US 20250258549A1

(19) **United States**
(12) **Patent Application Publication**
Hwang et al.

(10) **Pub. No.: US 2025/0258549 A1**
(43) **Pub. Date: Aug. 14, 2025**

(54) **BIMANUAL INTERACTIONS BETWEEN MAPPED HAND REGIONS FOR CONTROLLING VIRTUAL AND GRAPHICAL ELEMENTS**

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(21) Appl. No.: **19/196,466**

(22) Filed: **May 1, 2025**

Related U.S. Application Data

(63) Continuation of application No. 17/714,352, filed on Apr. 6, 2022.

(60) Provisional application No. 63/172,520, filed on Apr. 8, 2021.

Publication Classification

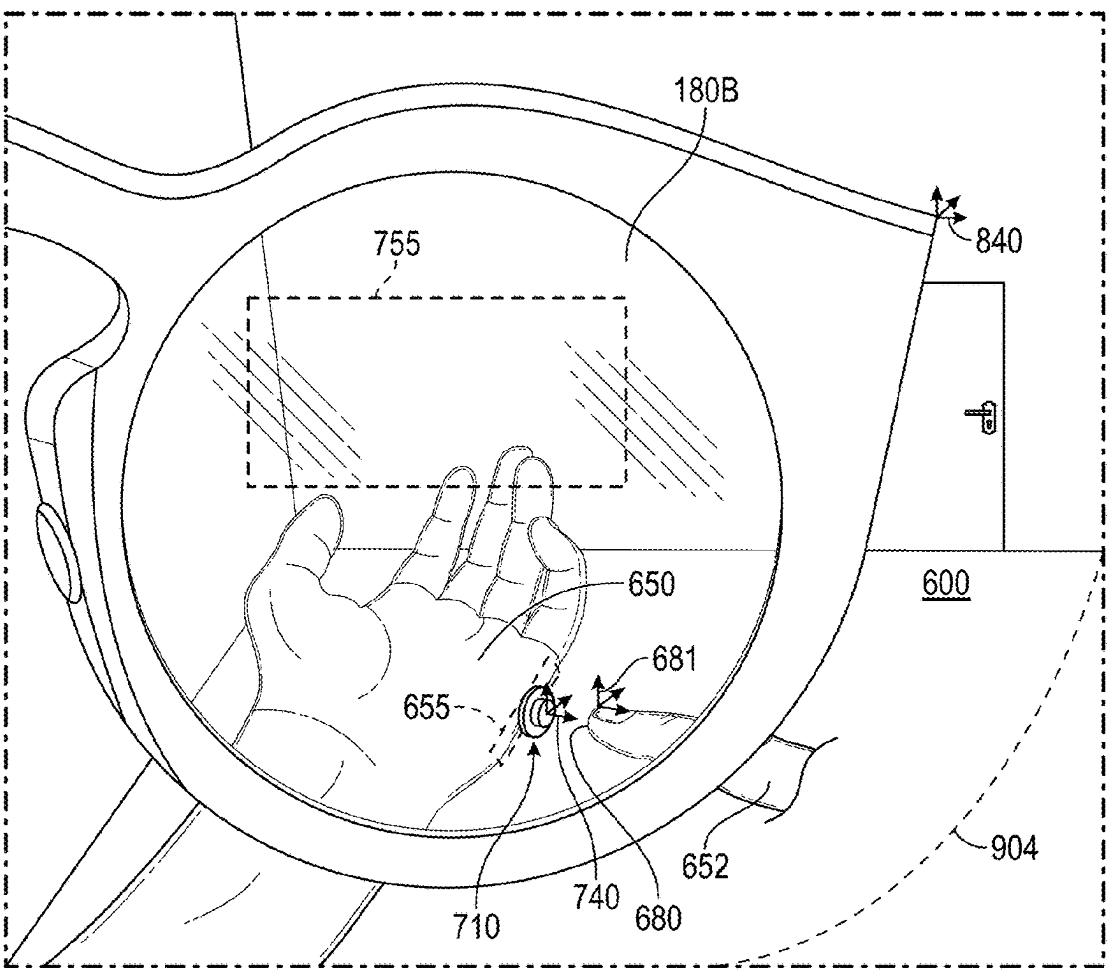
(51) **Int. Cl.**

G06F 3/01	(2006.01)
G06T 7/70	(2017.01)
G06T 19/00	(2011.01)
G06V 40/10	(2022.01)

(52) **U.S. Cl.**
CPC ***G06F 3/017*** (2013.01); ***G06T 7/70*** (2017.01); ***G06T 19/006*** (2013.01); ***G06V 40/11*** (2022.01)

(57) **ABSTRACT**

Example systems, devices, media, and methods are described for controlling the presentation of one or more virtual or graphical elements on a display in response to bimanual hand gestures detected by an eyewear device that is capturing frames of video data with its camera system. An image processing system detects a first hand and defines a mapped region relative to a surface of the detected first hand. The system presents a virtual target icon at a position within or near the mapped region. The image processing system detects a series of bimanual hand shapes, including the detected first hand and at least one fingertip of a second hand. In response to determining whether the detected series of bimanual hand shapes matches a predefined hand gesture, the system executes a selecting action that includes presenting one or more graphical elements on the display.



