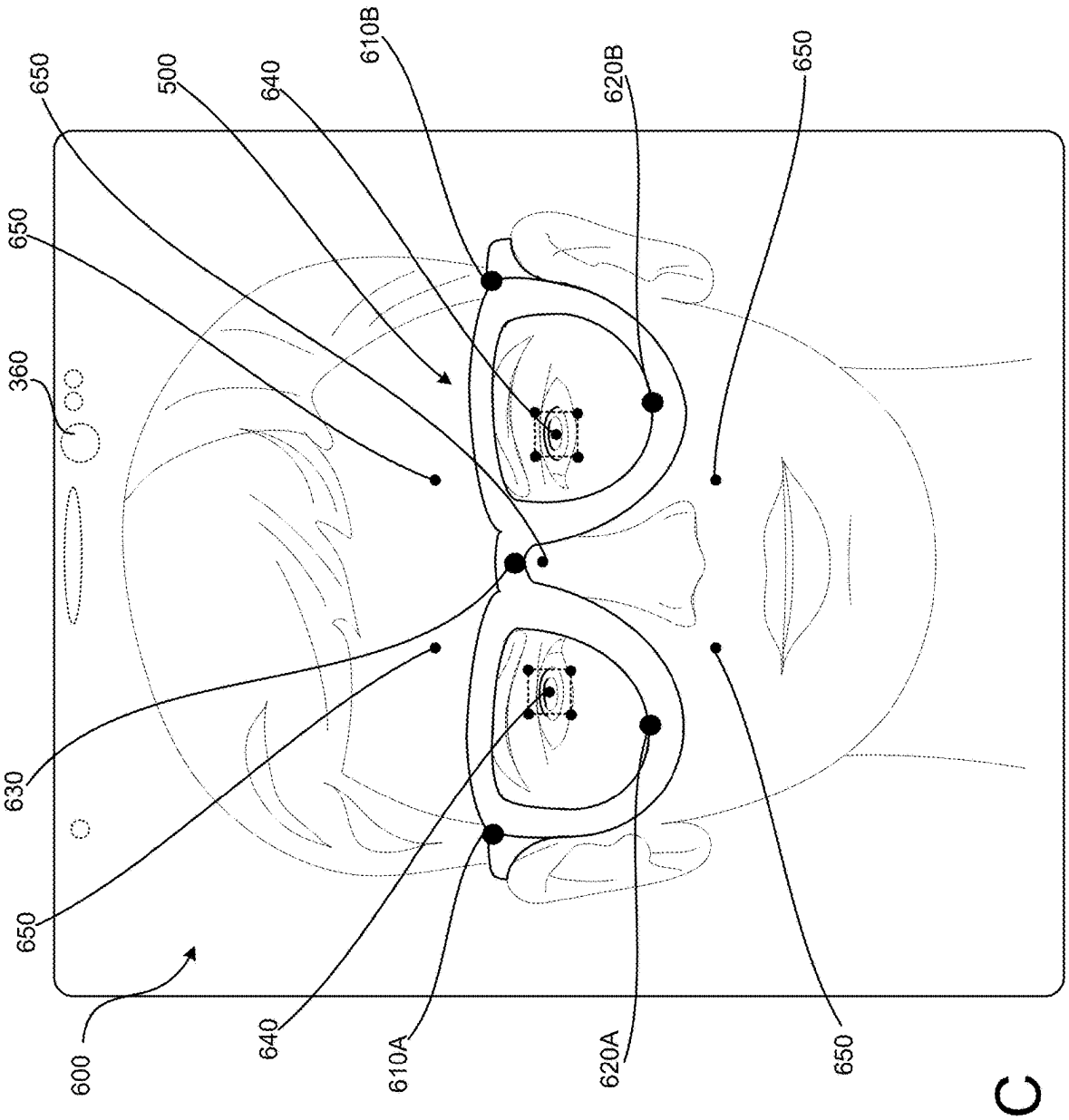


FIG. 6C

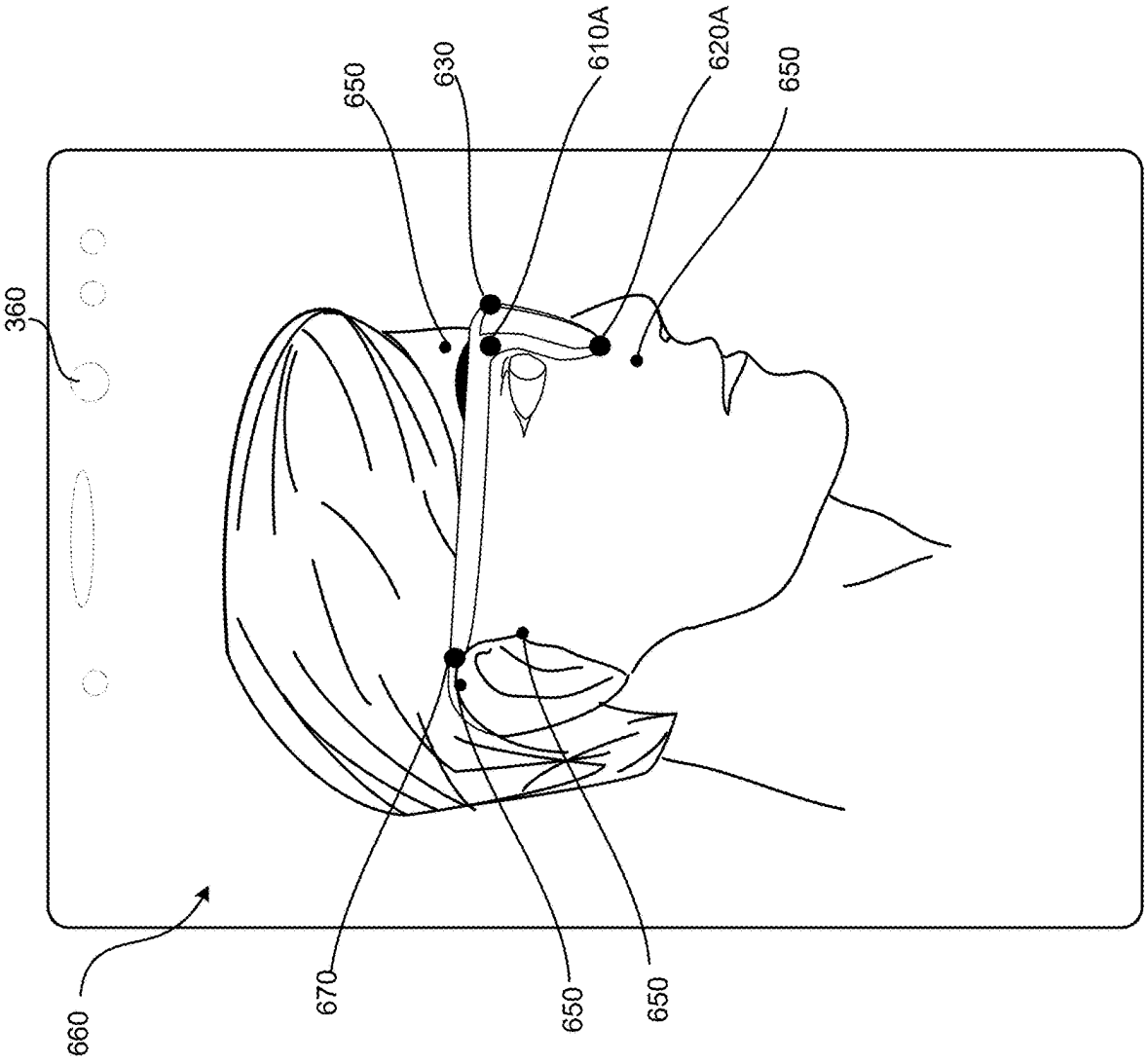


FIG. 6D

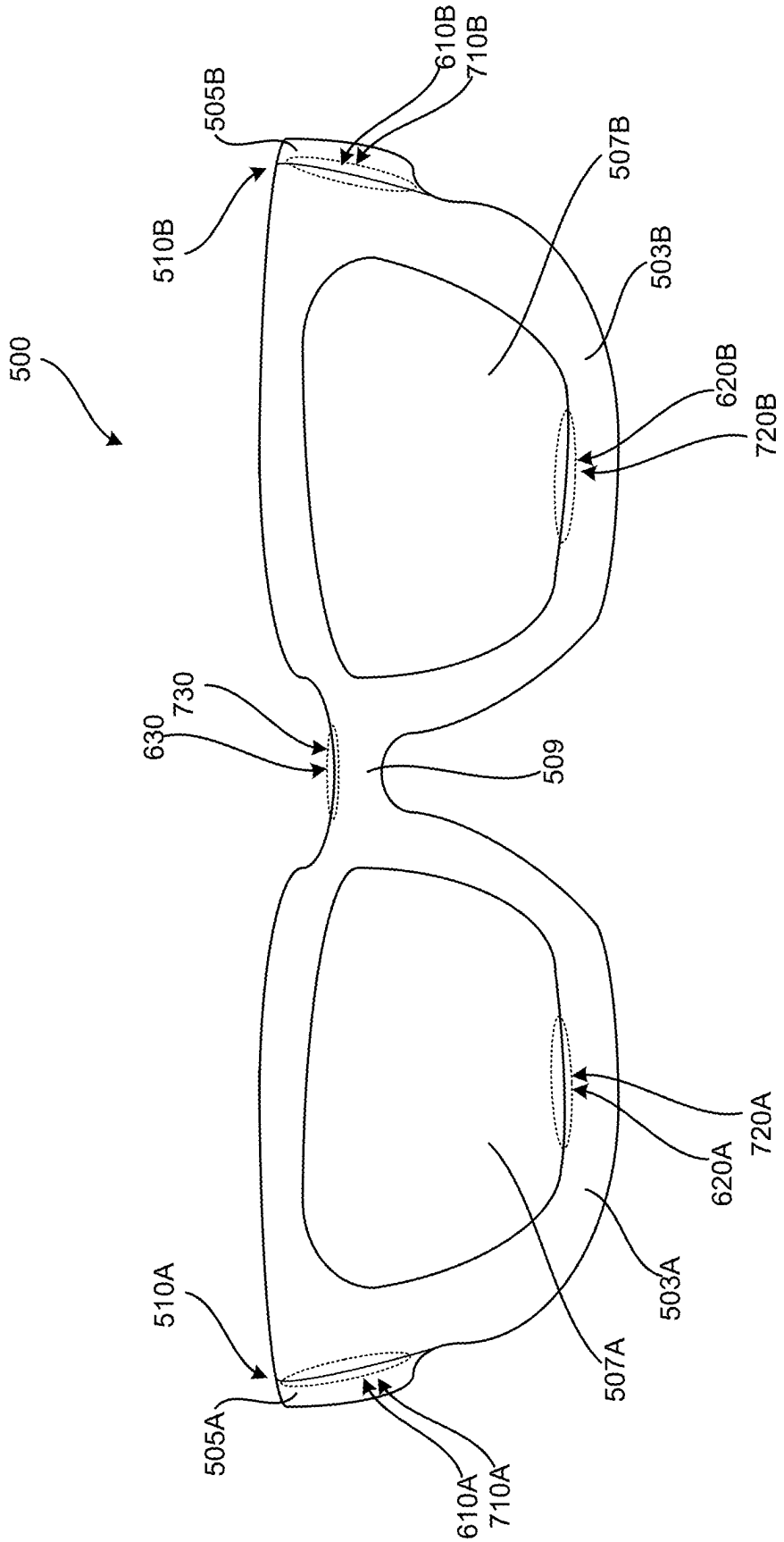

500
505B
610B
710B
510B
507B
503B
620B
720B
630
730
509
720A
620A
503A
507A
510A
505A
610A
710A

FIG. 7

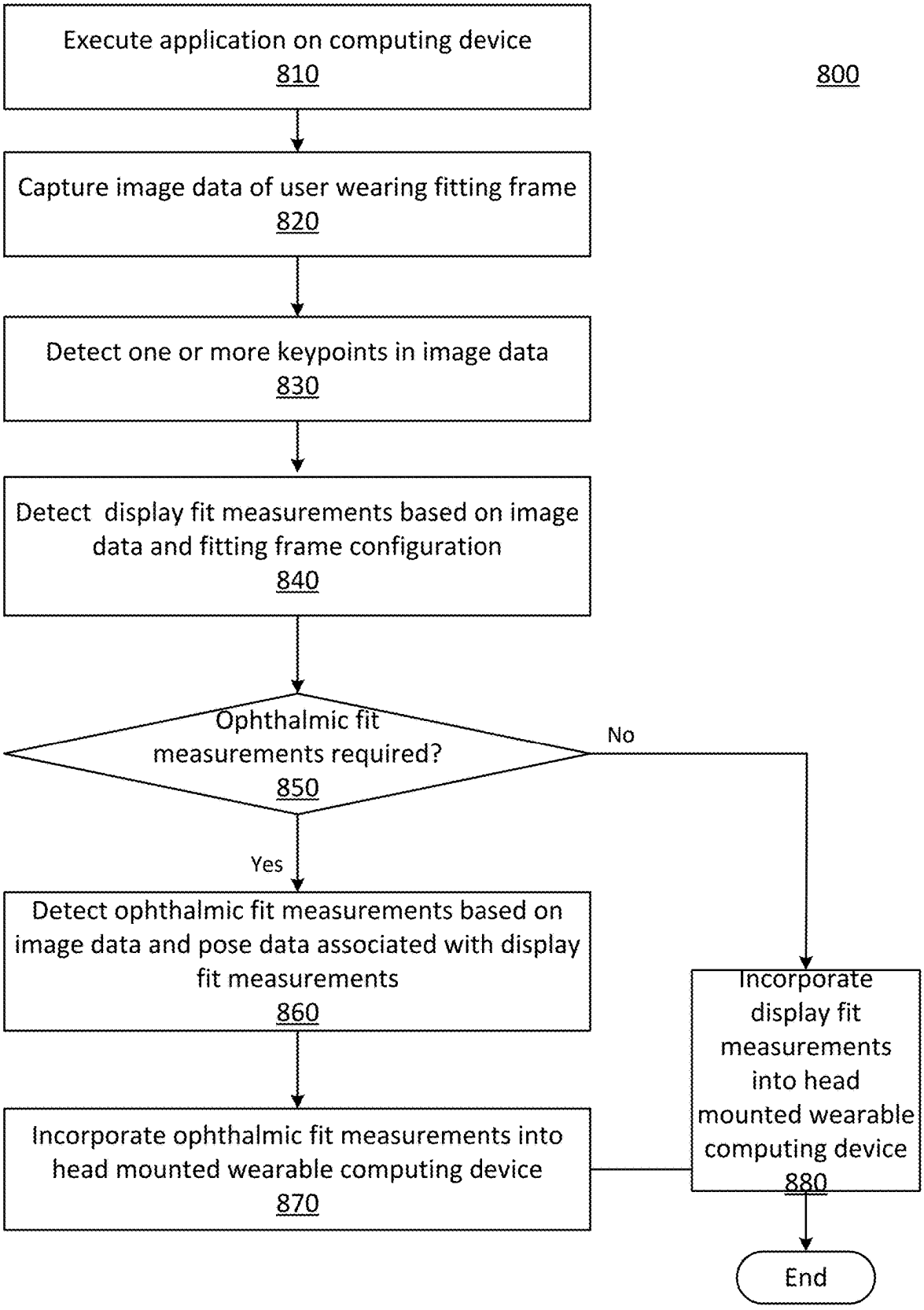

Execute application on computing device
810
800
Capture image data of user wearing fitting frame
820
Detect one or more keypoints in image data
830
Detect display fit measurements based on image data and fitting frame configuration
840
Ophthalmic fit measurements required?
850
No
Yes
Detect ophthalmic fit measurements based on image data and pose data associated with display fit measurements
860
Incorporate ophthalmic fit measurements into head mounted wearable computing device
870
Incorporate display fit measurements into head mounted wearable computing device
880
End

FIG. 8

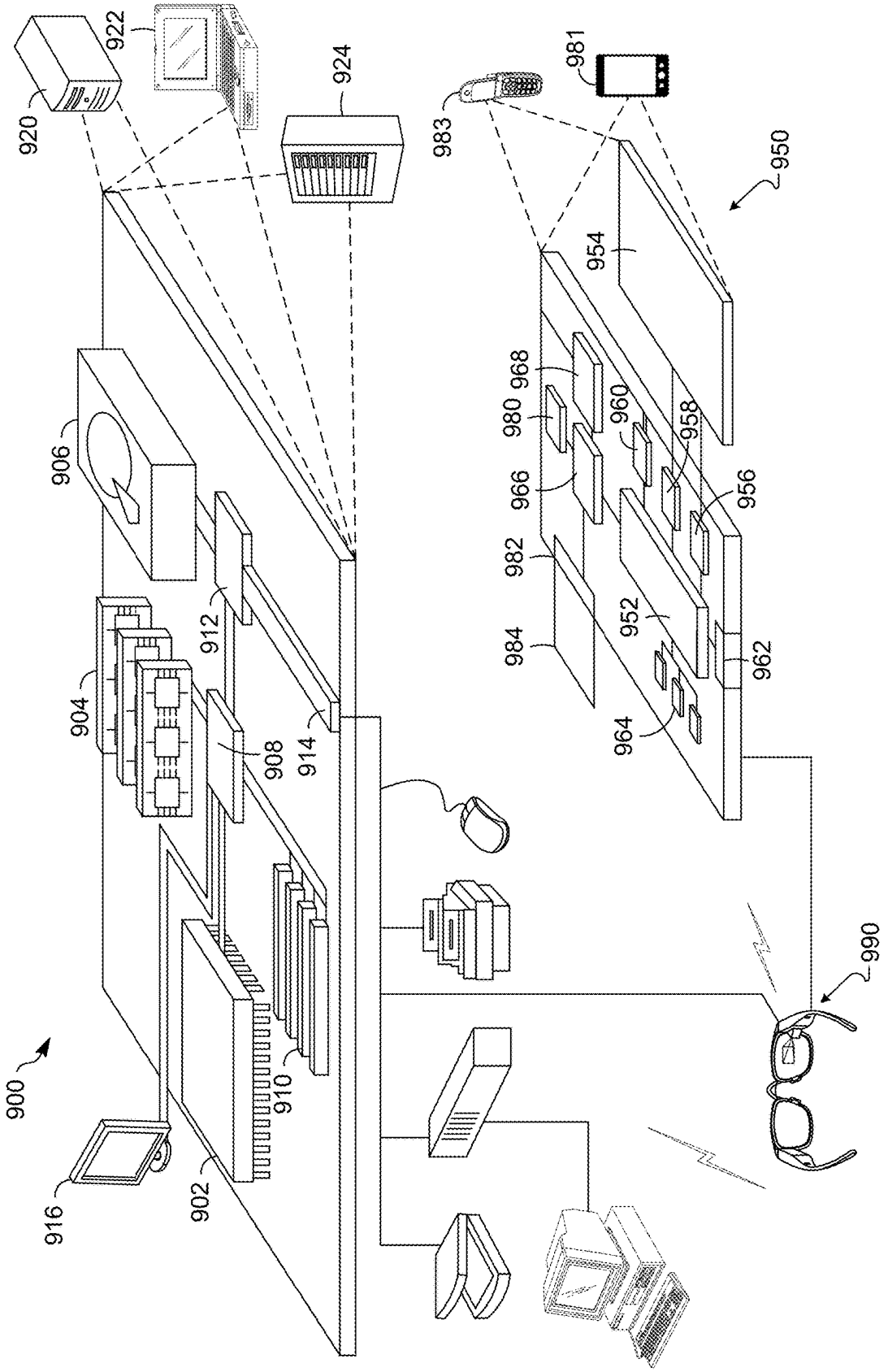

900
902
904
906
908
910
912
914
916
920
922
924
950
954
956
958
960
962
964
966
968
980
981
982
983
984
990
952

FIG. 9

IMAGE BASED DETECTION OF FIT FOR A HEAD MOUNTED WEARABLE COMPUTING DEVICE

TECHNICAL FIELD

This description relates in general to the prediction of wearable fit and/or display fit and/or ophthalmic fit of a wearable device, and in particular to the prediction of display fit and ophthalmic fit of a head worn computing device including display capability.

BACKGROUND

Wearable devices may include head worn devices including, for example, smart glasses, headsets, ear buds and the like, wrist and/or hand worn devices such as smart watches, smart bracelets, smart rings and the like, smart pendants, fitness trackers, cameras, body sensors, and other such devices. In some examples, a user may want to select and/or customize a wearable device for fit and/or function. For example, a user may wish to select and/or customize a pair of smart glasses to include selection of frames, incorporation of prescription lenses, and other such features. Existing systems for procurement of these types of wearable devices do not provide for accurate fitting and customization, particularly without access to a retail establishment.

SUMMARY

In one general aspect, a method of detecting display fit measurements for a head mounted wearable computing device including a display device includes detecting, by an application executing on a computing device, at least one keypoint on a fitting frame worn by a user from an image captured by a computing device; accessing configuration information associated with the fitting frame detected in the image; determining a three-dimensional pose of the fitting frame captured in the image based on the detecting of the at least one keypoint and the configuration information associated with the fitting frame; and determining a configuration of the display device of the head mounted wearable computing device based on the three-dimensional pose of the fitting frame as captured in the image.