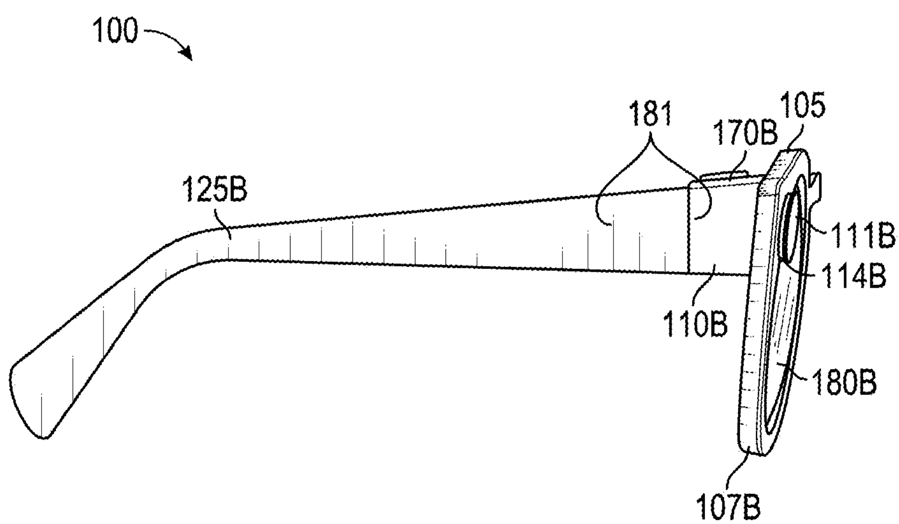


FIG. 1A

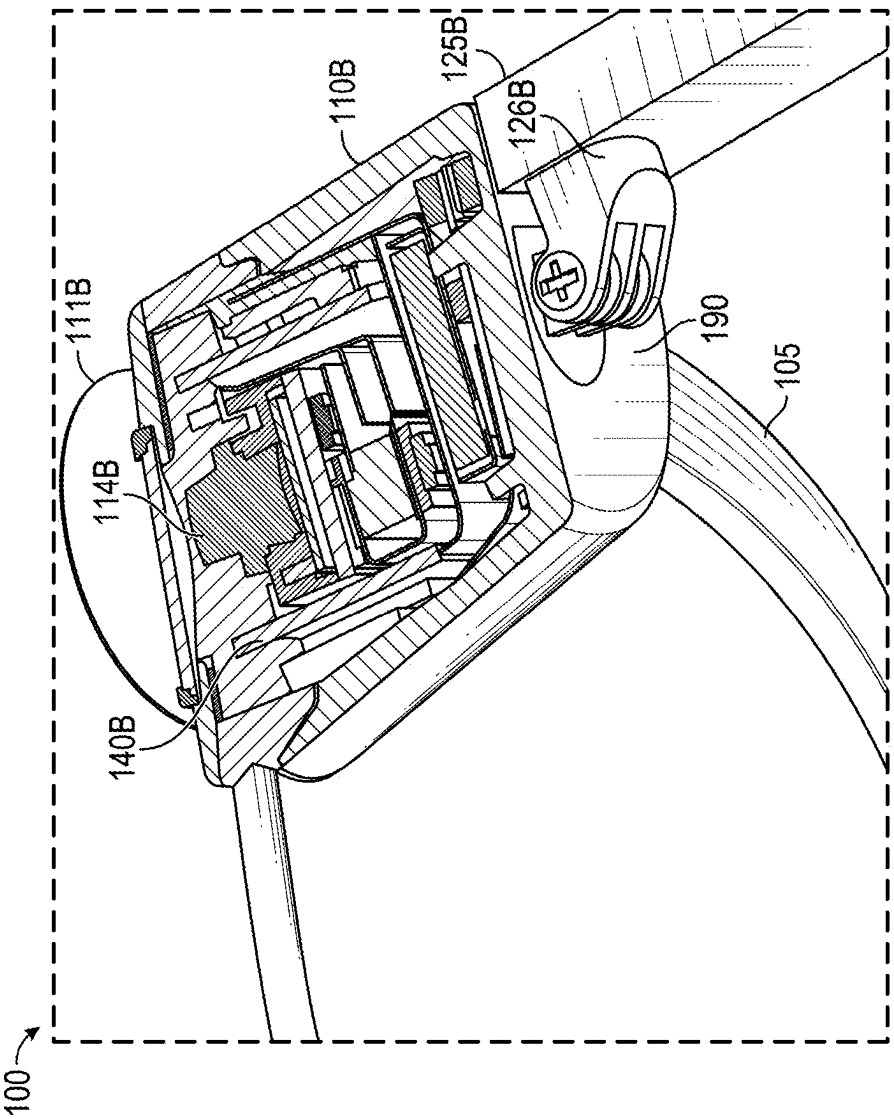


FIG. 1B

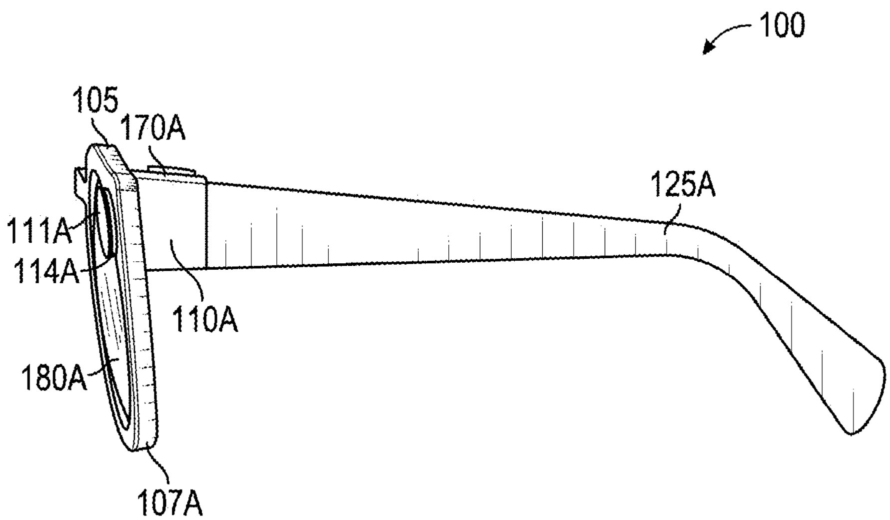


FIG. 1C

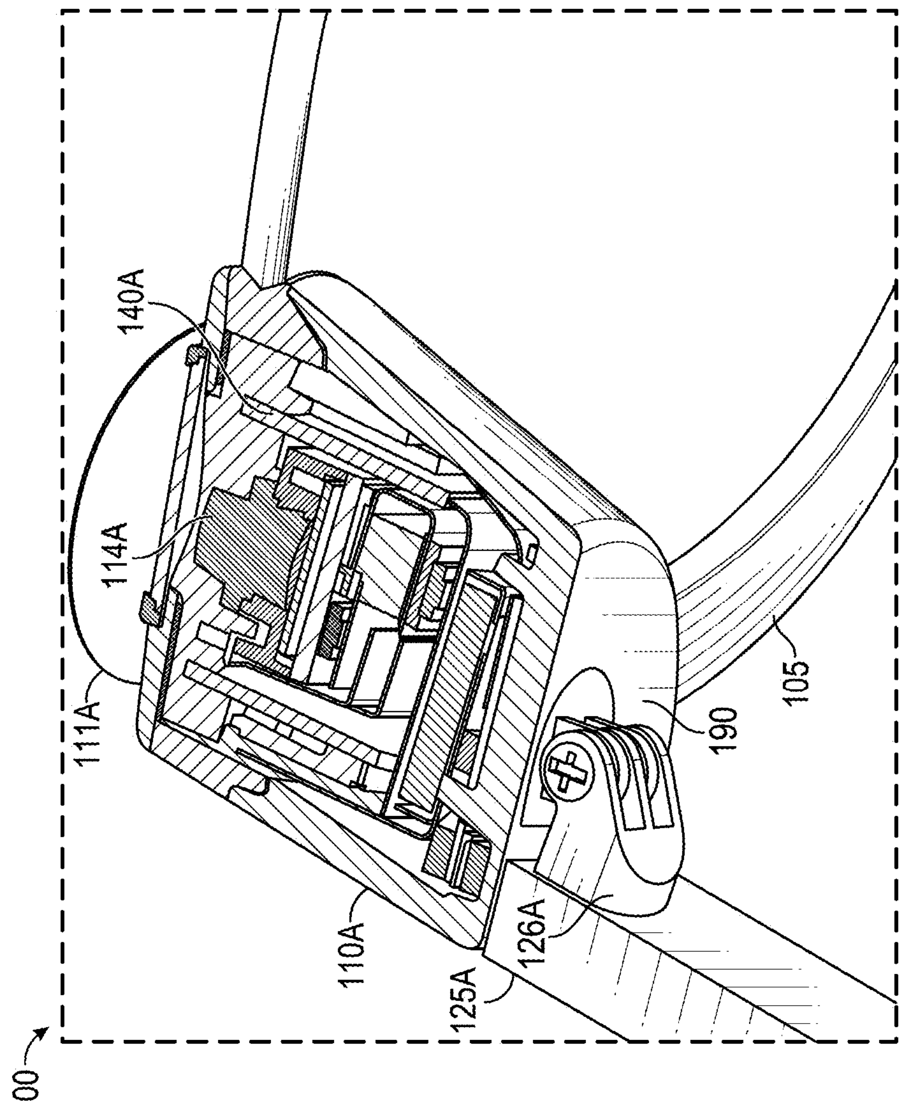


FIG. 1D

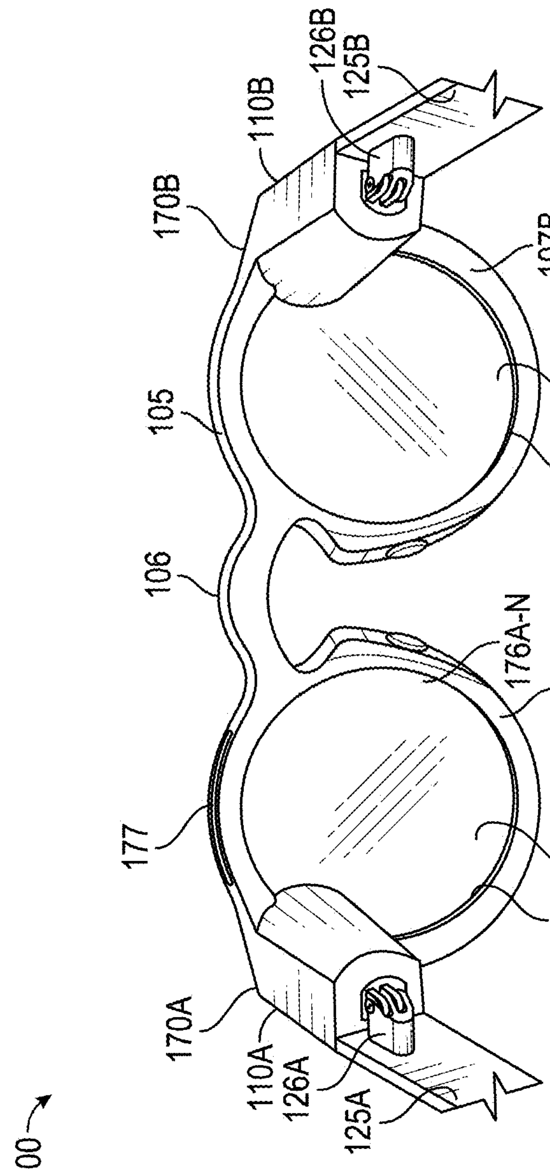

100
110A
126A
125A
170A
177
175A
180A
107A
176A-N
106
105
175B
180B
107B
170B
110B
126B
125B

FIG. 2A

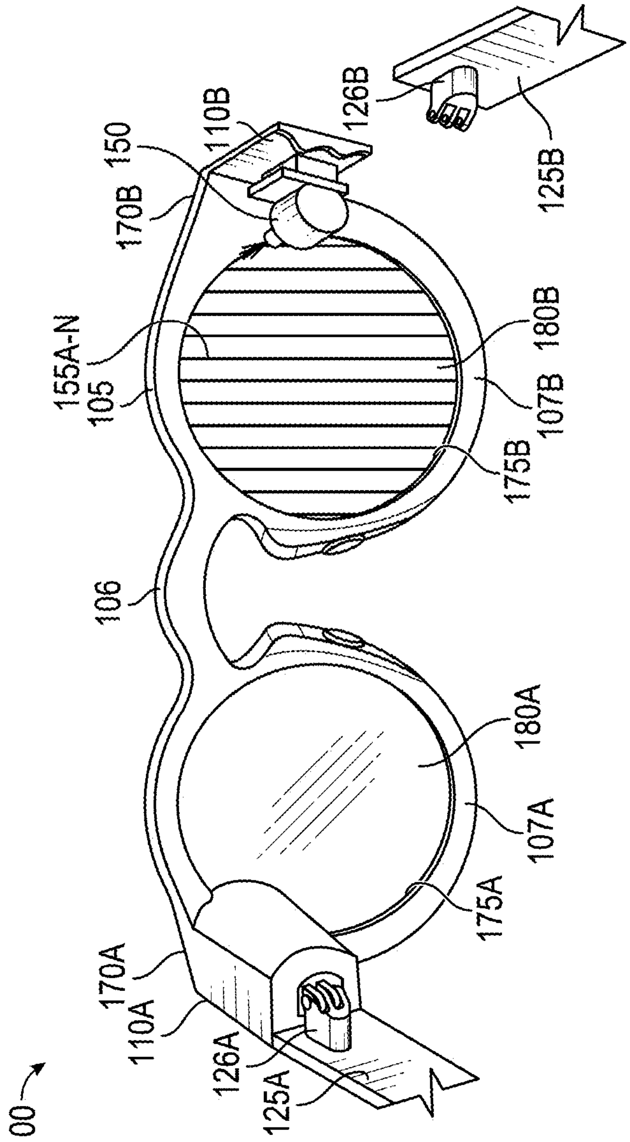

100
110A
170A
126A
125A
175A
107A
180A
106
105
155A-N
170B
150
110B
126B
125B
180B
107B
175B

FIG. 2B

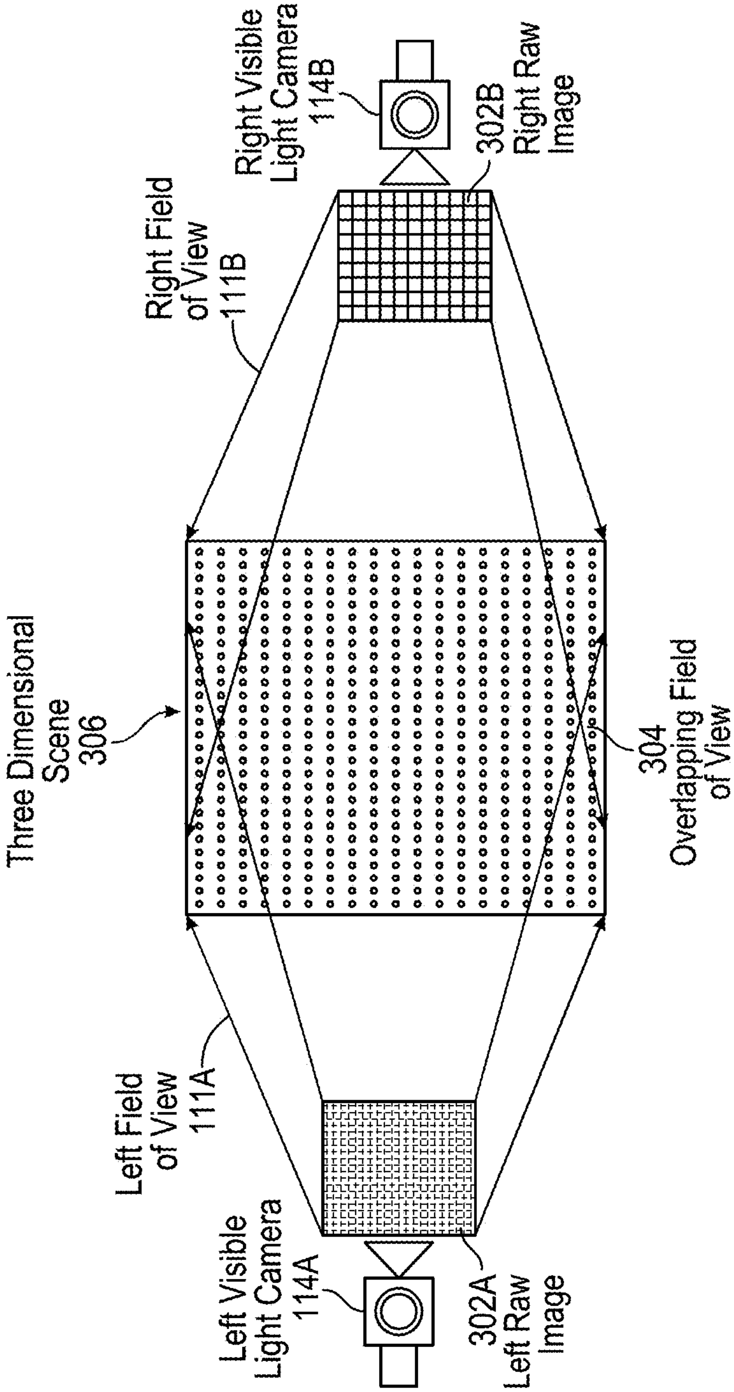

Right Visible
Light Camera
114B
302B
Right Raw
Image
Right Field
of View
111B
Three Dimensional
Scene
306
304
Overlapping Field
of View
Left Field
of View
111A
Left Visible
Light Camera
114A
302A
Left Raw
Image

FIG. 3

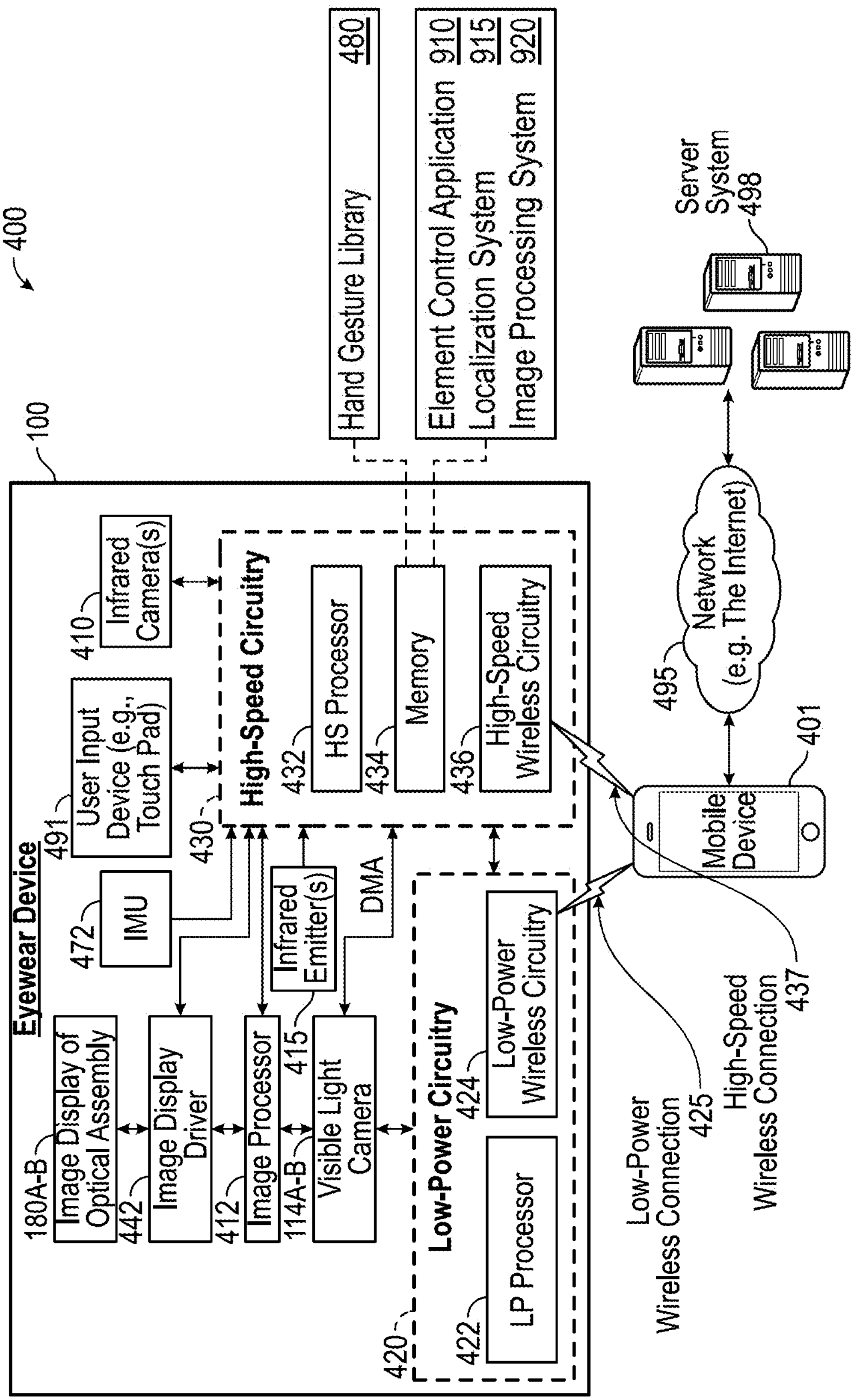

400
100
Eyewear Device
180A-B
Image Display of Optical Assembly
442
Image Display Driver
412
Image Processor
114A-B
Visible Light Camera
472
IMU
415
Infrared Emitter(s)
DMA
491
User Input Device (e.g., Touch Pad)
410
Infrared Camera(s)
430
High-Speed Circuitry
432
HS Processor
434
Memory
436
High-Speed Wireless Circuitry
420
Low-Power Circuitry
422
LP Processor
424
Low-Power Wireless Circuitry
Hand Gesture Library 480
Element Control Application 910
Localization System 915
Image Processing System 920
Server System 498
495
Network (e.g. The Internet)
401
Mobile Device
Low-Power Wireless Connection
425
High-Speed Wireless Connection
437

FIG. 4

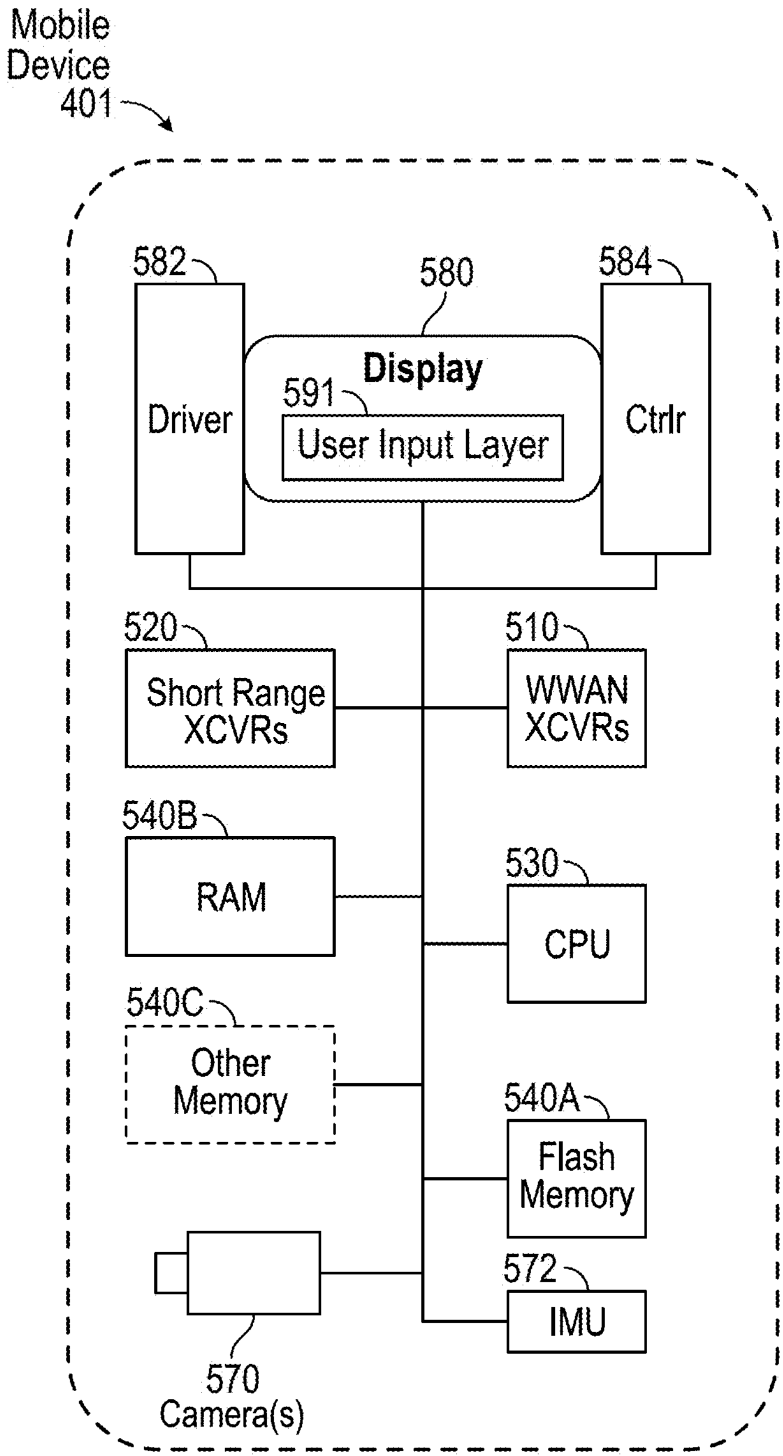

Mobile
Device
401
582
580
584
Display
591
User Input Layer
Driver
Ctrlr
520
510
Short Range
XCVRs
WWAN
XCVRs
540B
RAM
530
CPU
540C
Other
Memory
540A
Flash
Memory
572
IMU
570
Camera(s)

FIG. 5

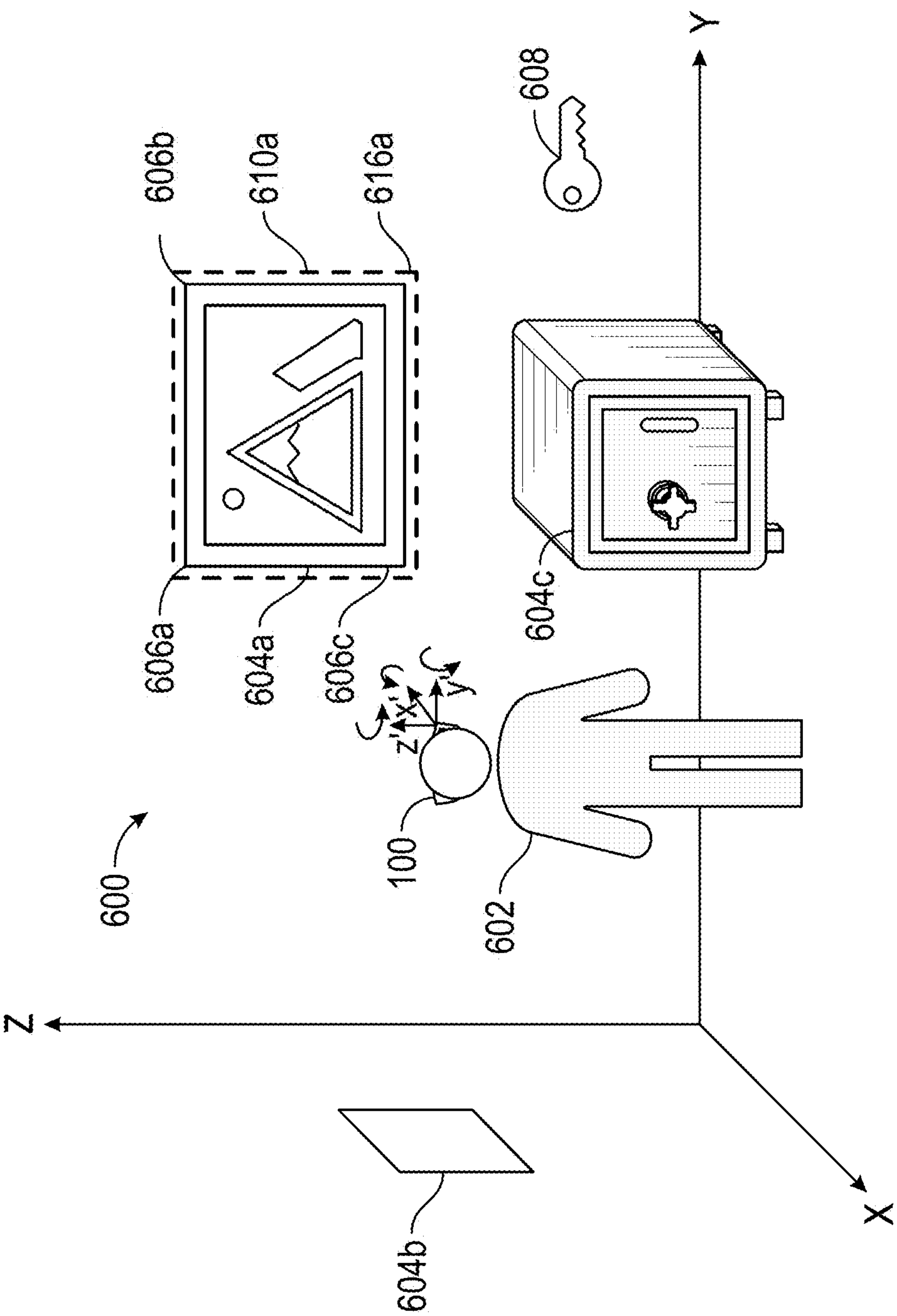

600
100
602
606a
604a
606c
606b
610a
616a
608
604c
604b
X
Y
Z
x'
y'
z'