In some implementations, detecting the at least one keypoint includes detecting at least one of a bridge portion of the fitting frame; a hinge point between a rim portion and an arm portion of the fitting frame; a peripheral edge portion of a lens of the fitting frame; or a saddle portion of the arm portion of the fitting frame.

In some implementations, determining the three-dimensional pose of the fitting frame includes accessing a three-dimensional model of the fitting frame captured in the image; and performing a comparison, including comparing a known position and orientation of the at least one keypoint detected in the image to a corresponding position and orientation of the at least one keypoint in the three-dimensional model of the fitting frame. Detecting at least one keypoint may include detecting a plurality of keypoints on the fitting frame in the image captured by the computing device; and performing the comparison may include, for each of the plurality of keypoints, comparing a known position and orientation of the keypoint detected in the image to a corresponding position and orientation of the keypoint in the three-dimensional model of the fitting frame. Determining the three-dimensional pose of the fitting frame may include performing a correspondence between a two-dimensional position of each keypoint detected in the image to a corresponding three-dimensional position of the respective keypoint in the three-dimensional model of the fitting frame.

In some implementations, the method may also include detecting a plurality of facial landmarks in the captured image; and determining ophthalmic fit measurements for the head mounted wearable computing device based on the detected plurality of facial landmarks. Detecting the plurality of facial landmarks may include detecting a pupil height in the image of the fitting frame worn by the user; detecting at least one of an interpupillary distance or a monocular pupil distance in the image of the fitting frame worn by the user; and determining a pantoscopic angle of the fitting frame worn by the user based on the determined three-dimensional pose of the fitting frame and the detected plurality of facial landmarks. Determining the configuration of the display device of the head mounted wearable computing device based on the three-dimensional pose of the fitting frame as captured in the image may include adapting the configuration of the display device of the head mounted wearable computing device to accommodate the ophthalmic fit measurements. Determining the configuration of the display device of the head mounted wearable computing device may include determining a user field of view based on the ophthalmic fit measurements and the three-dimensional pose of the fitting frame; and configuring an output coupler of the display device such that content output by the display device is displayed within the determined field of view.