FIG. 6

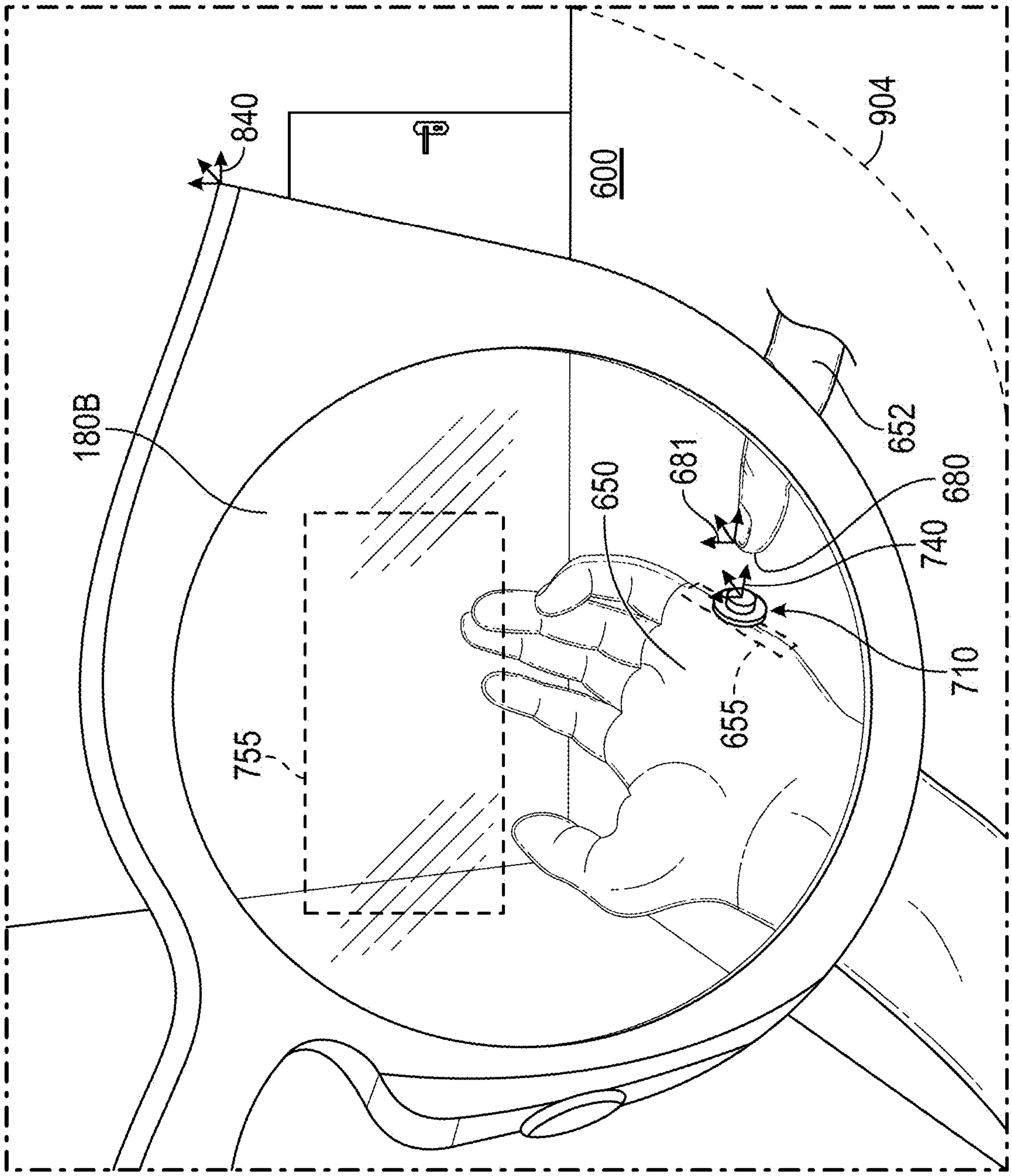


FIG. 7

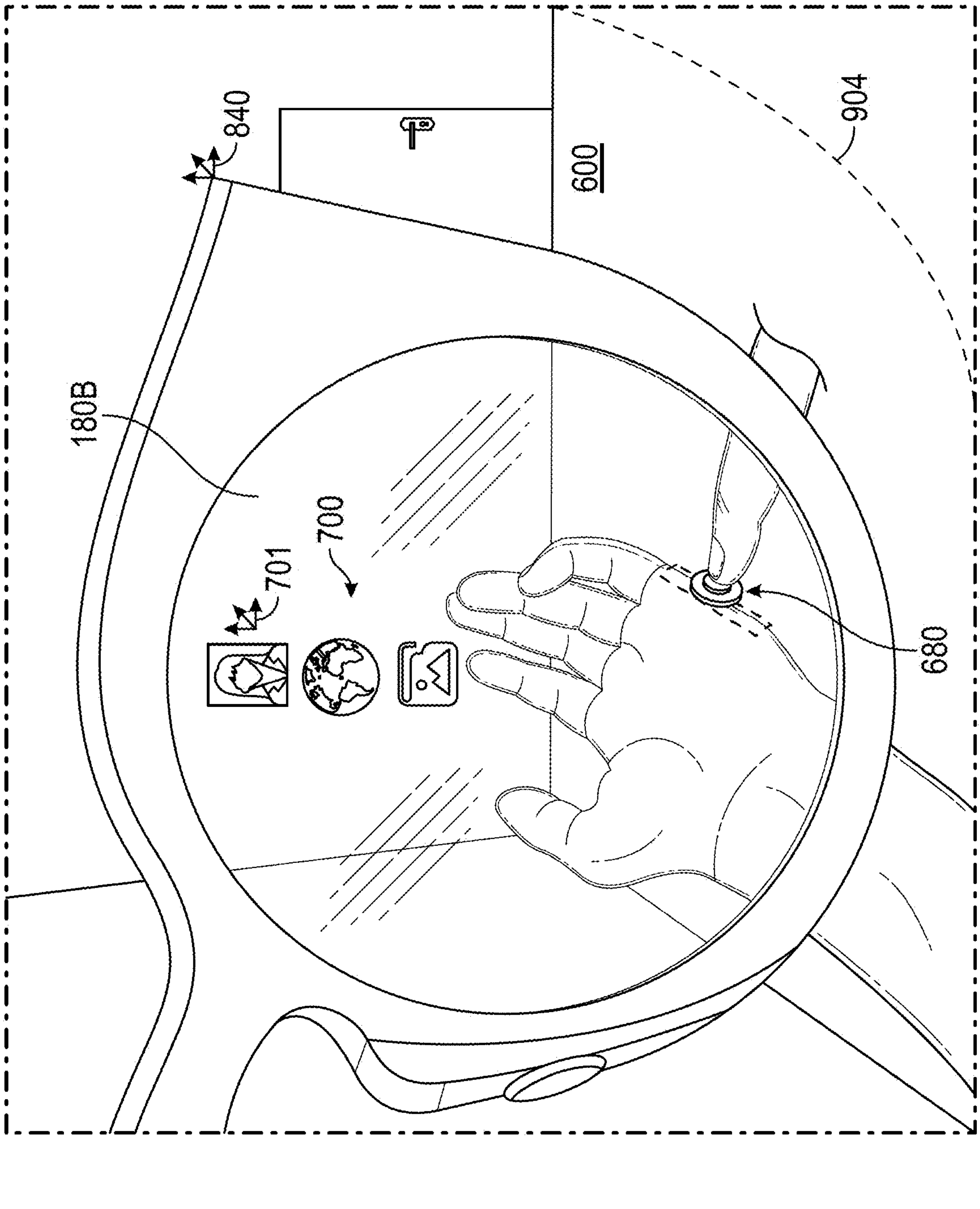


FIG. 8

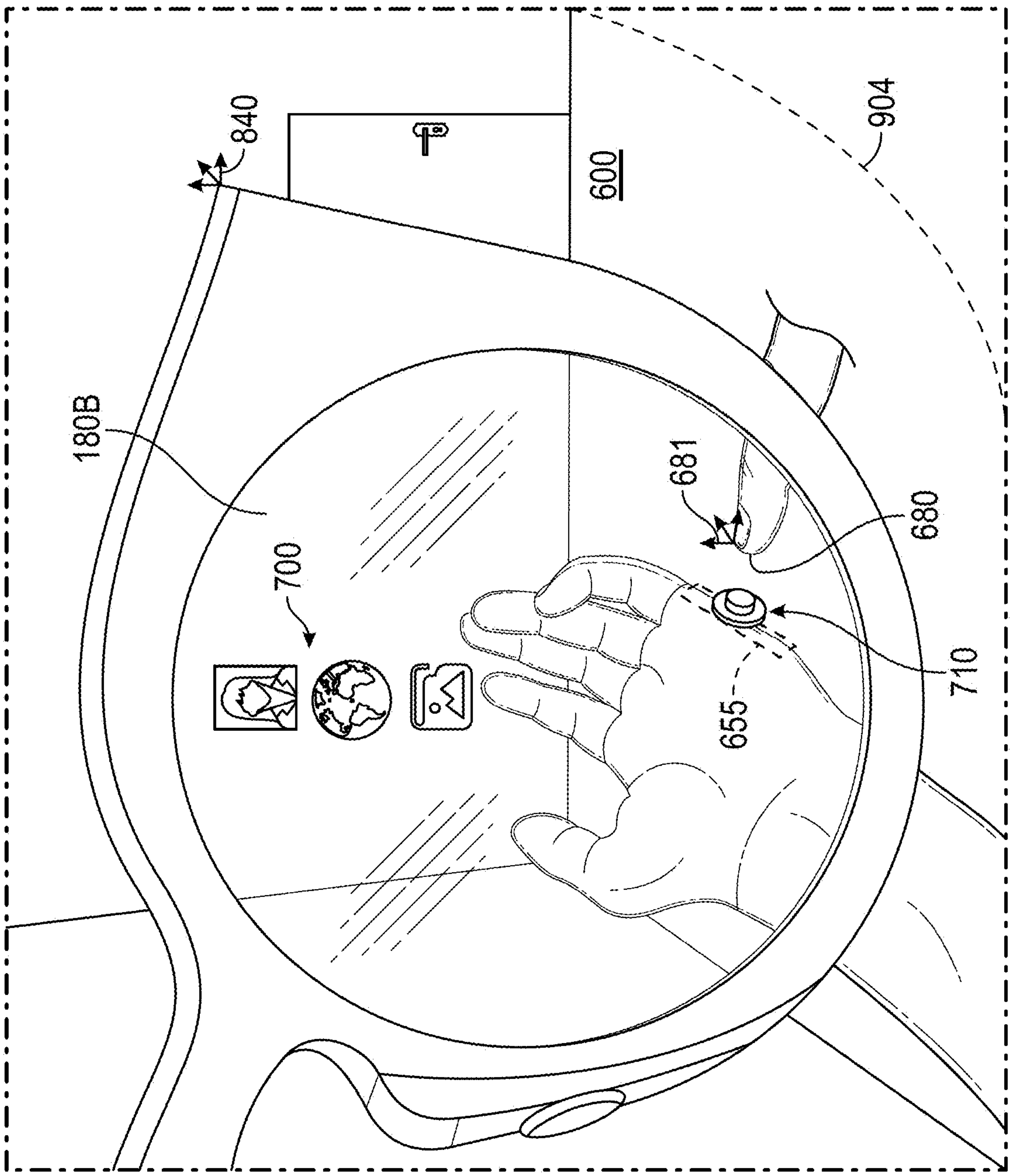


FIG. 9

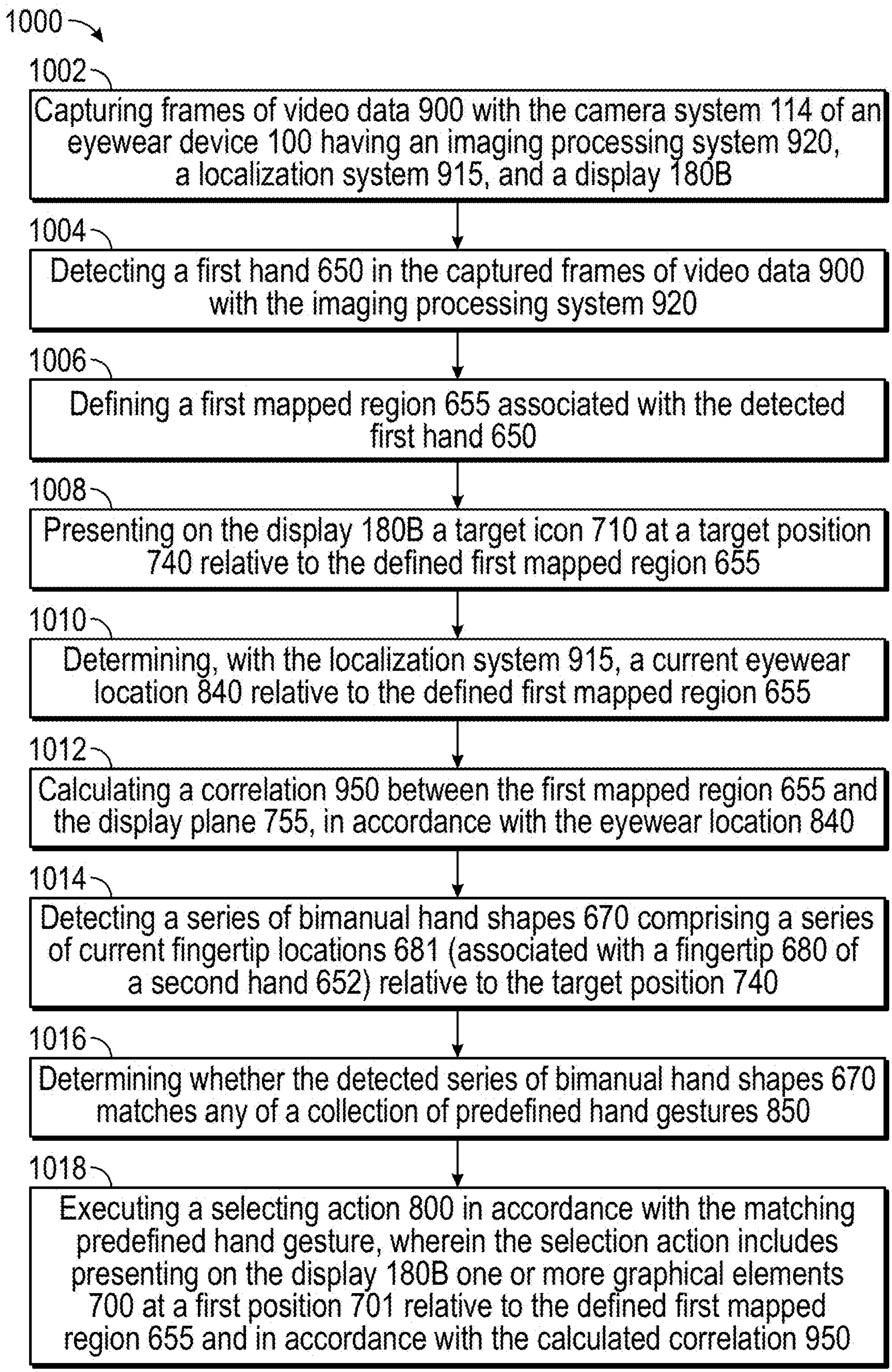

1000
1002
Capturing frames of video data 900 with the camera system 114 of an eyewear device 100 having an imaging processing system 920, a localization system 915, and a display 180B
1004
Detecting a first hand 650 in the captured frames of video data 900 with the imaging processing system 920
1006
Defining a first mapped region 655 associated with the detected first hand 650
1008
Presenting on the display 180B a target icon 710 at a target position 740 relative to the defined first mapped region 655
1010
Determining, with the localization system 915, a current eyewear location 840 relative to the defined first mapped region 655
1012
Calculating a correlation 950 between the first mapped region 655 and the display plane 755, in accordance with the eyewear location 840
1014
Detecting a series of bimanual hand shapes 670 comprising a series of current fingertip locations 681 (associated with a fingertip 680 of a second hand 652) relative to the target position 740
1016
Determining whether the detected series of bimanual hand shapes 670 matches any of a collection of predefined hand gestures 850
1018
Executing a selecting action 800 in accordance with the matching predefined hand gesture, wherein the selection action includes presenting on the display 180B one or more graphical elements 700 at a first position 701 relative to the defined first mapped region 655 and in accordance with the calculated correlation 950

FIG. 10

BIMANUAL INTERACTIONS BETWEEN MAPPED HAND REGIONS FOR CONTROLLING VIRTUAL AND GRAPHICAL ELEMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation of U.S. application Ser. No. 17/714,352 filed on Apr. 6, 2022, which claims priority to U.S. Provisional Application No. 63/172,520 filed on Apr. 8, 2021, the contents of all of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] Examples set forth in the present disclosure relate to the field of display control for electronic devices, including wearable devices such as eyewear. More particularly, but not by way of limitation, the present disclosure describes the real-time tracking of two-handed interactions between mapped hand regions for interacting with virtual elements on a display.

BACKGROUND

[0003] Many types of computers and electronic devices available today, such as mobile devices (e.g., smartphones, tablets, and laptops), handheld devices, and wearable devices (e.g., smart glasses, digital eyewear, headwear, headgear, and head-mounted displays), include a variety of cameras, sensors, wireless transceivers, input systems, and displays.

[0004] Graphical user interfaces allow the user to interact with displayed content, including virtual objects and graphical elements such as icons, taskbars, list boxes, menus, buttons, and selection control elements like cursors, pointers, handles, and sliders.

[0005] Virtual reality (VR) technology generates a complete virtual environment including realistic images, sometimes presented on a VR headset or other head-mounted display. VR experiences allow a user to move through the virtual environment and interact with virtual objects. Augmented reality (AR) is a type of VR technology that combines real objects in a physical environment with virtual objects and displays the combination to a user. The combined display gives the impression that the virtual objects are authentically present in the environment, especially when the virtual objects appear and behave like the real objects. Cross reality (XR) is generally understood as an umbrella term referring to systems that include or combine elements from AR, VR, and MR (mixed reality) environments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Features of the various examples described will be readily understood from the following detailed description, in which reference is made to the figures. A reference numeral is used with each element in the description and throughout the several views of the drawing. When a plurality of similar elements is present, a single reference numeral may be assigned to like elements, with an added lower-case letter referring to a specific element.

[0007] The various elements shown in the figures are not drawn to scale unless otherwise indicated. The dimensions of the various elements may be enlarged or reduced in the interest of clarity. The several figures depict one or more implementations and are presented by way of example only and should not be construed as limiting. Included in the drawing are the following figures:

[0008] FIG. **1**A is a side view (right) of an example hardware configuration of an eyewear device suitable for use in an example bimanual control system;

[0009] FIG. **1**B is a perspective, partly sectional view of a right corner of the eyewear device of FIG. **1**A depicting a right visible-light camera, and a circuit board;

[0010] FIG. **1**C is a side view (left) of an example hardware configuration of the eyewear device of FIG. **1**A, which shows a left visible-light camera;

[0011] FIG. **1**D is a perspective, partly sectional view of a left corner of the eyewear device of FIG. **1**C depicting the left visible-light camera, and a circuit board;

[0012] FIGS. **2**A and **2**B are rear views of example hardware configurations of an eyewear device utilized in an example bimanual control system;

[0013] FIG. **3** is a diagrammatic depiction of a three-dimensional scene, a left raw image captured by a left visible-light camera, and a right raw image captured by a right visible-light camera;

[0014] FIG. **4** is a functional block diagram of an example bimanual control system including a wearable device (e.g., an eyewear device) and a server system connected via various networks;

[0015] FIG. **5** is a diagrammatic representation of an example hardware configuration for a mobile device suitable for use in the example bimanual control system of FIG. **4**;

[0016] FIG. **6** is a schematic illustration of a user in an example environment for use in describing simultaneous localization and mapping;

[0017] FIG. **7** is a perspective illustration of an example bimanual interaction between mapped hand regions for presenting graphical elements on a display;

[0018] FIG. **8** is a perspective illustration of an example bimanual hand gesture for presenting graphical elements on a display;

[0019] FIG. **9** is a perspective illustration of another example bimanual interaction for controlling the presentation of graphical elements on a display; and

[0020] FIG. **10** is a flow chart listing the steps in an example method of controlling the presentation on a display of virtual elements or graphical elements in response to detected bimanual hand gestures.

DETAILED DESCRIPTION

[0021] Various implementations and details are described with reference to examples for presenting and controlling graphical elements and virtual elements in AR, VR, XR, or a combination thereof, using bimanual hand gestures. For example, a fingertip touching a virtual button on a mapped region of the other hand provides indirect virtual system input. In accordance with this example, active hand tracking detects the intersection of the fingertip with the virtual button, causing a system event that is closely correlated with the physical sensation of the fingertip touching the other hand.

[0022] Examples include a method of presenting a graphical element in response to bimanual gestures detected with an eyewear device. The eyewear device includes a camera system, an image processing system, a localization system, and a display. The method includes capturing frames of video data with the camera system and detecting a first hand in the captured frames of video data with the image processing system. The method further includes defining a first mapped region associated with the detected first hand, wherein the first mapped region is defined relative to a display plane; and presenting a target icon on the display at a target position relative to the defined first mapped region. To correlate the first mapped region on the hand with the display plane, the method includes determining, with the localization system, a current eyewear location relative to the defined first mapped region and calculating a correlation between the defined first mapped region and the display plane, in accordance with the current eyewear location.

[0023] In addition, the method includes detecting, with the image processing system, a series of bimanual hand shapes comprising the detected first hand and a series of current fingertip locations associated with a fingertip of a second hand, relative to the target position. The method further includes determining, with the image processing system, whether the detected series of bimanual hand shapes matches a predefined hand gesture selected from a plurality of predefined hand gestures. In response to a match, the method includes executing a selecting action in accordance with the matching predefined hand gesture.

[0024] Although the various systems and methods are described herein with reference to capturing sill images with an eyewear device, the technology described may be applied to selecting and capturing still images from a sequence of frames of video data that were captured by other devices.

[0025] The following detailed description includes systems, methods, techniques, instruction sequences, and computing machine program products illustrative of examples set forth in the disclosure. Numerous details and examples are included for the purpose of providing a thorough understanding of the disclosed subject matter and its relevant teachings. Those skilled in the relevant art, however, may understand how to apply the relevant teachings without such details. Aspects of the disclosed subject matter are not limited to the specific devices, systems, and method described because the relevant teachings can be applied or practice in a variety of ways. The terminology and nomenclature used herein is for the purpose of describing particular aspects only and is not intended to be limiting. In general, well-known instruction instances, protocols, structures, and techniques are not necessarily shown in detail.

[0026] The terms "coupled" or "connected" as used herein refer to any logical, optical, physical, or electrical connection, including a link or the like by which the electrical or magnetic signals produced or supplied by one system element are imparted to another coupled or connected system element. Unless described otherwise, coupled or connected elements or devices are not necessarily directly connected to one another and may be separated by intermediate components, elements, or communication media, one or more of which may modify, manipulate, or carry the electrical signals. The term "on" means directly supported by an element or indirectly supported by the element through another element that is integrated into or supported by the element.

[0027] The term "proximal" is used to describe an item or part of an item that is situated near, adjacent, or next to an object or person; or that is closer relative to other parts of the item, which may be described as "distal." For example, the end of an item nearest an object may be referred to as the proximal end, whereas the generally opposing end may be referred to as the distal end.

[0028] The orientations of the eyewear device, other mobile devices, associated components and any other devices incorporating a camera, an inertial measurement unit, or both such as shown in any of the drawings, are given by way of example only, for illustration and discussion purposes. In operation, the eyewear device may be oriented in any other direction suitable to the particular application of the eyewear device; for example, up, down, sideways, or any other orientation. Also, to the extent used herein, any directional term, such as front, rear, inward, outward, toward, left, right, lateral, longitudinal, up, down, upper, lower, top, bottom, side, horizontal, vertical, and diagonal are used by way of example only, and are not limiting as to the direction or orientation of any camera or inertial measurement unit as constructed or as otherwise described herein.

[0029] Advanced AR technologies, such as computer vision and object tracking, may be used to produce a perceptually enriched and immersive experience. Computer vision algorithms extract three-dimensional data about the physical world from the data captured in digital images or video. Object recognition and tracking algorithms are used to detect an object in a digital image or video, estimate its orientation or pose, and track its movement over time. Hand and finger recognition and tracking in real time is one of the most challenging and processing-intensive tasks in the field of computer vision.

[0030] The term "pose" refers to the static position and orientation of an object at a particular instant in time. The term "gesture" refers to the active movement of an object, such as a hand, through a series of poses, sometimes to convey a signal or idea. The terms, pose and gesture, are sometimes used interchangeably in the field of computer vision and augmented reality. As used herein, the terms "pose" or "gesture" (or variations thereof) are intended to be inclusive of both poses and gestures; in other words, the use of one term does not exclude the other.

[0031] The term "bimanual gesture" means and describes a gesture performed with both hands. One hand may be relatively stationary, while the other hand is moving. In some bimanual gestures, both hands appear relatively stationary; the gesture occurs in small movements between the fingers and surfaces of the two hands. Although the two hands may operate in relative opposition to perform a bimanual gesture, the term includes gestures made by both hands operating together, in tandem.

[0032] Additional objects, advantages and novel features of the examples will be set forth in part in the following description, and in part will become apparent to those skilled in the art upon examination of the following and the accompanying drawings or may be learned by production or operation of the examples. The objects and advantages of the present subject matter may be realized and attained by means of the methodologies, instrumentalities and combinations particularly pointed out in the appended claims.

[0033] Reference now is made in detail to the examples illustrated in the accompanying drawings and discussed below.

[0034] FIG. **1**A is a side view (right) of an example hardware configuration of an eyewear device **100** which includes a touch-sensitive input device or touchpad **181**. As shown, the touchpad **181** may have a boundary that is subtle and not easily seen; alternatively, the boundary may be plainly visible or include a raised or otherwise tactile edge that provides feedback to the user about the location and boundary of the touchpad **181**. In other implementations, the eyewear device **100** may include a touchpad on the left side.

[0035] The surface of the touchpad **181** is configured to detect finger touches, taps, and gestures (e.g., moving touches) for use with a GUI displayed by the eyewear device, on an image display, to allow the user to navigate through and select menu options in an intuitive manner, which enhances and simplifies the user experience.

[0036] Detection of finger inputs on the touchpad **181** can enable several functions. For example, touching anywhere on the touchpad **181** may cause the GUI to display or highlight an item on the image display, which may be projected onto at least one of the optical assemblies **180**A, **180**B. Double tapping on the touchpad **181** may select an item or icon. Sliding or swiping a finger in a particular direction (e.g., from front to back, back to front, up to down, or down to) may cause the items or icons to slide or scroll in a particular direction; for example, to move to a next item, icon, video, image, page, or slide. Sliding the finger in another direction may slide or scroll in the opposite direction; for example, to move to a previous item, icon, video, image, page, or slide. The touchpad **181** can be virtually anywhere on the eyewear device **100**.

[0037] In one example, an identified finger gesture of a single tap on the touchpad **181**, initiates selection or pressing of a graphical user interface element in the image presented on the image display of the optical assembly **180**A, **180**B. An adjustment to the image presented on the image display of the optical assembly **180**A, **180**B based on the identified finger gesture can be a primary action which selects or submits the graphical user interface element on the image display of the optical assembly **180**A, **180**B for further display or execution.

[0038] As shown, the eyewear device **100** includes a right visible-light camera **114**B. As further described herein, two cameras **114**A, **114**B capture image information for a scene from two separate viewpoints. The two captured images may be used to project a three-dimensional display onto an image display for viewing with 3D glasses.

[0039] The eyewear device **100** includes a right optical assembly **180**B with an image display to present images, such as depth images. As shown in FIGS. **1**A and **1**B, the eyewear device **100** includes the right visible-light camera **114**B. The eyewear device **100** can include multiple visible-light cameras **114**A, **114**B that form a passive type of three-dimensional camera, such as stereo camera, of which the right visible-light camera **114**B is located on a right corner **110**B. As shown in FIGS. **1**C-D, the eyewear device **100** also includes a left visible-light camera **114**A.

[0040] Left and right visible-light cameras **114**A, **114**B are sensitive to the visible-light range wavelength. Each of the visible-light cameras **114**A, **114**B have a different frontward facing field of view which are overlapping to enable generation of three-dimensional depth images, for example, right visible-light camera **114**B depicts a right field of view **111**B. Generally, a "field of view" is the part of the scene that is visible through the camera at a particular position and orientation in space. The fields of view **111**A and **111**B have an overlapping field of view **304** (FIG. **3**). Objects or object features outside the field of view **111**A, **111**B when the visible-light camera captures the image are not recorded in a raw image (e.g., photograph or picture). The field of view describes an angle range or extent, which the image sensor of the visible-light camera **114**A, **114**B picks up electromagnetic radiation of a given scene in a captured image of the given scene. Field of view can be expressed as the angular size of the view cone; i.e., an angle of view. The angle of view can be measured horizontally, vertically, or diagonally.

[0041] In an example configuration, one or both visible-light cameras **114**A, **114**B has a field of view of 100° and a resolution of 480×480 pixels. The "angle of coverage" describes the angle range that a lens of visible-light cameras **114**A, **114**B or infrared camera **410** (scc FIG. **2**A) can effectively image. Typically, the camera lens produces an image circle that is large enough to cover the film or sensor of the camera completely, possibly including some vignetting (e.g., a darkening of the image toward the edges when compared to the center). If the angle of coverage of the camera lens does not fill the sensor, the image circle will be visible, typically with strong vignetting toward the edge, and the effective angle of view will be limited to the angle of coverage.

[0042] Examples of such visible-light cameras **114**A, **114**B include a high-resolution complementary metal-oxide-semiconductor (CMOS) image sensor and a digital VGA camera (video graphics array) capable of resolutions of 480p (e.g., 640×480 pixels), 720p, 1080p, or greater. Other examples include visible-light cameras **114**A, **114**B that can capture high-definition (HD) video at a high frame rate (e.g., thirty to sixty frames per second, or more) and store the recording at a resolution of 1216 by 1216 pixels (or greater).

[0043] The eyewear device **100** may capture image sensor data from the visible-light cameras **114**A, **114**B along with geolocation data, digitized by an image processor, for storage in a memory. The visible-light cameras **114**A, **114**B capture respective left and right raw images in the two-dimensional space domain that comprise a matrix of pixels on a two-dimensional coordinate system that includes an X-axis for horizontal position and a Y-axis for vertical position. Each pixel includes a color attribute value (e.g., a red pixel light value, a green pixel light value, or a blue pixel light value); and a position attribute (e.g., an X-axis coordinate and a Y-axis coordinate).

[0044] In order to capture stereo images for later display as a three-dimensional projection, the image processor **412** (shown in FIG. **4**) may be coupled to the visible-light cameras **114**A, **114**B to receive and store the visual image information. The image processor **412**, or another processor, controls operation of the visible-light cameras **114**A, **114**B to act as a stereo camera simulating human binocular vision and may add a timestamp to each image. The timestamp on each pair of images allows display of the images together as part of a three-dimensional projection. Three-dimensional projections produce an immersive, life-like experience that is desirable in a variety of contexts, including virtual reality (VR) and video gaming.

[0045] FIG. **1**B is a perspective, cross-sectional view of a right corner **110**B of the eyewear device **100** of FIG. **1**A depicting the right visible-light camera **114**B of the camera system, and a circuit board. FIG. **1**C is a side view (left) of an example hardware configuration of an eyewear device **100** of FIG. **1**A, which shows a left visible-light camera **114**A of the camera system. FIG. **1**D is a perspective, cross-sectional view of a left corner **110**A of the eyewear device of FIG. **1**C depicting the left visible-light camera **114**A of the three-dimensional camera, and a circuit board.

[0046] Construction and placement of the left visible-light camera **114**A is substantially similar to the right visible-light camera **114**B, except the connections and coupling are on the left lateral side **170**A. As shown in the example of FIG. **1**B, the eyewear device **100** includes the right visible-light camera **114**B and a circuit board **140**B, which may be a flexible printed circuit board (PCB). A right hinge **126**B connects the right corner **110**B to a right temple **125**B of the eyewear device **100**. In some examples, components of the right visible-light camera **114**B, the flexible PCB **140**B, or other electrical connectors or contacts may be located on the right temple **125**B or the right hinge **126**B. A left hinge **126**A connects the left corner **110**A to a left temple **125**A of the eyewear device **100**. In some examples, components of the left visible-light camera **114**A, the flexible PCB **140**A, or other electrical connectors or contacts may be located on the left temple **125**A or the left hinge **126**A.

[0047] The right corner **110**B includes corner body **190** and a corner cap, with the corner cap omitted in the cross-section of FIG. **1**B. Disposed inside the right corner **110**B are various interconnected circuit boards, such as PCBs or flexible PCBs, that include controller circuits for right visible-light camera **114**B, microphone(s), low-power wireless circuitry (e.g., for wireless short range network communication via Bluetooth™), high-speed wireless circuitry (e.g., for wireless local area network communication via Wi-Fi).

[0048] The right visible-light camera **114**B is coupled to or disposed on the flexible PCB **140**B and covered by a visible-light camera cover lens, which is aimed through opening(s) formed in the frame **105**. For example, the right rim **107**B of the frame **105**, shown in FIG. **2**A, is connected to the right corner **110**B and includes the opening(s) for the visible-light camera cover lens. The frame **105** includes a front side configured to face outward and away from the eye of the user. The opening for the visible-light camera cover lens is formed on and through the front or outward-facing side of the frame **105**. In the example, the right visible-light camera **114**B has an outward-facing field of view **111**B (shown in FIG. **3**) with a line of sight or perspective that is correlated with the right eye of the user of the eyewear device **100**. The visible-light camera cover lens can also be adhered to a front side or outward-facing surface of the right corner **110**B in which an opening is formed with an outward-facing angle of coverage, but in a different outwardly direction. The coupling can also be indirect via intervening components.