In another general aspect, a non-transitory computer-readable medium may store executable instructions that, when executed by at least one processor, are configured to cause the at least one processor to capture an image of a fitting frame worn by a user; detect at least one keypoint on the fitting frame from the captured image; access configuration information associated with the fitting frame; determine a three-dimensional pose of the fitting frame captured in the image based on the detection of the at least one keypoint and the configuration information associated with the fitting frame; and determine a configuration of a display device of a head mounted wearable computing device based on the three-dimensional pose of the fitting frame as captured in the image.

In some implementations, the instructions cause the at least one processor to detect the at least one keypoint on the fitting frame in the captured image, including at least one of detect a first keypoint including a bridge portion of the fitting frame; detect a second keypoint including a hinge portion between a rim portion and an arm portion of the fitting frame; detect a third keypoint including a peripheral edge portion of a lens of the fitting frame; or detect a fourth keypoint including a saddle portion of the arm portion of the fitting frame. In some implementations, the instructions cause the at least one processor to determine the three-dimensional pose of the fitting frame, including access a three-dimensional model of the fitting frame captured in the image; and perform a comparison between a known position and orientation of the at least one keypoint detected in the image to a corresponding position and orientation of the at least one keypoint in the three-dimensional model of the fitting frame.

In some implementations, the instructions cause the at least one processor to detect a plurality of keypoints, and to perform the comparison, including, for each of the plurality of keypoints, compare a known position and orientation of the keypoint detected in the image to a corresponding

position and orientation of the keypoint in the three-dimensional model of the fitting frame. In some implementations, the instructions cause the at least one processor to determine the three-dimensional pose, including performing a correspondence between a two-dimensional position of each keypoint detected in the image to a corresponding three-dimensional position of the respective keypoint in the three-dimensional model of the fitting frame.

In some implementations, the instructions also cause the at least one processor to detect a plurality of facial landmarks in the captured image; and determine ophthalmic fit measurements for the head mounted wearable computing device based on the detected plurality of facial landmarks. The instructions may cause the at least one processor to detect the plurality of facial landmarks, including detect a pupil height in the image of the fitting frame worn by the user; detect at least one of an interpupillary distance or a monocular pupil distance in the image of the fitting frame worn by the user; and determine a pantoscopic angle of the fitting frame worn by the user based on the determined three-dimensional pose of the fitting frame and the detected plurality of facial landmarks. In some implementations, the instructions cause the at least one processor to adapt the configuration of the display device of the head mounted wearable computing device to accommodate the ophthalmic fit measurements, including determine a user field of view based on the ophthalmic fit measurements and the three-dimensional pose of the fitting frame; and configure an output coupler of the display device such that content output by the display device is displayed within the determined field of view.

The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates an example system, in accordance with implementations described herein.

FIG. **1**B is a front view, and FIG. **1**C is a rear view, of an example wearable computing device shown in FIG. **1**A, in accordance with implementations described herein.

FIGS. **2**A-**2**D illustrate example ophthalmic measurements.

FIG. **3** is a block diagram of a system, in accordance with implementations described herein.

FIGS. **4**A-**4**B illustrate image capture modes for determining display fit measurements and ophthalmic fit measurements, in accordance with implementations described herein.

FIGS. **5**A-**5**C are perspective views of example fitting frames, in accordance with implementations described herein.

FIGS. **6**A-**6**C illustrate an example frontal image of an example fitting frame worn by a user, and example features and/or keypoints and/or landmarks detected in the frontal image, in accordance with implementations described herein.

FIG. **6**D illustrates an example profile image of an example fitting frame worn by a user, and example features and/or keypoints and/or landmarks detected in the profile image, in accordance with implementations described herein.

FIG. **7** is a front view of an example fitting frame, in accordance with implementations described herein.

FIG. **8** is a flowchart of an example method, in accordance with implementations described herein.

FIG. **9** illustrates example computing devices of the computing systems discussed herein.

DETAILED DESCRIPTION

This disclosure relates to systems and methods for selection and fitting of a wearable computing device, including the determination of wearable fit and/or display fit and/or ophthalmic fit parameters associated with the wearable computing device. Systems and methods, in accordance with implementations described herein, provide for the determination of wearable fit and/or display fit and/or ophthalmic fit for a wearable computing device based on measurements detected within image data. In some implementations, systems and methods, in accordance with implementations described herein, provide for the detection of wearable fit and/or display fit and/or ophthalmic fit based on known parameters associated with a sample frame of the wearable computing device detected within the image data. In some examples, systems and methods as described herein provide for the detection of wearable fit and/or display fit and/or ophthalmic fit from image data, for wearable computing devices in the form of smart glasses that include a display and/or corrective/prescription lenses that are customized for the particular physical attributes, needs and preferences of a particular user. Systems and methods, in accordance with implementations described herein, may facilitate the capture of image data for the detection of measurement data by the user in a self-directed, or unsupervised, or unproctored manner, without access to a retail establishment and/or an in-person or virtual appointment with a sales agent.

Hereinafter, systems and methods, in accordance with implementations described herein, will be described with respect to the fitting of a wearable computing device in the form of a head mounted display device, such as, for example, smart glasses including a display device, such that content displayed by the display device is viewable by/visible to a user wearing the wearable computing device. In a situation in which the user would benefit from a head mounted wearable computing device including corrective lenses, systems and methods as described herein may provide for the determination of ophthalmic fit measurements, allowing for the incorporation of corrective/prescription lenses into the head mounted wearable computing device, while taking into account the features of the corrective/prescription lenses in the configuration of the display device for the head mounted wearable computing device. That is, systems and methods, in accordance with implementations described herein, may employ an image based capture system and method to provide for the fitting of a display device and corrective/prescription lenses such that content displayed by the display device is visible to the user wearing the head mounted wearable computing device.

FIG. **1**A illustrates a user operating mobile computing devices in a system in which the mobile computing devices can access one or more external resources **1100** via a network **1200**. FIG. **1**A provides a third person view of the user in an ambient environment **1000**, including various examples of mobile computing devices **100**, **180**, **190**, **200**. The example mobile computing devices shown in FIG. **1**A include a first head worn wearable computing device **100**, a second head worn wearable computing device **180**, a wrist worn computing device **190**, and a handheld computing device **200**. In some examples, the first head worn computing device **100** can include various components including

for example a display, a camera that can capture images of the ambient environment, audio input/output capability, user input capability and the like, such as in a head mounted display device, in the form of smart glasses, or a headset. In some examples, the second head worn computing device **180** can be an ear worn computing device such as headphones, or earbuds, and can include audio input/output capability, a camera that can capture images of the ambient environment, user input capability and the like. In some examples, the wrist worn computing device **190** can include a display, a camera that can capture images of the ambient environment, audio input/output capability, user input capability and the like, such as in a smart watch, or wristband. In some examples, the handheld computing device **200** can include a display, a camera that can capture images of the ambient environment, audio input/output capability, user input capability, and the like, such as in a smartphone. FIG. **1**A illustrates just some examples of mobile computing devices. The principles to be described herein may be applied to other types of mobile computing devices not specifically shown in FIG. **1**A. In some examples, the mobile computing devices, including the example computing devices shown in FIG. **1**A, can communicate with each other and/or with the external resources **1100**, to exchange information, to receive and transmit input and/or output, and the like.

FIG. **1**B is a front view, and FIG. **1**C is a rear view, of the example head mounted wearable computing device **100** shown in FIG. **1**A. In some implementations, the example head mounted wearable computing device **100** may take the form of a pair of smart glasses, or augmented reality glasses, as in the example shown in FIGS. **1**B and **1**C, or an augmented reality and/or virtual reality headset or goggles, and the like. Hereinafter, systems and methods in accordance with implementations described herein will be described with respect to the wearable computing device **100** in the form of smart glasses, simply for ease of discussion and illustration. The principles to be described herein can be applied to other types of wearable computing devices and/or combinations of mobile/wearable computing devices working together.

As shown in FIG. **1**B, the example head mounted wearable computing device **100** includes a frame **102**. In the example shown in FIGS. **1**B and **1**C, the frame **102** includes rim portions **103** surrounding glass portion(s) **107**, or lenses **107**. Arm portions **105** are coupled, for example, pivotably or rotatably coupled, to a respective rim portion **103** of the frame **102** by a respective hinge portion **110**. In some examples, the lenses **107** may be corrective/prescription lenses. In some examples, the lenses **107** may be glass portions that do not necessarily incorporate corrective/prescription parameters. In some examples, a bridge portion **109** may connect the rim portions **103** of the frame **102**. A display device **104** may be coupled in a portion of the frame **102**. In the example shown in FIGS. **1**B and **1**C, the display device **104** is coupled in the arm portion **105** of the frame **102**. With the display device **104** coupled in the arm portion **105**, an eye box **140** extends toward the lens(es) **107**, for output of content at an output coupler **144** at which content output by the display device **104** may be visible to the user. In some examples, the output coupler **144** may be substantially coincident with the lens(es) **107**. The head mounted wearable computing device **100** can also include an audio output device **106** (such as, for example, one or more speakers), an illumination device **108**, a sensing system **111**, a control system **112**, at least one processor **114**, and an outward facing image sensor **116**, or camera **116**. In some implementations, the display device **104** may include a see-through near-eye display. For example, the display device **104** may be configured to project light from a display source onto a portion of teleprompter glass functioning as a beamsplitter seated at an angle (e.g., 30-45 degrees). The beamsplitter may allow for reflection and transmission values that allow the light from the display source to be partially reflected while the remaining light is transmitted through. Such an optic design may allow a user to see both physical items in the world, for example, through the lenses **107**, next to content (for example, digital images, user interface elements, virtual content, and the like) generated by the display device **104**. In some implementations, waveguide optics may be used to depict content on the display device **104**.

In some implementations, the wearable computing device **100** may include a gaze tracking device **120** including, for example, one or more sensors **125**, to detect and track eye gaze direction and movement. Data captured by the sensor(s) **125** may be processed to detect and track gaze direction and movement as a user input. In some implementations, the sensing system **111** may include various sensing devices and the control system **112** may include various control system devices including, for example, one or more processors **114** operably coupled to the components of the control system **112**. In some implementations, the control system **112** may include a communication module providing for communication and exchange of information between the wearable computing device **100** and other external devices.

Numerous different sizing and fitting measurements and/or parameters may be taken into account when sizing and fitting the wearable computing device **100**, such as the example smart glasses shown in FIGS. **1**A-IC, for a particular user. This may include, for example, wearable fit parameters, or wearable fit measurements. Wearable fit parameters/measurements may take into account how a particular frame **102** fits and/or looks and/or feels on a particular user. Wearable fit parameters/measurements may take into consideration numerous factors such as, for example, whether the frame **102** is wide enough to be comfortable with respect to the temples yet also not so wide that the frame **102** cannot remain relatively stationary when worn by the user (i.e., too big, or too wide). Wearable fit parameters/measurements may take into consideration other factors such as whether the rim portions **103** and bridge portion **109** are sized so that the bridge portion **109** can rest comfortably on the bridge of the user's nose, whether the arm portions **105** are sized to comfortably rest on the user's ears, and other such comfort related considerations. Wearable fit parameters/measurements may take into account as-worn considerations including how the user naturally wears the frame **102**, such as, for example, head posture/how the user naturally holds his/her head, how the user positions the frame relative to his/her face, and the like. Wearable fit parameters/measurements may take into account whether the size and/or shape and/or contour of the frame **102** is aesthetically pleasing to the user, and is compatible with the user's facial features. In some examples, wearable fit parameters/measurements may take into account whether a fit associated with a particular frame configuration can accommodate incorporation of a display device such that a display area can be coordinated with the natural field of view of the user. In some examples, wearable fit parameters may take into account whether an eye tracking camera arrangement associated with a particular frame configuration can effectively track user eye gaze and movement.