[0049] As shown in FIG. **1**B, flexible PCB **140**B is disposed inside the right corner **110**B and is coupled to one or more other components housed in the right corner **110**B. Although shown as being formed on the circuit boards of the right corner **110**B, the right visible-light camera **114**B can be formed on the circuit boards of the left corner **110**A, the temples **125**A, **125**B, or the frame **105**.

[0050] FIGS. **2**A and **2**B are perspective views, from the rear, of example hardware configurations of the eyewear device **100**, including two different types of image displays. The eyewear device **100** is sized and shaped in a form configured for wearing by a user; the form of eyeglasses is shown in the example. The eyewear device **100** can take other forms and may incorporate other types of frameworks; for example, a headgear, a headset, or a helmet.

[0051] In the eyeglasses example, eyewear device **100** includes a frame **105** including a left rim **107**A connected to a right rim **107**B via a bridge **106** adapted to be supported by a nose of the user. The left and right rims **107**A, **107**B include respective apertures **175**A, **175**B, which hold a respective optical element **180**A, **180**B, such as a lens and a display device. As used herein, the term "lens" is meant to include transparent or translucent pieces of glass or plastic having curved or flat surfaces that cause light to converge or diverge or that cause little or no convergence or divergence.

[0052] Although shown as having two optical elements **180**A, **180**B, the eyewear device **100** can include other arrangements, such as a single optical element (or it may not include any optical element **180**A, **180**B), depending on the application or the intended user of the eyewear device **100**. As further shown, eyewear device **100** includes a left corner **110**A adjacent the left lateral side **170**A of the frame **105** and a right corner **110**B adjacent the right lateral side **170**B of the frame **105**. The corners **110**A, **110**B may be integrated into the frame **105** on the respective sides **170**A, **170**B (as illustrated) or implemented as separate components attached to the frame **105** on the respective sides **170**A, **170**B. Alternatively, the corners **110**A, **110**B may be integrated into temples (not shown) attached to the frame **105**.

[0053] In one example, the image display of optical assembly **180**A, **180**B includes an integrated image display. As shown in FIG. **2**A, each optical assembly **180**A, **180**B includes a suitable display matrix **177**, such as a liquid crystal display (LCD), an organic light-emitting diode (OLED) display, or any other such display. Each optical assembly **180**A, **180**B also includes an optical layer or layers **176**, which can include lenses, optical coatings, prisms, mirrors, waveguides, optical strips, and other optical components in any combination. The optical layers **176**A, **176**B, . . . **176**N (shown as **176**A-N in FIG. **2**A and herein) can include a prism having a suitable size and configuration and including a first surface for receiving light from a display matrix and a second surface for emitting light to the eye of the user. The prism of the optical layers **176**A-N extends over all or at least a portion of the respective apertures **175**A, **175**B formed in the left and right rims **107**A, **107**B to permit the user to see the second surface of the prism when the eye of the user is viewing through the corresponding left and right rims **107**A, **107**B. The first surface of the prism of the optical layers **176**A-N faces upwardly from the frame **105** and the display matrix **177** overlies the prism so that photons and light emitted by the display matrix **177** impinge the first surface. The prism is sized and shaped so that the light is refracted within the prism and is directed toward the eye of the user by the second surface of the prism of the optical layers **176**A-N. In this regard, the second surface of the prism of the optical layers **176**A-N can be convex to direct the light toward the center of the eye. The prism can optionally be sized and shaped to magnify the image projected by the display matrix **177**, and the light travels through the prism so that the image viewed from the second surface is larger in one or more dimensions than the image emitted from the display matrix **177**.

[0054] In one example, the optical layers **176**A-N may include an LCD layer that is transparent (keeping the lens open) unless and until a voltage is applied which makes the layer opaque (closing or blocking the lens). The image processor **412** on the eyewear device **100** may execute programming to apply the voltage to the LCD layer in order to produce an active shutter system, making the eyewear device **100** suitable for viewing visual content when displayed as a three-dimensional projection. Technologies other than LCD may be used for the active shutter mode, including other types of reactive layers that are responsive to a voltage or another type of input.

[0055] In another example, the image display device of optical assembly **180**A, **180**B includes a projection image display as shown in FIG. **2**B. Each optical assembly **180**A, **180**B includes a laser projector **150**, which is a three-color laser projector using a scanning mirror or galvanometer. During operation, an optical source such as a laser projector **150** is disposed in or on one of the temples **125**A, **125**B of the eyewear device **100**. Optical assembly **180**B in this example includes one or more optical strips **155**A, **155**B, . . . **155**N (shown as **155**A-N in FIG. **2**B) which are spaced apart and across the width of the lens of each optical assembly **180**A, **180**B or across a depth of the lens between the front surface and the rear surface of the lens.

[0056] As the photons projected by the laser projector **150** travel across the lens of each optical assembly **180**A, **180**B, the photons encounter the optical strips **155**A-N. When a particular photon encounters a particular optical strip, the photon is either redirected toward the user's eye, or it passes to the next optical strip. A combination of modulation of laser projector **150**, and modulation of optical strips, may control specific photons or beams of light. In an example, a processor controls optical strips **155**A-N by initiating mechanical, acoustic, or electromagnetic signals. Although shown as having two optical assemblies **180**A, **180**B, the eyewear device **100** can include other arrangements, such as a single or three optical assemblies, or each optical assembly **180**A, **180**B may have arranged different arrangement depending on the application or intended user of the eyewear device **100**.

[0057] As further shown in FIGS. **2**A and **2**B, eyewear device **100** includes a left corner **110**A adjacent the left lateral side **170**A of the frame **105** and a right corner **110**B adjacent the right lateral side **170**B of the frame **105**. The corners **110**A, **110**B may be integrated into the frame **105** on the respective lateral sides **170**A, **170**B (as illustrated) or implemented as separate components attached to the frame **105** on the respective sides **170**A, **170**B. Alternatively, the corners **110**A, **110**B may be integrated into temples **125**A, **125**B attached to the frame **105**.

[0058] In another example, the eyewear device **100** shown in FIG. **2**B may include two projectors, a left projector (not shown) and a right projector (shown as projector **150**). The left optical assembly **180**A may include a left display matrix **177**A (not shown) or a left set of optical strips **155**'A, **155**'B, . . . **155**'N (**155** prime, A through N, not shown) which are configured to interact with light from the left projector **150**A. Similarly, the right optical assembly **180**B may include a right display matrix **177**B (not shown) or a right set of optical strips **155**"A, **155**"B, . . . **155**"N (**155** double prime, A through N, not shown) which are configured to interact with light from the right projector **150**. In this example, the eyewear device **100** includes a left display and a right display.

[0059] FIG. **3** is a diagrammatic depiction of a three-dimensional scene **306**, a left raw image **302**A captured by a left visible-light camera **114**A, and a right raw image **302**B captured by a right visible-light camera **114**B. The left field of view **111**A may overlap, as shown, with the right field of view **111**B. The overlapping field of view **304** represents that portion of the image captured by both cameras **114**A, **114**B. The term 'overlapping' when referring to field of view means the matrix of pixels in the generated raw images overlap by thirty percent (30%) or more. 'Substantially overlapping' means the matrix of pixels in the generated raw images—or in the infrared image of scene-overlap by fifty percent (50%) or more. As described herein, the two raw images **302**A, **302**B may be processed to include a timestamp, which allows the images to be displayed together as part of a three-dimensional projection.

[0060] For the capture of stereo images, as illustrated in FIG. **3**, a pair of raw red, green, and blue (RGB) images are captured of a real scene **306** at a given moment in time—a left raw image **302**A captured by the left camera **114**A and right raw image **302**B captured by the right camera **114**B. When the pair of raw images **302**A, **302**B are processed (e.g., by the image processor **412**), depth images are generated. The generated depth images may be viewed on an optical assembly **180**A, **180**B of an eyewear device, on another display (e.g., the image display **580** on a mobile device **401**), or on a screen.

[0061] The generated depth images are in the three-dimensional space domain and can comprise a matrix of vertices on a three-dimensional location coordinate system that includes an X axis for horizontal position (e.g., length), a Y axis for vertical position (e.g., height), and a Z axis for depth (e.g., distance). Each vertex may include a color attribute (e.g., a red pixel light value, a green pixel light value, or a blue pixel light value); a position attribute (e.g., an X location coordinate, a Y location coordinate, and a Z location coordinate); a texture attribute; a reflectance attribute; or a combination thereof. The texture attribute quantifies the perceived texture of the depth image, such as the spatial arrangement of color or intensities in a region of vertices of the depth image.

[0062] In one example, the bimanual control system **400** (FIG. **4**) includes the eyewear device **100**, which includes a frame **105** and a left temple **125**A extending from a left lateral side **170**A of the frame **105** and a right temple **125**B extending from a right lateral side **170**B of the frame **105**. The eyewear device **100** may further include at least two visible-light cameras **114**A, **114**B having overlapping fields of view. In one example, the eyewear device **100** includes a left visible-light camera **114**A with a left field of view **111**A, as illustrated in FIG. **3**. The left camera **114**A is connected to the frame **105** or the left temple **125**A to capture a left raw image **302**A from the left side of scene **306**. The eyewear device **100** further includes a right visible-light camera **114**B with a right field of view **111**B. The right camera **114**B is connected to the frame **105** or the right temple **125**B to capture a right raw image **302**B from the right side of scene **306**.

[0063] FIG. **4** is a functional block diagram of an example bimanual control system **400** that includes a wearable device (e.g., an eyewear device **100**), a mobile device **401**, and a server system **498** connected via various networks **495** such as the Internet. As shown, the bimanual control system **400** includes a low-power wireless connection **425** and a high-speed wireless connection **437** between the eyewear device **100** and the mobile device **401**.

[0064] As shown in FIG. **4**, the eyewear device **100** includes one or more visible-light cameras **114**A, **114**B that capture still images, video images, or both still and video images, as described herein. The cameras **114**A, **114**B may have a direct memory access (DMA) to high-speed circuitry **430** and function as a stereo camera. The cameras **114**A, **114**B may be used to capture initial-depth images that may be rendered into three-dimensional (3D) models that are texture-mapped images of a red, green, and blue (RGB) imaged scene. The device **100** may also include a depth sensor **213**, which uses infrared signals to estimate the position of objects relative to the device **100**. The depth sensor **213** in some examples includes one or more infrared emitter(s) **215** and infrared camera(s) **410**.

[0065] The eyewear device **100** further includes two image displays of each optical assembly **180**A, **180**B (one associated with the left side **170**A and one associated with the right side **170**B). The eyewear device **100** also includes an image display driver **442**, an image processor **412**, low-power circuitry **420**, and high-speed circuitry **430**. The image displays of each optical assembly **180**A, **180**B are for presenting images, including still images, video images, or still and video images. The image display driver **442** is coupled to the image displays of each optical assembly **180**A, **180**B in order to control the display of images.

[0066] The eyewear device **100** additionally includes one or more speakers **440** (e.g., one associated with the left side of the eyewear device and another associated with the right side of the eyewear device). The speakers **440** may be incorporated into the frame **105**, temples **125**, or corners **110** of the eyewear device **100**. The one or more speakers **440** are driven by audio processor **443** under control of low-power circuitry **420**, high-speed circuitry **430**, or both. The speakers **440** are for presenting audio signals including, for example, a beat track. The audio processor **443** is coupled to the speakers **440** in order to control the presentation of sound.

[0067] The components shown in FIG. **4** for the eyewear device **100** are located on one or more circuit boards, for example a printed circuit board (PCB) or flexible printed circuit (FPC), located in the rims or temples. Alternatively, or additionally, the depicted components can be located in the corners, frames, hinges, or bridge of the eyewear device **100**. Left and right visible-light cameras **114**A, **114**B can include digital camera elements such as a complementary metal-oxide-semiconductor (CMOS) image sensor, a charge-coupled device, a lens, or any other respective visible or light capturing elements that may be used to capture data, including still images or video of scenes with unknown objects.

[0068] As shown in FIG. **4**, high-speed circuitry **430** includes a high-speed processor **432**, a memory **434**, and high-speed wireless circuitry **436**. In the example, the image display driver **442** is coupled to the high-speed circuitry **430** and operated by the high-speed processor **432** in order to drive the left and right image displays of each optical assembly **180**A, **180**B. High-speed processor **432** may be any processor capable of managing high-speed communications and operation of any general computing system needed for eyewear device **100**. High-speed processor **432** includes processing resources needed for managing high-speed data transfers on high-speed wireless connection **437** to a wireless local area network (WLAN) using high-speed wireless circuitry **436**.

[0069] In some examples, the high-speed processor **432** executes an operating system such as a LINUX operating system or other such operating system of the eyewear device **100** and the operating system is stored in memory **434** for execution. In addition to any other responsibilities, the high-speed processor **432** executes a software architecture for the eyewear device **100** that is used to manage data transfers with high-speed wireless circuitry **436**. In some examples, high-speed wireless circuitry **436** is configured to implement Institute of Electrical and Electronic Engineers (IEEE) 802.11 communication standards, also referred to herein as Wi-Fi. In other examples, other high-speed communications standards may be implemented by high-speed wireless circuitry **436**.

[0070] The low-power circuitry **420** includes a low-power processor **422** and low-power wireless circuitry **424**. The low-power wireless circuitry **424** and the high-speed wireless circuitry **436** of the eyewear device **100** can include short-range transceivers (Bluetooth™ or Bluetooth Low-Energy (BLE)) and wireless wide, local, or wide-area network transceivers (e.g., cellular or Wi-Fi). Mobile device **401**, including the transceivers communicating via the low-power wireless connection **425** and the high-speed wireless connection **437**, may be implemented using details of the architecture of the eyewear device **100**, as can other elements of the network **495**.