Display fit parameters, or display fit measurements may be taken into account when sizing and fitting the wearable computing device **100** for a particular user. Display fit parameters/measurements may be used to configure the display device **104** for a set of frames **102** for a particular user, so that content displayed by the display device **104** is visible to the user. For example, display fit parameters/measurements may provide an indication of placement of the display device **104** so that content displayed by the display device **104** is captured within at least a set portion of the field of view of the user. For example, the display fit parameters/measurements may be used to configure the display device **104** to provide at least a set level of gazability, corresponding to an amount, or portion, or percentage of the display of content that is visible to the user at a set brightness level and a set pupil size at a periphery (for example, a least visible corner) of the field of view of the user. The display fit parameters/measurements may be used to configure the display device **104** to provide the best possible placement of the display of content to the user for a particular set of frames **102**.

In some examples, ophthalmic fit parameters, or ophthalmic fit measurements may be taken into account when sizing and fitting the wearable computing device **100** including prescription, or corrective lenses **107**. Some example ophthalmic fit measurements are shown in FIGS. **2**A-**2**D. Ophthalmic fit measurements may include, for example, a pupil height PH (a distance from a center of the pupil to a bottom of the lens **107**), including for example, a left pupil height and a right pupil height. Ophthalmic fit measurements may include an interpupillary distance IPD (a distance between the pupils). IPD may be characterized by a monocular pupil distance, for example, a left pupil distance LPD (a distance from a central portion of the bridge of the nose to the left pupil) and a right pupil distance RPD (a distance from the central portion of the bridge of nose to right pupil). Ophthalmic fit measurements may include a pantoscopic angle PA (an angle defined by the tilt of the lens **107** with respect to vertical). Ophthalmic fit measurements may include a vertex distance V (a distance from the cornea to the lens **107**) including, for example a left vertex distance and a right vertex distance. Ophthalmic fit measurements may include other such parameters, or measures that provide for the sizing and/or fitting of a head mounted wearable computing device **100** including a display device **104** as described above. FIG. **2**C illustrates a vertex distance V associated with a relatively lower diopter lens **107**. FIG. **2**D illustrates a vertex distance V associated with a relatively higher diopter lens **107**. Ophthalmic fit measurements may be taken into account when fitting the wearable computing device **100**, including the display device **104**, for the user. For example, ophthalmic fit measurements (together with display fit measurements) may provide for placement of the display of content by the display device **104** within an eye box defined by a three-dimensional volume extending between the lens **107** and the eye of the user, where the display of content will be within the field of view of the user, and within a corrected field of view of the user, and thus visible to the user.

In a system and method, in accordance with implementations described herein, image data may be captured via an application executing on a computing device operated by the user, such as the computing device **200** described above with respect to FIG. **1**A, or other computing device operated by the user. Wearable fit measurements and/or display fit measurements and/or ophthalmic fit measurements may be detected from image data obtained in this manner to size and fit a head mounted wearable computing device, such as the wearable computing device **100** described above including a display and/or corrective lenses for a specific user. The image data may be captured via an application executing on the computing device **200** operated by the user in an unsupervised, or unproctored manner, without the need for access to a retail establishment, without the need for an appointment with a fitting/sales professional and the like. In some implementations, the detection of the wearable fit and/or display fit and/or ophthalmic fit measurements may be based on detection of physical features or attributes of sample frames worn by the user included in the image data. A three-dimensional model of the head of the user may be generated, or produced, or defined, based on measurements (for example, measurements of physical attributes of the user) detected within the captured image data. In some implementations, detection of the physical features and/or attributes in the image data may provide for this detection using an image sensor, or camera, of the computing device **200** without relying on data collected by a depth sensor. In some implementations, a depth sensor included in the computing device **200** may provide for the collection of three-dimensional measures associated with the detected physical features and/or attributes of the sample frames and/or facial/cranial features of the user.

FIG. **3** is a block diagram of an example system for determining display fit measurements and ophthalmic fit measurements for a wearable computing device, in accordance with implementations described herein. The system may include one or more computing devices **300**. The computing device **300** can communicate selectively via a network **306** to access external resources **302** such as, for example, server computer systems, processors, databases, memory storage, and the like. The computing device **300** can operate under the control of a control system **370**. The computing device **300** can communicate with one or more external computing devices **304** (another wearable computing device, another mobile computing device and the like) either directly (via wired and/or wireless communication), or via the network **306**. In some implementations, the computing device **300** includes a communication module **380** to facilitate external communication. In some implementations, the computing device **300** includes a sensing system **320** including various sensing system components including, for example one or more image sensors **322**, one or more position/orientation sensor(s) **324** (including for example, an inertial measurement unit, accelerometer, gyroscope, magnetometer and the like), one or more audio sensors **326** that can detect audio input, and other such sensors. The computing device **300** can include more, or fewer, sensing devices and/or combinations of sensing devices.

In some implementations, the computing device **300** may include one or more image sensor(s), or camera(s) **360**. The camera(s) **360** can include, for example, outward facing cameras, world facing cameras, and the like that can capture still and/or moving images of an environment outside of the computing device **300**. In some implementations, the one or more camera(s) **360** may include a depth sensor. The still and/or moving images may be displayed by a display device of an output system **340** and/or transmitted externally via the communication module **380** and the network **306**, and/or stored in a memory **330** of the computing device **300**. The computing device **300** may include one or more processor(s) **350**. The processors **350** may include various modules or engines configured to perform various functions. In some examples, the processor(s) **350** include object recognition

module(s), feature recognition module(s), pattern recognition module(s), configuration identification modules(s), and other such processors. The processor(s) **350** may be formed in a substrate configured to execute one or more machine executable instructions or pieces of software, firmware, or a combination thereof. The processor(s) **350** can be semiconductor-based that include semiconductor material that can perform digital logic. The memory **330** may include any type of storage device that stores information in a format that can be read and/or executed by the processor(s) **350**. The memory **330** may store applications and modules that, when executed by the processor(s) **350**, perform certain operations. In some examples, the applications and modules may be stored in an external storage device and loaded into the memory **330**.

FIGS. **4**A and **4**B illustrate example computing devices, such as the computing device **300** described above with respect to FIG. **3**, operated by a user to capture display fit measurements and/or ophthalmic fit measurements for a wearable computing device to be customized for use by the user. In FIG. **4**A, the example computing device **300**A is in the form of a handheld computing device, such as a smartphone. In FIG. **4**B, the example computing device **300** is in the form of a laptop computing device **300**B. FIGS. **4**A and **4**B provide two examples of computing devices **300** which may be used to capture image data for processing by a sizing simulator to carry out the systems and methods described herein. The principles to be described herein may be carried out by other types of computing devices, and in particular computing devices capable of executing applications thereon to make use of image capture capability, display capability, and external communication and processing to collect and process display fit measurements and/or ophthalmic measurements for customizing a wearable computing device for a particular user.

In the example shown in FIG. **4**A, the user is holding the computing device **300**A, so that the head and face of the user is in the field of view of a camera **360**A of the computing device **300**A, and the camera **360**A can capture an image of the head and face of the user. The captured image may be displayed to the user on a display device **342**A of the computing device **300**A, so that the user can verify that his/her head and face are captured within the field of view of the camera **360**A. Similarly, as shown in FIG. **4**B, the computing device **300**B is positioned relative to the user so that the head and face of the user are captured within the field of view of the camera **360**B of the computing device **300**B, and the camera **360**B can capture an image of the head and face of the user. The captured image may be displayed to the user on a display device **342**B of the computing device **300**B, so that the user can verify that his/her head and face are captured within the field of view of the camera **360**B. In the example arrangements shown in FIGS. **4**A and **4**B, image data captured by the camera **360** may be processed (for example, by recognition engine(s) and simulation engine(s) of external processor(s) as shown in FIG. **3**) to detect wearable fit and/or display fit and/or ophthalmic fit measurements, and to determine for example, frame and/or lens sizing and contouring, display device configuration, and the like for the customization of a wearable computing device, such as, for example, the head mounted wearable computing device **100** shown in FIGS. **1**B and **1**C for the user.

In the example shown in FIGS. **4**A and **4**B, the user is wearing an example fitting frame **500**. The fitting frame **500** is included in the image of the head and face of the user that is captured by the camera **360** of the computing device **300**.

As described above, the detection of wearable fit and/or display fit and/or ophthalmic fit measurements from the captured image data may be facilitated by the detection of one or more physical features and/or attributes associated with the fitting frames worn by the user during the capture of image data. In some examples, the user may try on, or sample, a number of different fitting frames from a collection, or a kit of sample fitting frames. A fitting kit including the sample fitting frames may be provided to the user in advance of a fitting session. This may allow the user to assess at least some wearable fit parameters. For example, by trying on, or sampling a number of different fitting frames from of the fitting kit including the sample fitting frames, the user may assess factors such as, for example physical sizing, comfort, aesthetics and the like. The user may select a fitting frame from the fitting kit including the sample fitting frames for use during the fitting session. The sample fitting frames including in the fitting kit may mimic the size, shape, weight and the like of actual frames to be incorporated into the head mounted wearable computing device **100** based on the data captured during the fitting session, so as to provide the user with a relatively accurate fit and feel. Image data captured via the application running on the computing device **200** during the fitting session may be used to determine display fit and/or ophthalmic fit. Measurement data collected in this manner may be used to tailor the display device **104**, and in particular, the image display area produced by the display device **104**, for the user and the selected fitting frame based on the measurements detected from the image data. Measurement data collected in this manner may be used to incorporate corrective, or prescription lenses into the head mounted wearable computing device **100**. Measurement data collected in this manner may be used to both configure the display device **104** for the user and the selected frames, and also incorporate corrective/prescription lenses into the head mounted wearable computing device **100**.

FIGS. **5**A-**5**C illustrate example fitting frames **500**, for example a first example fitting frame **500**A, a second example fitting frame **500**B, and a third example fitting frame **500**C, for fitting a head mounted wearable computing device, in accordance with implementations described herein. The example fitting frames **500** may be physically, or geometrically representative of actual frames of a head mounted wearable computing device to be worn by a user, but simply for sizing/fitting purposes, and thus non-functional. The example fitting frames **500** shown in FIGS. **5**A-**5**C are examples of sample fitting frames **500** that could be included in a fitting kit provided to the user for consideration in advance of the fitting session. The principles to be described herein are applicable to fitting frames having other shapes and/or sizes and/or configurations. The first example fitting frame **500**A shown in FIG. **5**A has a first size and/or shape and/or contour defined by a first set of physical features. The first example fitting frame **500**A may be considered to be a medium sized frame having D-shaped rim portions **503**A, **503**B. The second example fitting frame **500**B shown in FIG. **5**B has a second size and/or shape and/or contour defined by a second set of physical features. The second example fitting frame **500**B may be considered to be a medium sized frame having rounded rim portions **503**A, **503**B. The third example fitting frame **500**C shown in FIG. **5**C has a third size and/or shape and/or contour defined by a third set of physical features. The third example fitting frame **500**C may be considered to be a large sized frame having rectangular rim portions **503**A, **503**B. The example fitting frames **500** (**500**A, **500**B, **500**C) shown in FIGS. **5**A-**5**C are presented for purposes of discussion and illus-

tration. The principles to be described herein may be applied to other fitting frames, having other sizes and/or shapes and/or contours defined by other physical features.

Each of the example fitting frames **500** (**500**A, **500**B, **500**C) shown in FIGS. **5**A-**5**C includes a first rim portion **503**A surrounding a first glass portion, or first lens **507**A, and a second rim portion **503**B surrounding a second glass portion, or second lens **507**B. The first rim portion **503**A/first lens **507**A may be configured to be positioned to correspond to a first eye of the user, and the second rim portion **503**B/first lens **507**B may be configured to be positioned to correspond to a second eye of the user when the example fitting frame **500** (**500**A, **500**B, **500**C) is worn by the user. A bridge portion **509** may extend between inner end portions of the rim portions **503**A, **503**B to connect the rim portions **503**A, **503**B of the example fitting frame **500** (**500**A, **500**B, **500**C). The bridge portion **509** may be configured to rest on the nose of the user, to position the first rim portion **503**A/first lens **507**A to correspond to the first eye, and to position the second rim portion **503**B/second lens **507**B to correspond to the second eye. A first arm portion **505**A may be coupled, for example pivotably or rotatably coupled to an outer end portion of the first rim portion **503**A by a first hinge portion **510**A. A second arm portion **505**B may be coupled, for example pivotably or rotatably coupled to an outer end portion of the second rim portion **503**B by a second hinge portion **510**B. The first and second arm portions **505**A, **505**B may each include ear saddle portions **515**A, **515**B that are configured to rest on respective first and second ears of the user when the example fitting frame **500** (**500**A, **500**B, **500**C) is worn by the user

As described above, a fitting frame in accordance with implementations described herein may include physical features or attributes that may be detected, or identified, or recognized in image data including the fitting frame as worn by the user. FIG. **6**A illustrates an example two-dimensional image plane **600**, or image **600**, of a user wearing the example fitting frame **500**. The example image **600** may be captured by the camera **360** of the computing device **300** operated by the user, through an application executed by the computing device **300**. In the example shown in FIG. **6**A, the image **600** is displayed on the display device **342** of the computing device **300**. This may allow the user to visually verify that the captured image data includes capture of the fitting frame **500**, facial and/or cranial and/or optical features of the user, and the like. In an example in which the computing device **300** is a handheld mobile computing device such as a smartphone, a self-portrait mode, or a selfie mode, may be invoked for the capture of image data by camera **360** of the computing device **300**.

The image **600** may include a two-dimensional array of pixels captured by the camera **360**. In some examples, features detected within the image **600** may correspond to positions, for example, two-dimensional coordinate positions, of the detected features within the image **600**. FIG. **6**B illustrates some examples of detectable keypoints, or detectable features, associated with the fitting frame **500** worn by the user while the image data is captured. Keypoints, or features, detected in the image data, may allow a three-dimensional pose of the fitting frame **500** on the face of the user to be determined, which may in turn be used to determine display fit information and/or ophthalmic fit information associated with the fitting frame **500** as worn by the user. Detection of these types of keypoints associated with the fitting frame **500** worn by the user in the image data are critical in the determination of the display fit and/or ophthalmic fit information that allows the head mounted wearable computing device **100** to be configured for the user.

The example arrangement shown in FIG. **6**B includes an example keypoint **610**A at a position in the image **600** corresponding to a hinged coupling point between the first rim portion **503**A and the first arm portion **505**A of the fitting frame **500**, for example, a position corresponding to the first hinge portion **510**A pivotably coupling the rim portion **503**A and the first arm portion **505**A. The example arrangement shown in FIG. **6**B includes an example keypoint **610**B at a position in the image **600** corresponding to a hinged coupling point between the second rim portion **503**B and the second arm portion **505**B of the fitting frame **500**. The example arrangement shown in FIG. **6**B includes an example keypoint **620**A at a position corresponding to a bottom peripheral edge portion of the first lens **507**A of the fitting frame **500**, and an example keypoint **620**B at a position corresponding to a bottom peripheral edge portion of the second lens **507**B of the fitting frame **500**. The example keypoints **620**A, **620**B are simply example keypoints corresponding to a particular peripheral edge portion of the lenses **507**. Keypoints can also and/or instead be defined at other peripheral edge portion(s) of the lenses **507** such as, for example, a top peripheral edge portion, a left peripheral edge portion and/or a right peripheral edge portion of the lenses **507**. In some examples, keypoint(s) defined along the peripheral edge portion of the lenses **507** may correspond to designated section(s) of the lenses **507**. In some examples, keypoint(s) defined along the peripheral edge portion of the lenses **507** may correspond to a particular point along the peripheral edge of the lenses **507**. The example arrangement shown in FIG. **6**B includes an example keypoint **630** at a position in the image **600** corresponding to the bridge portion **509** of the fitting frame **500**.

The example image **600** shown in FIGS. **6**A and **6**B is a substantially frontal image, and the example keypoints **610**, **620**, **630**, or features **610**, **620**, **630** are just some examples of detectable keypoints, or features, associated with the fitting frame **500** worn by the user that may be detected in the image **600** to in turn detect display fit and/or ophthalmic fit associated with the fitting frame **500** for the user. Other keypoints, or features, associated with the fitting frame **500** may be detected in the image **600** to facilitate the determination of display fit and/or ophthalmic fit. Examples of other detectable keypoints, or detectable features may include, for example, a top portion of the lenses **507**, inner peripheral portions of the lenses **507** (i.e., portions of the lenses **507** adjacent to the bridge portion **509** of the fitting frame **500**), outer peripheral portions of the lenses **507** (i.e., portions of the lenses **507** adjacent to the hinge portions **510** of the fitting frame **500**), and the like. Distribution of the detectable keypoints, or features, across the fitting frame **500**, and separation of the keypoints, or features, may improve detection accuracy and correlation with the three-dimensional model. Additionally, other keypoints, or features associated with the fitting frame **500** may be detected in a profile image of the user, or an image that is captured at an angle with respect to the user, which may include portions of the arm portion(s) **505** of the fitting frame **500**, position of the ear saddle point(s) **515** with respect to the ear of the user, position of the rim portion(s) **503** with respect to the face of the user, and the like. More, or fewer, keypoints and/or combinations of keypoints associated with the fitting frame **500** may be detected in the image **600** to determine display fit and/or ophthalmic fit of the fitting frame **500** for the user. As noted above, detection of specific keypoints associated

with the fitting frame **500** worn by the user in the image data are critical in the determination of the display fit and/or ophthalmic fit information that allows the head mounted wearable computing device **100** to be configured for the user.

FIG. **6**C illustrates a plurality of facial landmarks (together with the example detectable keypoints **610**, **620**, **630**, or features **610**, **620**, **630** described above with respect to FIG. **6**B) which may be detected in the two-dimensional image **600** captured by the camera **360** of the computing device **300**. In some examples, pupils, and in particular a pupil center **640** for each eye of the user, may be detected in the image **600**. In some examples, other facial landmarks **650** may be detected in the image **600**. In the example shown in FIG. **6**C, some example facial landmarks **650** include the bridge of the nose, a quadrant surrounding the bridge of the nose at the temple and cheeks, simply for purposes of discussion and illustration. Other facial landmarks may be detected to facilitate the identification of features related to positioning of the fitting frame **500** on the head/face of the user. The facial landmarks **650** may provide, for example, indexing for positioning of the fitting frame **500** relative to the user's head/face, and the like.

In some implementations, a side, or profile image **660** may be captured, as shown in FIG. **6**D. The example image **660** shown in FIG. **6**D is a substantially full profile image **660**, simply for purposes of discussion and illustration. The information detected from the profile image **660** may be detected from side images that are taken at less than 90 degrees from the frontal image **600** shown in FIGS. **6**A-**6**C. As shown in FIG. **6**D, additional keypoints, or features associated with the fitting frames, and additional facial/cranial landmarks, may be detected in the side, or profile image **660**. In the example shown in FIG. **6**D, a keypoint **670** may be detected at a position in the image **660** corresponding to the ear saddle portion **515**A of the arm portion **505**A of the fitting frame **500**. Facial/cranial landmarks **650** may be detected, for example, at portions of the ear of the user, for example, a front crease portion of the ear, a top portion of the ear, and the like. Other keypoints and/or facial/cranial features may also be detected from the side/profile image **660**. Similarly, a tilt, or angle (for example, pantoscopic angle PA) of the fitting frame **500**, for example, relative to the face of the user, may be detected from a side, or profile image **660**. That is, while an angle between the rim portion **503** and the arm portion **505** of the fitting frame **500** may be known, the tilt or angle of the fitting frame **500** will vary based on numerous factors. These factors may include, for example, how the user wears the fitting frame **500** (closer to/further from the eyes, higher/lower on the nose, etc.), the positioning of the ears relative to the nose of the user, and other such factors.

In some implementations, detected keypoints associated with the fitting frame **500** (such as the detected example keypoints **610**, **620**, **630**, **670** or features **610**, **620**, **630**, **670** shown in FIGS. **6**B-**6**D), alone and/or together with detected facial/cranial features of the user (such as the detected pupil center **640** and facial landmarks **650** shown in FIGS. **6**C and **6**D) may be used to determine a pose, for example, a three-dimensional pose of the fitting frame **500** on the face of the user. This three-dimensional pose of the fitting frame **500** on the face of the user may be used to determine display fit and/or ophthalmic fit for the head mounted wearable computing device **100**, for example in the form of smart glasses. In some examples, a configuration of the frame **102** of the head mounted wearable computing device **100** to be configured corresponds to a configuration of the fitting frame **500** worn by the user in the image **600**. In some examples, a configuration of the frame **102** of the head mounted wearable computing device **100** to be configured does not necessarily correspond to the configuration of the fitting frame **500**.

In some examples, data extracted from, for example, the two-dimensional frontal image **600** and the corresponding detected three-dimensional pose of the fitting frame **500** on the face of the user may be synthesized to assess gazability of the fitting frame **500** for the user. That is, this data may by synthesized to determine a configuration of the display device **104** included in the head mounted wearable computing device **100** may allow the display device **104** to be configured such that content output by the display device **104** is within a field of view of the user wearing the head mounted wearable computing device **100**. For example, the display device **104** may be configured such that content output by the display device **104** and displayed at the output coupler **144** is captured within the field of view of the user and is visible to the user.

As noted above, three-dimensional pose information related to the pupils (for example, the pupil center(s) **640**) and the face of the user (for example, the detected facial landmark(s) **650**), together with the three-dimensional pose information of the fitting frame **500**, may allow for the determination of lens related measurements (for example, pupil height, vertex distance, pantoscopic angle and the like). As noted above, the three-dimensional position and orientation, or pose, of the fitting frame **500** may be determined based on detection and/or identification of the one or more keypoints **610**, **620**, **630**, or features **610**, **620**, **630** in the image data captured by the camera **360** of the computing device **300** operated by the user. In some examples, additional information may be obtained from the side, or profile image **660** as described above with respect to FIG. **6**D. Although there may be some flex in the fitting frame **500**, in some examples the fitting frame **500** may be considered to be a substantially rigid body with three degrees of movement. Thus, a relatively precise detection of at least one known point on the fitting frame **500** may be used to determine the three-dimensional position of the fitting frame **500**. One or more of the keypoints **610**, **620**, **630**, or features **610**, **620**, **630** may be reliably detectable in the image **600**, and a position of the detected one or more keypoints **610**, **620**, **630**, or features **610**, **620**, **630** is known in the three-dimensional space associated with the fitting frame **500**.