[0071] Memory **434** includes any storage device capable of storing various data and applications, including, among other things, camera data generated by the left and right visible-light cameras **114**A, **114**B, the infrared camera(s) **410**, the image processor **412**, and images generated for display by the image display driver **442** on the image display of each optical assembly **180**A, **180**B. Although the memory **434** is shown as integrated with high-speed circuitry **430**, the memory **434** in other examples may be an independent, standalone element of the eyewear device **100**. In certain such examples, electrical routing lines may provide a connection through a chip that includes the high-speed processor **432** from the image processor **412** or low-power processor **422** to the memory **434**. In other examples, the high-speed processor **432** may manage addressing of memory **434** such that the low-power processor **422** will boot the high-speed processor **432** any time that a read or write operation involving memory **434** is needed.

[0072] As shown in FIG. **4**, the high-speed processor **432** of the eyewear device **100** can be coupled to the camera system (visible-light cameras **114**A, **114**B), the image display driver **442**, the user input device **491**, and the memory **434**. As shown in FIG. **5**, the CPU **530** of the mobile device **401** may be coupled to a camera system **570**, a mobile display driver **582**, a user input layer **591**, and a memory **540**A.

[0073] The server system **498** may be one or more computing devices as part of a service or network computing system, for example, that include a processor, a memory, and network communication interface to communicate over the network **495** with an eyewear device **100** and a mobile device **401**.

[0074] The output components of the eyewear device **100** include visual elements, such as the left and right image displays associated with each lens or optical assembly **180**A, **180**B as described in FIGS. **2**A and **2**B (e.g., a display such as a liquid crystal display (LCD), a plasma display panel (PDP), a light emitting diode (LED) display, a projector, or a waveguide). The eyewear device **100** may include a user-facing indicator (e.g., an LED, a loudspeaker, or a vibrating actuator), or an outward-facing signal (e.g., an

LED, a loudspeaker). The image displays of each optical assembly **180**A, **180**B are driven by the image display driver **442**. In some example configurations, the output components of the eyewear device **100** further include additional indicators such as audible elements (e.g., loudspeakers), tactile components (e.g., an actuator such as a vibratory motor to generate haptic feedback), and other signal generators. For example, the device **100** may include a user-facing set of indicators, and an outward-facing set of signals. The user-facing set of indicators are configured to be seen or otherwise sensed by the user of the device **100**. For example, the device **100** may include an LED display positioned so the user can see it, a one or more speakers positioned to generate a sound the user can hear, or an actuator to provide haptic feedback the user can feel. The outward-facing set of signals are configured to be seen or otherwise sensed by an observer near the device **100**. Similarly, the device **100** may include an LED, a loudspeaker, or an actuator that is configured and positioned to be sensed by an observer.

[0075] The input components of the eyewear device **100** may include alphanumeric input components (e.g., a touch screen or touchpad configured to receive alphanumeric input, a photo-optical keyboard, or other alphanumeric-configured elements), pointer-based input components (e.g., a mouse, a touchpad, a trackball, a joystick, a motion sensor, or other pointing instruments), tactile input components (e.g., a button switch, a touch screen or touchpad that senses the location, force or location and force of touches or touch gestures, or other tactile-configured elements), and audio input components (e.g., a microphone), and the like. The mobile device **401** and the server system **498** may include alphanumeric, pointer-based, tactile, audio, and other input components.

[0076] In some examples, the eyewear device **100** includes a collection of motion-sensing components referred to as an inertial measurement unit **472**. The motion-sensing components may be micro-electro-mechanical systems (MEMS) with microscopic moving parts, often small enough to be part of a microchip. The inertial measurement unit (IMU) **472** in some example configurations includes an accelerometer, a gyroscope, and a magnetometer. The accelerometer senses the linear acceleration of the device **100** (including the acceleration due to gravity) relative to three orthogonal axes (x, y, z). The gyroscope senses the angular velocity of the device **100** about three axes of rotation (pitch, roll, yaw). Together, the accelerometer and gyroscope can provide position, orientation, and motion data about the device relative to six axes (x, y, z, pitch, roll, yaw). The magnetometer, if present, senses the heading of the device **100** relative to magnetic north. The position of the device **100** may be determined by location sensors, such as a GPS unit **473**, one or more transceivers to generate relative position coordinates, altitude sensors or barometers, and other orientation sensors. Such positioning system coordinates can also be received over the wireless connections **425**, **437** from the mobile device **401** via the low-power wireless circuitry **424** or the high-speed wireless circuitry **436**.

[0077] The IMU **472** may include or cooperate with a digital motion processor or programming that gathers the raw data from the components and compute a number of useful values about the position, orientation, and motion of the device **100**. For example, the acceleration data gathered from the accelerometer can be integrated to obtain the velocity relative to each axis (x, y, z); and integrated again to obtain the position of the device **100** (in linear coordinates, x, y, and z). The angular velocity data from the gyroscope can be integrated to obtain the position of the device **100** (in spherical coordinates). The programming for computing these useful values may be stored in memory **434** and executed by the high-speed processor **432** of the eyewear device **100**.

[0078] The eyewear device **100** may optionally include additional peripheral sensors, such as biometric sensors, specialty sensors, or display elements integrated with eyewear device **100**. For example, peripheral device elements may include any I/O components including output components, motion components, position components, or any other such elements described herein. For example, the biometric sensors may include components to detect expressions (e.g., hand expressions, facial expressions, vocal expressions, body gestures, or eye tracking), to measure bio signals (e.g., blood pressure, heart rate, body temperature, perspiration, or brain waves), or to identify a person (e.g., identification based on voice, retina, facial characteristics, fingerprints, or electrical bio signals such as electroencephalogram data), and the like.

[0079] The mobile device **401** may be a smartphone, tablet, laptop computer, access point, or any other such device capable of connecting with eyewear device **100** using both a low-power wireless connection **425** and a high-speed wireless connection **437**. Mobile device **401** is connected to server system **498** and network **495**. The network **495** may include any combination of wired and wireless connections.

[0080] The bimanual control system **400**, as shown in FIG. **4**, includes a computing device, such as mobile device **401**, coupled to an eyewear device **100** over a network. The bimanual control system **400** includes a memory for storing instructions and a processor for executing the instructions. Execution of the instructions of the bimanual control system **400** by the processor **432** configures the eyewear device **100** to cooperate with the mobile device **401**. The bimanual control system **400** may utilize the memory **434** of the eyewear device **100** or the memory elements **540**A, **540**B, **540**C of the mobile device **401** (FIG. **5**). Also, the bimanual control system **400** may utilize the processor elements **432**, **422** of the eyewear device **100** or the central processing unit (CPU) **530** of the mobile device **401** (FIG. **5**). In addition, the bimanual control system **400** may further utilize the memory and processor elements of the server system **498**. In this aspect, the memory and processing functions of the bimanual control system **400** can be shared or distributed across the processors and memories of the eyewear device **100**, the mobile device **401**, and the server system **498**.

[0081] The memory **434**, in some example implementations, includes or is coupled to a hand gesture library **480**, as described herein. The process of detecting a hand shape, in some implementations, involves comparing the pixel-level data in one or more captured frames of video data **900** to the hand gestures stored in the library **480** until a good match is found.

[0082] The memory **434** additionally includes, in some example implementations, an element control application **910**, a localization system **915**, and an image processing system **920**. In a bimanual control system **400** in which a camera is capturing frames of video data **900**, the element control application **910** configures the processor **432** to control the movement of a series of virtual items **700** on a display in response to detecting one or more hand shapes or gestures. The localization system **915** configures the processor **432** to obtain localization data for use in determining the position of the eyewear device **100** relative to the physical environment. The localization data may be derived from a series of images, an IMU unit **472**, a GPS unit **473**, or a combination thereof. The image processing system **920** configures the processor **432** to present a captured still image on a display of an optical assembly **180**A, **180**B in cooperation with the image display driver **442** and the image processor **412**.

[0083] FIG. **5** is a high-level functional block diagram of an example mobile device **401**. Mobile device **401** includes a flash memory **540**A which stores programming to be executed by the CPU **530** to perform all or a subset of the functions described herein.

[0084] The mobile device **401** may include a camera **570** that comprises at least two visible-light cameras (first and second visible-light cameras with overlapping fields of view) or at least one visible-light camera and a depth sensor with substantially overlapping fields of view. Flash memory **540**A may further include multiple images or video, which are generated via the camera **570**.

[0085] As shown, the mobile device **401** includes an image display **580**, a mobile display driver **582** to control the image display **580**, and a display controller **584**. In the example of FIG. **5**, the image display **580** includes a user input layer **591** (e.g., a touchscreen) that is layered on top of or otherwise integrated into the screen used by the image display **580**.

[0086] Examples of touchscreen-type mobile devices that may be used include (but are not limited to) a smart phone, a personal digital assistant (PDA), a tablet computer, a laptop computer, or other portable device. However, the structure and operation of the touchscreen-type devices is provided by way of example; the subject technology as described herein is not intended to be limited thereto. For purposes of this discussion, FIG. **5** therefore provides a block diagram illustration of the example mobile device **401** with a user interface that includes a touchscreen input layer **591** for receiving input (by touch, multi-touch, or gesture, and the like, by hand, stylus, or other tool) and an image display **580** for displaying content

[0087] As shown in FIG. **5**, the mobile device **401** includes at least one digital transceiver (XCVR) **510**, shown as WWAN XCVRs, for digital wireless communications via a wide-area wireless mobile communication network. The mobile device **401** also includes additional digital or analog transceivers, such as short-range transceivers (XCVRs) **520** for short-range network communication, such as via NFC, VLC, DECT, ZigBee, Bluetooth™, or Wi-Fi. For example, short range XCVRs **520** may take the form of any available two-way wireless local area network (WLAN) transceiver of a type that is compatible with one or more standard protocols of communication implemented in wireless local area networks, such as one of the Wi-Fi standards under IEEE 802.11.

[0088] To generate location coordinates for positioning of the mobile device **401**, the mobile device **401** can include a global positioning system (GPS) receiver. Alternatively, or additionally the mobile device **401** can utilize either or both the short range XCVRs **520** and WWAN XCVRs **510** for generating location coordinates for positioning. For example, cellular network, Wi-Fi, or Bluetooth™ based positioning systems can generate very accurate location coordinates, particularly when used in combination. Such location coordinates can be transmitted to the eyewear device over one or more network connections via XCVRs **510**, **520**.

[0089] The client device **401** in some examples includes a collection of motion-sensing components referred to as an inertial measurement unit (IMU) **572** for sensing the position, orientation, and motion of the client device **401**. The motion-sensing components may be micro-electro-mechanical systems (MEMS) with microscopic moving parts, often small enough to be part of a microchip. The inertial measurement unit (IMU) **572** in some example configurations includes an accelerometer, a gyroscope, and a magnetometer. The accelerometer senses the linear acceleration of the client device **401** (including the acceleration due to gravity) relative to three orthogonal axes (x, y, z). The gyroscope senses the angular velocity of the client device **401** about three axes of rotation (pitch, roll, yaw). Together, the accelerometer and gyroscope can provide position, orientation, and motion data about the device relative to six axes (x, y, z, pitch, roll, yaw). The magnetometer, if present, senses the heading of the client device **401** relative to magnetic north.

[0090] The IMU **572** may include or cooperate with a digital motion processor or programming that gathers the raw data from the components and compute a number of useful values about the position, orientation, and motion of the client device **401**. For example, the acceleration data gathered from the accelerometer can be integrated to obtain the velocity relative to each axis (x, y, z); and integrated again to obtain the position of the client device **401** (in linear coordinates, x, y, and z). The angular velocity data from the gyroscope can be integrated to obtain the position of the client device **401** (in spherical coordinates). The programming for computing these useful values may be stored in on or more memory elements **540**A, **540**B, **540**C and executed by the CPU **530** of the client device **401**.

[0091] The transceivers **510**, **520** (i.e., the network communication interface) conforms to one or more of the various digital wireless communication standards utilized by modern mobile networks. Examples of WWAN transceivers **510** include (but are not limited to) transceivers configured to operate in accordance with Code Division Multiple Access (CDMA) and 3rd Generation Partnership Project (3GPP) network technologies including, for example and without limitation, 3GPP type 2 (or 3GPP2) and LTE, at times referred to as "4G." For example, the transceivers **510**, **520** provide two-way wireless communication of information including digitized audio signals, still image and video signals, web page information for display as well as web-related inputs, and various types of mobile message communications to/from the mobile device **401**.

[0092] The mobile device **401** further includes a microprocessor that functions as a central processing unit (CPU); shown as CPU **530** in FIG. **4**. A processor is a circuit having elements structured and arranged to perform one or more processing functions, typically various data processing functions. Although discrete logic components could be used, the examples utilize components forming a programmable CPU. A microprocessor for example includes one or more integrated circuit (IC) chips incorporating the electronic elements to perform the functions of the CPU. The CPU **530**, for example, may be based on any known or available microprocessor architecture, such as a Reduced Instruction Set Computing (RISC) using an ARM architecture, as commonly used today in mobile devices and other portable electronic devices. Of course, other arrangements of processor circuitry may be used to form the CPU **530** or processor hardware in smartphone, laptop computer, and tablet.

[0093] The CPU **530** serves as a programmable host controller for the mobile device **401** by configuring the mobile device **401** to perform various operations, for example, in accordance with instructions or programming executable by CPU **530**. For example, such operations may include various general operations of the mobile device, as well as operations related to the programming for applications on the mobile device. Although a processor may be configured by use of hardwired logic, typical processors in mobile devices are general processing circuits configured by execution of programming.

[0094] The mobile device **401** includes a memory or storage system, for storing programming and data. In the example, the memory system may include a flash memory **540**A, a random-access memory (RAM) **540**B, and other memory components **540**C, as needed. The RAM **540**B serves as short-term storage for instructions and data being handled by the CPU **530**, e.g., as a working data processing memory. The flash memory **540**A typically provides longer-term storage.

[0095] Hence, in the example of mobile device **401**, the flash memory **540**A is used to store programming or instructions for execution by the CPU **530**. Depending on the type of device, the mobile device **401** stores and runs a mobile operating system through which specific applications are executed. Examples of mobile operating systems include Google Android, Apple IOS (for iPhone or iPad devices), Windows Mobile, Amazon Fire OS, RIM BlackBerry OS, or the like.