As noted above, systems and methods, in accordance with implementations described herein, may facilitate the fitting of a head mounted wearable computing device based on image data captured via an application running on a computing device operated by a user. The image data may be captured by the user and the wearable computing device may be fitted and configured for the user in a self-directed, or unsupervised, or unproctored manner, without requiring access to a retail establishment and/or an in-person or virtual appointment with a sales agent. The capture and processing of the image data will be described in more detail below.

A user wanting to select, fit and configure a head mounted wearable computing device **100** as described above may have access to, or be provided, one or more fitting frames, or a sample set of fitting frames, for consideration in advance of the fitting process. In some examples, the user may try on each fitting frame included in the sample set of fitting frames, to assess factors such as size, comfort, appearance, compatibility with facial features, overall wearability, and the like associated with each. The user may select a fitting frame **500** from the sample set of fitting frames based

on these and/or other factors, to use going forward in the fitting and configuration process.

In some examples, the sample set of fitting frames to be tried on and/or assessed may be selected by the user from a plurality of fitting frames available for try on. In some examples, the system (for example, from within a module of the application executing on computing device **300** operated by the user) may suggest the sample set of fitting frames to the user, based on an analysis of physical features of the user and shapes and/or sizes and/or configurations of frames which may be compatible with the detected physical features. In some examples, the sample set of fitting frames may be provided to the user in advance of initiating the process for the fitting and configuring of the head mounted wearable computing device **100**.

The ability to physically try on one or more pairs of fitting frames **500** provides the user with the opportunity to physically assess fit, to make a determination of which of the fitting frames **500** is/are physically most comfortable, properly/comfortably align with facial and/or cranial features (eyes, nose bridge, ear saddle points, cheek contact points, etc.) and the like. This assessment of wearable fit by the user, making use of physical fitting frames **500** prior to fitting and configuration of the head mounted wearable computing device **100**, may yield a head mounted wearable computing device **100** that is more suited to the particular user. The selection of a fitting frame **500** in this manner, based on physical wearable fit by the user, may yield a more accurate fitting and configuration of the head mounted wearable computing device **100** for the user.

In some situations, it may be that a single fitting frame **500** is available to the user for the fitting and configuration of the head mounted wearable computing device **100**. In this situation, the fitting and configuration process may be carried out as to be described below, with additional measures taken for the determination of wearable fit of a particular frame **102** for incorporation into the head mounted wearable computing device **100**.

In some examples, the user may operate the computing device **300** (as in, for example, FIGS. **4**A and/or **4**B) to launch the application and initiate the fitting and configuration of the head mounted wearable computing device **100** using the selected fitting frame **500** (for example, as selected from the sample set of fitting frames as described above). In some examples, the application executing on the computing device **300** operated by the user may prompt the user to initiate image capture while wearing the selected fitting frame **500**. Hereinafter, this process will be described based on the capture of a frontal image **600**, as described above with respect to FIGS. **6**A-**6**C, simply for ease of discussion and illustration. However, in some implementations, data detected in profile images **660** as shown in FIG. **6**D, and/or semi-profile images may be used in the fitting and configuration of a head mounted display device **100** for the user.

In some examples, the application may prompt the user to confirm the selection of a particular fitting frame **500** to be worn by the user during the capture of image data. Thus, in some situations, configuration information related to the selected fitting frame **500** to be worn during the image capture may be known. This may include, for example, linear and/or angular measurements and/or contours associated with the selected fitting frame **500**, a two-dimensional model and/or a three-dimensional model of the selected fitting frame **500**, and other such information. This known information associated with the selected fitting frame **500** may be accessible to the application executing on the computing device **300**. For example, this known configuration information may be stored in a database accessible to the application executing on the computing device **300**. Known configuration information associated with the selected fitting frame may further enhance the accuracy and efficiency of the fitting and configuration of the head mounted wearable computing device **100** for the user.

As shown in FIG. **7** and as described above, various keypoints, or features, associated with the fitting frame **500** can be detected within the frontal image **600** captured by the camera **360** of the computing device **300** operated by the user. In the example arrangement shown in FIG. **7**, a first keypoint **610**A is located at a first known position **710**A on the fitting frame **500**, corresponding to a hinged coupling point **510**A between the first rim portion **503**A and the first arm portion **505**A of the fitting frame **500**. Similarly, a second keypoint **610**B is located at a second known position **710**B on the fitting frame **500**, corresponding to a hinged coupling point **510**B between the second rim portion **503**B and the second arm portion **505**B of the fitting frame **500**. A third keypoint **620**A is located at a third known position **720**A on the fitting frame **500**, corresponding to a bottom peripheral edge portion of the first lens **507**A, and a fourth keypoint **620** is located at a fourth know position **720**B on the fitting frame **500**, at a position corresponding to a bottom peripheral edge portion of the second lens **507**B. A fifth keypoint **630** is located at a fifth known position **730** on the fitting frame **500**, at a position corresponding to a central portion of the bridge portion **509** of the fitting frame **500**. Detection of the keypoints **610**, **620**, **630** and identification of the corresponding known positions **710**, **720**, **730** on the fitting frame **500** may provide fixed points of reference on the fitting frame **500** that may be used to detect and/or to refine the three-dimensional pose of the fitting frame **500** on the face of the user. Detected features or attributes associated with each of the detected keypoints **610**, **620**, **630** can be compared to known features or attributes (known position, geometry, contour, distance and the like) to determine depth, for example with respect to the camera **360**. This may facilitate the determination of the three-dimensional pose of the fitting frame **500** on the face of the user.

For example, the detected keypoints **610**, **620**, **630** and the corresponding known positions **710**, **720**, **730** on the fitting frame **500** may be matched to the corresponding set of points/positions on the three-dimensional model of the fitting frame **500**. As noted above, the three-dimensional model of the fitting frame **500** may be previously stored and accessible via the application executing on the computing device **300**. Thus, a known set of correspondences between the three-dimensional model of the fitting frame **500** and the corresponding points detected in the image **600** may be used to determine the three-dimensional pose of the fitting frame **500**.

In some implementations, detected facial/cranial landmarks, such as the example landmarks **650** shown in FIGS. **6**A-**6**D, may facilitate the detection and identification of the keypoints, or features of the fitting frame **500**. For example, detection and identification of the bottom peripheral edge portion of the first lens **507** defining the example keypoint **620**A described above may be compacted or refined, and/or accuracy may be increased, based on detection beneath the keypoint **620**A of a landmark **650** defining the cheek of the user, a landmark **650** to the right of keypoint **620**A defining the bridge of the nose of the user, and the like. Other keypoints defined at other peripheral edge portions of the lenses **507** (i.e., top and/or left and/or right peripheral edge

portions of the lenses **507**) may be compacted and/or refined based on detection of other landmarks **650** in a similar manner.

In some implementations, the detection of keypoints, or features, associated with the fitting frame **500** worn by the user in the image **600** may rely on comparison against a database populated with synthetic data, actual data, and a combination of synthetic data and actual data. Synthetic data may include, for example three-dimensional renderings of glasses and three-dimensional renderings of heads, in different combinations of poses, lighting conditions and the like, that may be combined to produce exceptionally large numbers of different rendered combinations of glasses worn on heads in various conditions. Actual data may include, for example, image data capturing actual people wearing glasses. The synthetic data and the actual data may be combined to produce additional combinations of glasses on heads, in different poses, conditions and the like. This data (the synthetic data, the actual data, and the combined data) may be amassed to train a neural network that can then output continuously improving results in the matching of keypoints on the fitting frames to points in the three-dimensional models.

In some situations, a well developed/densely populated neural network may be available for a particular fitting frame **500**, including training data representing a relatively large number of poses and positions and angles of the fitting frame **500**. In this situation, an image, for example, the frontal image **600** described above with respect to FIGS. **6**A-**6**C, may be fed into the neural network established for that fitting frame **500**, and a correspondence between the image **600** of the user wearing the fitting frame **500** and the data populating the neural network can be detected, without necessarily requiring the detection of keypoints in the image **600** prior to the processing of the image **600** by the neural network.

In some implementations, a process similar to the fitting and configuration process may be applied to the calibration, or recalibration, of the head mounted wearable computing device **100** after the head mounted wearable computing device **100** has been delivered to the user. For example, a new product setup process for the head mounted wearable computing device **100** that has been configured for the user may include a fine tuning of the display characteristics once the head mounted wearable computing device **100** has been delivered. For example, an application executing on the computing device **300** operated by the user may prompt the user to capture image data including the user wearing the head mounted wearable computing device **100**. Detection of keypoints on the head mounted wearable computing device **100** may be detected to determine the three-dimensional pose of the head mounted wearable computing device **100** on the face of the user, and relative to the user's eyes/eye box. Control software controlling operation of the display device **104** may adjust an output of content to, for example, optimize where the content is displayed. This may optimize gazability, and improve the user viewing experience.

The measurements, or parameters described above may be collected to determine display fit characteristics for a user wearing a selected fitting frame **500**. The measurements, or parameters described above may allow for fitting of the display device of the head mounted wearable computing device (such as the display device **104** of the head mounted wearable computing device **100** shown in FIGS. **1**B and **1**C) such that the pupil of the user will be as centrally aligned as possible within the eye box **140**, so that the user eye gaze passes through the output coupler **144**, where displayed content is visible to the user on the lens **107**. The measurements, or parameters described above may allow for configuration of the display device **104** of the head mounted wearable computing device **100**, such that the display of content is visible to the user within a relatively large portion of the field of view of the user.

Systems and methods, in accordance with implementations described herein, may provide for the collection of measurements to determine ophthalmic fit characteristics for a user wearing the selected fitting frame **500**. In some implementations, the systems and methods may provide for the collection of measurements to determine both display fit characteristics and ophthalmic fit characteristics. As described above with respect to FIGS. **2**A-**2**D, ophthalmic measurements may be detected within the image data captured by the camera **360** of the computing device **300** operated by the user. These measurements, including, for example, pupil height, interpupillary distance, monocular pupil distance, pantoscopic angle, vertex distance, and other such parameters, or measures, may be detected within the image data and processed for the incorporation of corrective, or prescription lenses into the head mounted wearable computing device **100**. In some examples, these ophthalmic measurements are used in coordination with the display fit measurements described above to provide both a proper display fit for a particular user, together with the corrective/prescription lens needs of the user.

FIG. **8** is a flowchart of an example method **800** of operating a computing system to configure a head mounted wearable computing device including a display for a user. A user operating a computing device (such as, for example, the computing device **300** described above) may cause the computing device to execute an application. The application may provide for detection of display fit measurements and/or ophthalmic fit measurements from image data captured by the computing device (block **810**). A camera (such as, for example, the camera **360** of the computing device **300** described above) is operated to capture image data of a user wearing a fitting frame (block **820**). The fitting frame may be selected from one or more sample fitting frames available to the user (such as, for example, the fitting frames **500** described above with respect to FIGS. **5**A-**7**). The system may detect one or more keypoints, or features on the fitting frame (such as, for example, the keypoints **610**, **620**, **630** and/or **670**, the facial/cranial landmarks **640**, **650** described above, and the like) (block **830**).

In some examples, analysis of the image capture data for detection of the keypoints and/or features and/or landmarks may be performed by the computing device, for example, the object recognition module and/or the pattern recognition module of the processor **350** of the computing device described above. In some examples, the detection of the keypoints and/or features and/or landmarks may be performed by an external device, such as, for example, an object recognition module and/or a pattern recognition module of the server included in the external resources **302** in communication with the computing device **300** as described above.

Display fit measurements including a three-dimensional pose of the fitting frame may be determined based on the positions of the detected keypoints and/or features and/or landmarks relative to a configuration of the fitting frame (block **840**). Ophthalmic fit measurements, if required (block **850**), may be detected from the image data, and from display fit measurements, for a user requiring corrective/prescription lenses to be incorporated into the head mounted wearable computing device (blocks **860**, **870** and **880**). In

some examples, the analysis for determining the display fit measurements and/or the ophthalmic fit measurements may be performed by the computing device (such as, for example, the configuration identification module of the processor **350** of the computing device **300** described above). In some examples, the analysis for determining the display fit measurements and/or the ophthalmic fit measurements may be performed by an external computing device (such as a configuration identification module of the server included in the external resources **302** in communication with the computing device **300** described above). The ophthalmic fit measurements and the display fit measurements may be incorporated into the head mounted wearable computing device for the user, to provide a viewing experience that is tailored for the optical needs of the user.

FIG. **9** shows an example of a computing device **900** and a mobile computer device **950**, which may be used with the techniques described here. Computing device **900** is intended to represent various forms of digital computers, such as laptops, desktops, tablets, workstations, personal digital assistants, smart devices, appliances, electronic sensor-based devices, televisions, servers, blade servers, mainframes, and other appropriate computing devices. Computing device **950** is intended to represent various forms of mobile devices, such as personal digital assistants, cellular telephones, smart phones, and other similar computing devices. The components shown here, their connections and relationships, and their functions, are meant to be exemplary only, and are not meant to limit implementations of the inventions described and/or claimed in this document.

Computing device **900** includes a processor **902**, memory **904**, a storage device **906**, a high-speed interface **908** connecting to memory **904** and high-speed expansion ports **910**, and a low speed interface **912** connecting to low speed bus **914** and storage device **906**. The processor **902** can be a semiconductor-based processor. The memory **904** can be a semiconductor-based memory. Each of the components **902**, **904**, **906**, **908**, **910**, and **912**, are interconnected using various busses, and may be mounted on a common motherboard or in other manners as appropriate. The processor **902** can process instructions for execution within the computing device **900**, including instructions stored in the memory **904** or on the storage device **906** to display graphical information for a GUI on an external input/output device, such as display **916** coupled to high speed interface **908**. In other implementations, multiple processors and/or multiple buses may be used, as appropriate, along with multiple memories and types of memory. Also, multiple computing devices **900** may be connected, with each device providing portions of the necessary operations (e.g., as a server bank, a group of blade servers, or a multi-processor system).

The memory **904** stores information within the computing device **900**. In one implementation, the memory **904** is a volatile memory unit or units. In another implementation, the memory **904** is a non-volatile memory unit or units. The memory **904** may also be another form of computer-readable medium, such as a magnetic or optical disk. In general, the computer-readable medium may be a non-transitory computer-readable medium.

The storage device **906** is capable of providing mass storage for the computing device **900**. In one implementation, the storage device **906** may be or contain a computer-readable medium, such as a floppy disk device, a hard disk device, an optical disk device, or a tape device, a flash memory or other similar solid state memory device, or an array of devices, including devices in a storage area network or other configurations. A computer program product can be tangibly embodied in an information carrier. The computer program product may also contain instructions that, when executed, perform one or more methods and/or computer-implemented methods, such as those described above. The information carrier is a computer- or machine-readable medium, such as the memory **904**, the storage device **906**, or memory on processor **902**.

The high speed controller **908** manages bandwidth-intensive operations for the computing device **900**, while the low speed controller **912** manages lower bandwidth-intensive operations. Such allocation of functions is exemplary only. In one implementation, the high-speed controller **908** is coupled to memory **904**, display **916** (e.g., through a graphics processor or accelerator), and to high-speed expansion ports **910**, which may accept various expansion cards (not shown). In the implementation, low-speed controller **912** is coupled to storage device **906** and low-speed expansion port **914**. The low-speed expansion port, which may include various communication ports (e.g., USB, Bluetooth, Ethernet, wireless Ethernet) may be coupled to one or more input/output devices, such as a keyboard, a pointing device, a scanner, or a networking device such as a switch or router, e.g., through a network adapter.

The computing device **900** may be implemented in a number of different forms, as shown in the figure. For example, it may be implemented as a standard server **920**, or multiple times in a group of such servers. It may also be implemented as part of a rack server system **924**. In addition, it may be implemented in a computer such as a laptop computer **922**. Alternatively, components from computing device **900** may be combined with other components in a mobile device (not shown), such as device **950**. Each of such devices may contain one or more of computing device **900**, **950**, and an entire system may be made up of multiple computing devices **900**, **950** communicating with each other.

Computing device **950** includes a processor **952**, memory **964**, an input/output device such as a display **954**, a communication interface **966**, and a transceiver **968**, among other components. The device **950** may also be provided with a storage device, such as a microdrive or other device, to provide additional storage. Each of the components **950**, **952**, **964**, **954**, **966**, and **968**, are interconnected using various buses, and several of the components may be mounted on a common motherboard or in other manners as appropriate.

The processor **952** can execute instructions within the computing device **950**, including instructions stored in the memory **964**. The processor may be implemented as a chipset of chips that include separate and multiple analog and digital processors. The processor may provide, for example, for coordination of the other components of the device **950**, such as control of user interfaces, applications run by device **950**, and wireless communication by device **950**.

Processor **952** may communicate with a user through control interface **958** and display interface **956** coupled to a display **954**. The display **954** may be, for example, a TFT LCD (Thin-Film-Transistor Liquid Crystal Display) or an OLED (Organic Light Emitting Diode) display, or other appropriate display technology. The display interface **956** may comprise appropriate circuitry for driving the display **954** to present graphical and other information to a user. The control interface **958** may receive commands from a user and convert them for submission to the processor **952**. In addition, an external interface **962** may be provided in communication with processor **952**, so as to enable near area

communication of device **950** with other devices. External interface **962** may provide, for example, for wired communication in some implementations, or for wireless communication in other implementations, and multiple interfaces may also be used.

The memory **964** stores information within the computing device **950**. The memory **964** can be implemented as one or more of a computer-readable medium or media, a volatile memory unit or units, or a non-volatile memory unit or units. Expansion memory **984** may also be provided and connected to device **950** through expansion interface **982**, which may include, for example, a SIMM (Single In Line Memory Module) card interface. Such expansion memory **984** may provide extra storage space for device **950**, or may also store applications or other information for device **950**. Specifically, expansion memory **984** may include instructions to carry out or supplement the processes described above, and may include secure information also. Thus, for example, expansion memory **984** may be provided as a security module for device **950**, and may be programmed with instructions that permit secure use of device **950**. In addition, secure applications may be provided via the SIMM cards, along with additional information, such as placing identifying information on the SIMM card in a non-hackable manner.

The memory may include, for example, flash memory and/or NVRAM memory, as discussed below. In one implementation, a computer program product is tangibly embodied in an information carrier. The computer program product contains instructions that, when executed, perform one or more methods, such as those described above. The information carrier is a computer- or machine-readable medium, such as the memory **964**, expansion memory **984**, or memory on processor **952**, that may be received, for example, over transceiver **968** or external interface **962**.

Device **950** may communicate wirelessly through communication interface **966**, which may include digital signal processing circuitry where necessary. Communication interface **966** may provide for communications under various modes or protocols, such as GSM voice calls, SMS, EMS, or MMS messaging, CDMA, TDMA, PDC, WCDMA, CDMA2000, or GPRS, among others. Such communication may occur, for example, through radio-frequency transceiver **968**. In addition, short-range communication may occur, such as using a Bluetooth, low power Bluetooth, Wi-Fi, or other such transceiver (not shown). In addition, GPS (Global Positioning System) receiver module **980** may provide additional navigation- and location-related wireless data to device **950**, which may be used as appropriate by applications running on device **950**.

Device **950** may also communicate audibly using audio codec **960**, which may receive spoken information from a user and convert it to usable digital information. Audio codec **960** may likewise generate audible sound for a user, such as through a speaker, e.g., in a handset of device **950**. Such sound may include sound from voice telephone calls, may include recorded sound (e.g., voice messages, music files, etc.) and may also include sound generated by applications operating on device **950**.

The computing device **950** may be implemented in a number of different forms, as shown in the figure. For example, it may be implemented as a cellular telephone **983**. It may also be implemented as part of a smart phone **981**, personal digital assistant, or other similar mobile device.

Various implementations of the systems and techniques described here can be realized in digital electronic circuitry, integrated circuitry, specially designed ASICs (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations can include implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which may be special or general purpose, coupled to receive data and instructions from, and to transmit data and instructions to, a storage system, at least one input device, and at least one output device.

These computer programs (also known as modules, programs, software, software applications or code) include machine instructions for a programmable processor, and can be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms "machine-readable medium" "computer-readable medium" refers to any computer program product, apparatus and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term "machine-readable signal" refers to any signal used to provide machine instructions and/or data to a programmable processor.

To provide for interaction with a user, the systems and techniques described here can be implemented on a computer having a display device (e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, or LED (light emitting diode)) for displaying information to the user and a keyboard and a pointing device (e.g., a mouse or a trackball) by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well. For example, feedback provided to the user can be any form of sensory feedback (e.g., visual feedback, auditory feedback, or tactile feedback), and input from the user can be received in any form, including acoustic, speech, or tactile input.

The systems and techniques described here can be implemented in a computing system that includes a back end component (e.g., as a data server), or that includes a middleware component (e.g., an application server), or that includes a front end component (e.g., a client computer having a graphical user interface or a Web browser through which a user can interact with an implementation of the systems and techniques described here), or any combination of such back end, middleware, or front end components. The components of the system can be interconnected by any form or medium of digital data communication (e.g., a communication network). Examples of communication networks include a local area network ("LAN"), a wide area network ("WAN"), and the Internet.

The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

In some embodiments, the computing devices depicted in FIG. **9** can include sensors that interface with an AR/VR headset (AR glasses/eyeglasses/VR headset/AR headset/IMD device **990**). For example, one or more sensors included on computing device **950** or other computing device depicted in FIG. **9**, can provide input to AR/VR headset **990** or in general, provide input to an AR/VR space. The sensors can include, but are not limited to, a touchscreen, accelerometers, gyroscopes, pressure sensors, biometric sensors, temperature sensors, humidity sensors, and

ambient light sensors. Computing device **950** can use the sensors to determine an absolute position and/or a detected rotation of the computing device in the AR/VR space that can then be used as input to the AR/VR space. For example, computing device **950** may be incorporated into the AR/VR space as a virtual object, such as a controller, a laser pointer, a keyboard, a weapon, etc. Positioning of the computing device/virtual object by the user when incorporated into the AR/VR space can allow the user to position the computing device to view the virtual object in certain manners in the AR/VR space.

In some embodiments, one or more input devices included on, or connected to, the computing device **950** can be used as input to the AR/VR space. The input devices can include, but are not limited to, a touchscreen, a keyboard, one or more buttons, a trackpad, a touchpad, a pointing device, a mouse, a trackball, a joystick, a camera, a microphone, earphones or buds with input functionality, a gaming controller, or other connectable input device. A user interacting with an input device included on the computing device **950** when the computing device is incorporated into the AR/VR space can cause a particular action to occur in the AR/VR space.

In some embodiments, one or more output devices included on the computing device **950** can provide output and/or feedback to a user of the AR/VR headset **990** in the AR/VR space. The output and feedback can be visual, tactical, or audio. The output and/or feedback can include, but is not limited to, rendering the AR/VR space or the virtual environment, vibrations, turning on and off or blinking and/or flashing of one or more lights or strobes, sounding an alarm, playing a chime, playing a song, and playing of an audio file. The output devices can include, but are not limited to, vibration motors, vibration coils, piezoelectric devices, electrostatic devices, light emitting diodes (LEDs), strobes, and speakers.

In some embodiments, computing device **950** can be placed within AR/VR headset **990** to create an AR/VR system. AR/VR headset **990** can include one or more positioning elements that allow for the placement of computing device **950**, such as smart phone **981**, in the appropriate position within AR/VR headset **990**. In such embodiments, the display of smart phone **981** can render stereoscopic images representing the AR/VR space or virtual environment.

In some embodiments, the computing device **950** may appear as another object in a computer-generated, 3D environment. Interactions by the user with the computing device **950** (e.g., rotating, shaking, touching a touchscreen, swiping a finger across a touch screen) can be interpreted as interactions with the object in the AR/VR space. As just one example, computing device can be a laser pointer. In such an example, computing device **950** appears as a virtual laser pointer in the computer-generated, 3D environment. As the user manipulates computing device **950**, the user in the AR/VR space sees movement of the laser pointer. The user receives feedback from interactions with the computing device **950** in the AR/VR environment on the computing device **950** or on the AR/VR headset **990**.

In some embodiments, a computing device **950** may include a touchscreen. For example, a user can interact with the touchscreen in a particular manner that can mimic what happens on the touchscreen with what happens in the AR/VR space. For example, a user may use a pinching-type motion to zoom content displayed on the touchscreen. This pinching-type motion on the touchscreen can cause information provided in the AR/VR space to be zoomed. In another example, the computing device may be rendered as a virtual book in a computer-generated, 3D environment. In the AR/VR space, the pages of the book can be displayed in the AR/VR space and the swiping of a finger of the user across the touchscreen can be interpreted as turning/flipping a page of the virtual book. As each page is turned/flipped, in addition to seeing the page contents change, the user may be provided with audio feedback, such as the sound of the turning of a page in a book.

In some embodiments, one or more input devices in addition to the computing device (e.g., a mouse, a keyboard) can be rendered in a computer-generated, 3D environment. The rendered input devices (e.g., the rendered mouse, the rendered keyboard) can be used as rendered in the AR/VR space to control objects in the AR/VR space.

A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention.

In addition, the logic flows depicted in the figures do not require the particular order shown, or sequential order, to achieve desirable results. In addition, other steps may be provided, or steps may be eliminated, from the described flows, and other components may be added to, or removed from, the described systems. Accordingly, other embodiments are within the scope of the following claims.

Further to the descriptions above, a user is provided with controls allowing the user to make an election as to both if and when systems, programs, devices, networks, or features described herein may enable collection of user information (e.g., information about a user's social network, social actions, or activities, profession, a user's preferences, or a user's current location), and if the user is sent content or communications from a server. In addition, certain data may be treated in one or more ways before it is stored or used, so that user information is removed. For example, a user's identity may be treated so that no user information can be determined for the user, or a user's geographic location may be generalized where location information is obtained (such as to a city, ZIP code, or state level), so that a particular location of a user cannot be determined. Thus, the user may have control over what information is collected about the user, how that information is used, and what information is provided to the user.

The computer system (e.g., computing device) may be configured to wirelessly communicate with a network server over a network via a communication link established with the network server using any known wireless communications technologies and protocols including radio frequency (RF), microwave frequency (MWF), and/or infrared frequency (IRF) wireless communications technologies and protocols adapted for communication over the network.

In accordance with aspects of the disclosure, implementations of various techniques described herein may be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations of them. Implementations may be implemented as a computer program product (e.g., a computer program tangibly embodied in an information carrier, a machine-readable storage device, a computer-readable medium, a tangible computer-readable medium), for processing by, or to control the operation of, data processing apparatus (e.g., a programmable processor, a computer, or multiple computers). In some implementations, a tangible computer-readable storage medium may be configured to store instructions that when executed cause a processor to perform a process. A computer program, such as the computer program(s) described above, may be written

in any form of programming language, including compiled or interpreted languages, and may be deployed in any form, including as a standalone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program may be deployed to be processed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network.

Specific structural and functional details disclosed herein are merely representative for purposes of describing example embodiments. Example embodiments, however, may be embodied in many alternate forms and should not be construed as limited to only the embodiments set forth herein.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the embodiments. As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and/or "including," when used in this specification, specify the presence of the stated features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof.

It will be understood that when an element is referred to as being "coupled," "connected," or "responsive" to, or "on," another element, it can be directly coupled, connected, or responsive to, or on, the other element, or intervening elements may also be present. In contrast, when an element is referred to as being "directly coupled," "directly connected," or "directly responsive" to, or "directly on," another element, there are no intervening elements present. As used herein the term "and/or" includes any and all combinations of one or more of the associated listed items.

Spatially relative terms, such as "beneath," "below," "lower," "above," "upper," and the like, may be used herein for ease of description to describe one element or feature in relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 70 degrees or at other orientations) and the spatially relative descriptors used herein may be interpreted accordingly.

Example embodiments of the concepts are described herein with reference to cross-sectional illustrations that are schematic illustrations of idealized embodiments (and intermediate structures) of example embodiments. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, example embodiments of the described concepts should not be construed as limited to the particular shapes of regions illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. Accordingly, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the actual shape of a region of a device and are not intended to limit the scope of example embodiments.

It will be understood that although the terms "first," "second," etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. Thus, a "first" element could be termed a "second" element without departing from the teachings of the present embodiments.

Unless otherwise defined, the terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which these concepts belong. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and/or the present specification and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

While certain features of the described implementations have been illustrated as described herein, many modifications, substitutions, changes, and equivalents will now occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover such modifications and changes as fall within the scope of the implementations. It should be understood that they have been presented by way of example only, not limitation, and various changes in form and details may be made. Any portion of the apparatus and/or methods described herein may be combined in any combination, except mutually exclusive combinations. The implementations described herein can include various combinations and/or sub-combinations of the functions, components, and/or features of the different implementations described.

What is claimed is:

1. A method of detecting fit measurements for a wearable computing device, the method comprising:

receiving, by an application executing on a computing device, a selection of a frame;

detecting at least one feature of the frame worn by a user in a two-dimensional (2D) image captured by the computing device operated by the user;

accessing configuration information associated with the frame;

determining a three-dimensional pose of the frame captured in the image based on the detecting of the at least one feature and the configuration information associated with the frame; and

determining a configuration of a display device of the wearable computing device based on the three-dimensional pose of the frame as captured in the image.

2. The method of claim **1**, wherein detecting the at least one feature includes detecting at least one of:

a bridge portion of the frame;

a hinge point between a rim portion and an arm portion of the frame;

a peripheral edge portion of a lens of the frame; or

a saddle portion of the arm portion of the frame.

3. The method of claim **1**, wherein determining the three-dimensional pose of the frame includes:

accessing a three-dimensional model of the frame captured in the image; and

performing a comparison, including comparing a known position and orientation of the at least one feature detected in the image to a corresponding position and orientation of the at least one feature in the three-dimensional model of the frame.

4. The method of claim 3, wherein

detecting at least one feature includes detecting a plurality of features on the frame in the image captured by the computing device; and

performing the comparison includes, for each of the plurality of features, comparing a known position and orientation of the feature detected in the image to a corresponding position and orientation of the feature in the three-dimensional model of the frame.

5. The method of claim 4, wherein determining the three-dimensional pose of the frame includes performing a correspondence between a two-dimensional position of each feature detected in the image to a corresponding three-dimensional position of the feature in the three-dimensional model of the frame.

6. The method of claim 1, further comprising:

detecting a plurality of facial landmarks in the image captured by the computing device; and

determining ophthalmic fit measurements for the wearable computing device based on the plurality of facial landmarks detected in the image.

7. The method of claim 6, wherein detecting the plurality of facial landmarks includes:

detecting a pupil height in the image including the frame worn by the user;

detecting at least one of an interpupillary distance or a monocular pupil distance in the image including the frame worn by the user; and

determining a pantoscopic angle of the frame worn by the user based on the three-dimensional pose of the frame and the plurality of facial landmarks.

8. The method of claim 7, wherein determining the configuration of the display device of the wearable computing device based on the three-dimensional pose of the frame as captured in the image includes adapting the configuration of the display device of the wearable computing device to accommodate the ophthalmic fit measurements.

9. The method of claim 8, wherein determining the configuration of the display device of the wearable computing device includes:

determining a field of view of the user based on the ophthalmic fit measurements and the three-dimensional pose of the frame; and

configuring an output coupler of the display device such that content output by the display device is displayed within the field of view.

10. A non-transitory computer-readable medium storing executable instructions that, when executed by at least one processor, are configured to cause the at least one processor to:

receive a selection of a frame;

capture an image of the frame worn by a user;

detect at least one feature of the frame from the image;

access configuration information associated with the frame;

determine a three-dimensional pose of the frame captured in the image based on detection of the at least one feature and the configuration information associated with the frame; and

determine a configuration of a display device of a wearable computing device based on the three-dimensional pose of the frame as captured in the image.

11. The non-transitory computer-readable medium of claim 10, wherein the instructions cause the at least one processor to detect the at least one feature on the frame in the image, including at least one of:

detect a first feature including a bridge portion of the frame;

detect a second feature including a hinge portion between a rim portion and an arm portion of the frame;

detect a third feature including a peripheral edge portion of a lens of the frame; or

detect a fourth feature including a saddle portion of the arm portion of the fitting-frame.

12. The non-transitory computer-readable medium of claim 11, wherein the instructions cause the at least one processor to determine the three-dimensional pose of the frame, including:

access a three-dimensional model of the frame captured in the image; and

perform a comparison between a known position and orientation of the at least one feature detected in the image to a corresponding position and orientation of the at least one feature in the three-dimensional model of the frame.

13. The non-transitory computer-readable medium of claim 12, wherein the instructions cause the at least one processor to detect a plurality of features, and to perform the comparison, including, for each of the plurality of features:

compare a known position and orientation of the feature detected in the image to a corresponding position and orientation of the feature in the three-dimensional model of the frame.

14. The non-transitory computer-readable medium of claim 13, wherein the instructions cause the at least one processor to determine the three-dimensional pose, including:

performing a correspondence between a two-dimensional position of each feature detected in the image to a corresponding three-dimensional position of the feature in the three-dimensional model of the frame.

15. The non-transitory computer-readable medium of claim 10, wherein the instructions also cause the at least one processor to:

detect a plurality of facial landmarks in the image; and

determine ophthalmic fit measurements for the wearable computing device based on the plurality of facial landmarks detected in the image.

16. The non-transitory computer-readable medium of claim 15, wherein the instructions cause the at least one processor to detect the plurality of facial landmarks, including:

detect a pupil height in the image including the frame worn by the user;

detect at least one of an interpupillary distance or a monocular pupil distance in the image including the frame worn by the user; and

determine a pantoscopic angle of the frame worn by the user based on the three-dimensional pose of the frame and the plurality of facial landmarks.

17. The non-transitory computer-readable medium of claim 16, wherein the instructions cause the at least one processor to adapt the configuration of the display device of the wearable computing device to accommodate the ophthalmic fit measurements, including:

determine a field of view of the user based on the ophthalmic fit measurements and the three-dimensional pose of the frame; and

configure an output coupler of the display device such that content output by the display device is displayed within the field of view.

* * * * *