[0096] The processor **432** within the eyewear device **100** may construct a map of the environment surrounding the eyewear device **100**, determine a location of the eyewear device within the mapped environment, and determine a relative position of the eyewear device to one or more objects in the mapped environment. The processor **432** may construct the map and determine location and position information using a simultaneous localization and mapping (SLAM) algorithm applied to data received from one or more sensors. Sensor data includes images received from one or both of the cameras **114**A, **114**B, distance(s) received from a laser range finder, position information received from a GPS unit **473**, motion and acceleration data received from an IMU **572**, or a combination of data from such sensors, or from other sensors that provide data useful in determining positional information. In the context of augmented reality, a SLAM algorithm is used to construct and update a map of an environment, while simultaneously tracking and updating the location of a device (or a user) within the mapped environment. The mathematical solution can be approximated using various statistical methods, such as particle filters, Kalman filters, extended Kalman filters, and covariance intersection. In a system that includes a high-definition (HD) video camera that captures video at a high frame rate (e.g., thirty frames per second), the SLAM algorithm updates the map and the location of objects at least as frequently as the frame rate; in other words, calculating and updating the mapping and localization thirty times per second.

[0097] Sensor data includes image(s) received from one or both cameras **114**A, **114**B, distance(s) received from a laser range finder, position information received from a GPS unit **473**, motion and acceleration data received from an IMU **472**, or a combination of data from such sensors, or from other sensors that provide data useful in determining positional information.

[0098] FIG. **6** depicts an example physical environment **600** along with elements that are useful when using a SLAM application and other types of tracking applications (e.g., natural feature tracking (NFT)). A user **602** of eyewear device **100** is present in an example physical environment **600** (which, in FIG. **6**, is an interior room). The processor **432** of the eyewear device **100** determines its position with respect to one or more objects **604** within the environment **600** using captured images, constructs a map of the environment **600** using a coordinate system (x, y, z) for the environment **600**, and determines its position within the coordinate system. Additionally, the processor **432** determines a head pose (roll, pitch, and yaw) of the eyewear device **100** within the environment by using two or more location points (e.g., three location points **606***a*, **606***b*, and **606***c*) associated with a single object **604***a*, or by using one or more location points **606** associated with two or more objects **604***a*, **604***b*, **604***c*. The processor **432** of the eyewear device **100** may position a virtual object **608** (such as the key shown in FIG. **6**) within the environment **600** for viewing during an augmented reality experience.

[0099] The localization system **915** in some examples a virtual marker **610***a* associated with a virtual object **608** in the environment **600**. In augmented reality, markers are registered at locations in the environment to assist devices with the task of tracking and updating the location of users, devices, and objects (virtual and physical) in a mapped environment. Markers are sometimes registered to a high-contrast physical object, such as the relatively dark object, such as the framed picture **604***a*, mounted on a lighter-colored wall, to assist cameras and other sensors with the task of detecting the marker. The markers may be preassigned or may be assigned by the eyewear device **100** upon entering the environment. Markers can be encoded with or otherwise linked to information. A marker might include position information, a physical code (such as a bar code or a QR code; either visible to the user or hidden), or a combination thereof. A set of data associated with the marker is stored in the memory **434** of the eyewear device **100**. The set of data includes information about the marker **610***a*, the marker's position (location and orientation), one or more virtual objects, or a combination thereof. The marker position may include three-dimensional coordinates for one or more marker landmarks **616***a*, such as the corner of the generally rectangular marker **610***a* shown in FIG. **6**. The marker location may be expressed relative to real-world geographic coordinates, a system of marker coordinates, a position of the eyewear device **100**, or other coordinate system. The one or more virtual objects associated with the marker **610***a* may include any of a variety of material, including still images, video, audio, tactile feedback, executable applications, interactive user interfaces and experiences, and combinations or sequences of such material. Any type of content capable of being stored in a memory and retrieved when the marker **610***a* is encountered or associated with an assigned marker may be classified as a virtual object in this context. The key **608** shown in FIG. **6**, for example, is a virtual object displayed as a still image, cither 2D or 3D, at a marker location.

[0100] In one example, the marker **610***a* may be registered in memory as being located near and associated with a physical object **604***a* (e.g., the framed work of art shown in FIG. **6**). In another example, the marker may be registered in memory as being a particular position with respect to the eyewear device **100**.

[0101] FIG. **10** is a flow chart **1000** depicting an example method of controlling the presentation of a virtual element or graphical element on the display **180** of an eyewear device **100**. Although the steps are described with reference to the eyewear device **100** described herein, other implementations of the steps described, for other types of devices, will be understood by one of skill in the art from the description herein. One or more of the steps shown and described may be performed simultaneously, in a series, in an order other than shown and described, or in conjunction with additional steps. Some steps may be omitted or, in some applications, repeated.

[0102] Block **1002** in FIG. **10** describes an example step of capturing frames a video data **900** with the camera system **114** of an eyewear device **100**. In some implementations, the camera system **114** includes one or more cameras **114**A, **114**B, as described herein, for capturing either still images or frames of video data **900**. The eyewear device **100** includes an image processing system **920**, a localization system **915**, and one or more displays **180**A, **180**B. For example, as shown in FIG. **7**, the eyewear device **100** includes a semi-transparent image display **180**B which, as described herein, may include a semi-transparent lens layer and a display matrix layer configured to present images on the lens of the eyewear device. Graphical and virtual elements **700** (see FIG. **8**) are presented as an overlay relative the physical environment **600**. The effect, as shown, allows the viewer to see and interact with the presented elements **700** while the surrounding environment **600** also remains visible through the display **180**B.

[0103] In some implementations, the high-speed processor **432** of the eyewear device **100** stores the captured frames of video data **900** with a camera system **114** as the wearer moves through a physical environment **600**. As described herein and shown in FIG. **7**, the camera system **114** typically has a camera field of view **904** that captures images and video beyond the limits of the display **180**B.

[0104] The camera system **114**, in some implementations, includes one or more high-resolution, digital cameras equipped with a CMOS image sensor capable of capturing high-definition still images and high-definition video at relatively high frame rates (e.g., thirty frames per second or more). Each frame of digital video includes depth information for a plurality of pixels in the image. In this aspect, the camera system **114** serves as a high-definition scanner by capturing a detailed input image of the physical environment. The camera system **114**, in some implementations, includes a pair of high-resolution digital cameras **114**A, **114**B coupled to the eyewear device **100** and spaced apart to acquire a left-camera raw image and a right-camera raw image, as described herein. When combined, the raw images form an input image that includes a matrix of three-dimensional pixel locations. The example method, at block **1002**, in some implementations, includes storing the captured frames of video data **900** in memory **434** on the eyewear device **100**, at least temporarily, such that the frames are available for analysis.

[0105] Block **1004** describes an example step of detecting a first hand **650** in the captured frames of video data **900** with the image processing system **920**. In some example implementations, the image processing system **920** analyzes the pixel-level data in the captured frames of video data **900** to determine whether the frame includes a human hand and, if so, whether the framed includes the upturned palm or palmar surface of the hand, as illustrated in FIG. **7**.

[0106] Block **1006** describes an example step of defining a first mapped region **655** associated with the detected first hand **650**. The defined first mapped region **655** is persistently associated with the detected first hand **650**, such that the first mapped region **655** moves as the first hand **650** moves, over time, as detected in the captured frames of video data **900**. The first mapped region **655** may or may not be presented on the display **180**B for viewing by the user.

[0107] FIG. **7** is a perspective illustration of an example bimanual interaction between mapped hand regions which includes an example first mapped region **655** along the ulnar side of the first hand **650**. The ulna is the thinner of the two bones in the forearm, located on the side opposite the thumb. For an upturned left hand, as shown, the ulnar side lies along the palmar surface near the shortest or pinkie finger. Any of a variety of other suitable hand surfaces may be identified for use in defining the first mapped region **655**. The first hand **650** may be predefined to be the left hand, as shown. In some implementations, the first hand to be detected with the palmar side up is defined as the first hand **650**. In some implementations, the system includes a process for selecting and setting the hand, right of left, which will serve as the first hand **650**.

[0108] The first mapped region **655**, in some implementations, is defined relative to one or more landmarks on the first hand **650**. For example, the ulnar side of the palm is gently curved and extends from about the wrist crease to the digital crease (i.e., the start of the fingers). The first mapped region **655** in some implementations is bounded by lines and curved lines that approximate the size and curved shapes detected along the first hand **650**. For example, a generally rectangular first mapped region **655** like the one shown in FIG. **7** includes short sides having a generally convex shape that follow the thickness of the palm and longer sides that follow the lengthwise contour of the ulnar side of the palm. In other implementations, the first mapped region **655** includes one or more planar segments that are sized and shaped to approximate the ulnar side of the palm.

[0109] In one aspect, the defined first mapped region **655** operates as a simulated or virtual input component (e.g., a virtual touch screen or touchpad). Compared to virtual elements displayed in mid-air, the use of a mapped region **655** on the hand provides tactile feedback to the user. In addition to feeling one or more input actions (e.g., a fingertip touching the hand near the mapped region **655**), the accuracy of touch inputs is generally reliable and accurate due to proprioception (i.e., awareness of the location and movement of body parts, including of course the hands and fingers). Tactile feedback and proprioception will facilitate the learning, case of use, endurance, and efficacy of various bimanual gestures performed by both hands. For example, the touching gesture described herein includes a fingertip **680** touching and making a small indentation into the flesh of the first hand **650**. This and other gestures are based on tactile sensations that are familiar, easy to learn and execute, and less prone to fatigue, compared to mid-air or surface-bound gestures. Moreover, the use of both hands, in front of the body, allows the user to brace the weight of the arms and hands against the torso or while resting on another surface such as a tabletop.

[0110] The process of defining a first mapped region **655** at block **1006**, in some implementations, is accomplished by the image processing system **920**. After the first hand **650** is detected at block **1002**, the image processing system **920** determines whether the detected first hand **650** matches a start shape selected from a plurality of predefined starting hand shapes, as stored in a library of hand gestures **480**. The predefined starting hand shapes, as described, include shapes that expose the palmar surface, for example, and any other suitable surface of a hand. In a related aspect, the process of exposing the palmar surface may include a rotating motion of the hand over time. Accordingly, the predefined starting hand shapes may include gestural movements, such as supinating the hand to expose the palmar surface. In this aspect, the process at block **1006**, in some implementations, includes comparing the detected first hand **650** captured in the video data **900**, over a period of time, sometimes on a pixel-by-pixel level, to the plurality of predefined starting hand shapes that are stored in the hand gesture library **480** until a match is identified. As used herein, the term match is meant to include substantial matches or near matches, which may be governed by a predetermined confidence value associated with possible or candidate matches. The detected hand shape data may include three-dimensional coordinates for the wrist, up to fifteen interphalangeal joints, up five fingertips, and other skeletal or soft-tissue landmarks found in a captured frame. In some examples, the detecting process includes calculating the sum of the geodesic distances between the detected hand shape fingertip coordinates and a set of fingertip coordinates for each hand gesture stored in the library **480**. A sum that falls within a configurable threshold accuracy value represents a match.

[0111] As shown in FIG. **6**, the display plane **755** may be defined by one or more discrete points or positions along or near the lens of the display **180**B. For example, the display plane **755** may be defined by a rectangular shape, as shown, which lies along a plane that is generally parallel to the display **180**B. The display plane **755** may or may not be presented on the display **180**B for viewing by the user.

[0112] Block **1008** in FIG. **10** describes an example step of presenting a target icon **710** on the display **180**B. The target icon **710** is presented at a target position **740**. The target position **740** is defined relative to first mapped region **655**, such that target position **740** moves as the first mapped region **655** on the hand moves, over time, as detected in the captured frames of video data **900**.

[0113] As the name suggests, the target icon **710** provides a target within or near the first mapped region **655** on the first hand. The target icon **710** in some implementations includes a highlighted area extending along all or part of the first mapped region **655**, an area defined by a pattern (e.g., a color, marking, shading, or other decoration), or a closed area defined by a boundary. The target icon area may include a circle, polygon, or other shape, appearing in two or three dimensions; it may or may not be conformed to the shape of the mapped region **655**. As shown in FIG. **7**, the target icon **710** may be a virtual button that includes an apparently movable button cap supported by a housing. Any of a variety of other icons may be designed and presented as a target for the fingertip **680** approaching the mapped region **655**.

[0114] Block **1010** in FIG. **10** describes an example step of determining, with the localization system **915**, a current eyewear location **840** relative to the defined first mapped region **655**. The localization system **915**, in some implementations, configures the processor **432** on the eyewear **100** to obtain localization data for use in determining the current eyewear location **840** relative to the defined first mapped region **655**. The localization data may be derived from the captured frames of video data **900**, an IMU unit **472**, a GPS unit **473**, or a combination thereof. The localization system **915** may construct a virtual map of various elements within the camera field of view **904** using a SLAM algorithm, as described herein, updating the map and the location of objects at least as frequently as the frame rate of the camera system **114** (e.g., calculating and updating the mapping and localization of the current eyewear location **840** as frequently as thirty times per second, or more).

[0115] Block **1012** describes an example step of calculating a correlation **950** between the defined first mapped region **655** (associated with the hand **650**) and the display plane **755**, in accordance with the current eyewear location **840** (as determined in block **1010**). The term correlation **950** refers to and includes one or more vectors, matrices, formulas, or other mathematical expressions sufficient to define the three-dimensional distance between the defined first mapped region **655** and the display plane **755**, in accordance with the current eyewear location **840**. The current eyewear location **840**, of course, is tied to or persistently associated with the display plane **755** that lies along the display **180**B supported by the frame of the eyewear device **100**. In this aspect, the correlation **950** performs the function of calibrating the motion of the eyewear **100** (and the display plane **755**) with the motion of the hand **650** (and the defined mapped region **655**). The correlation **950** mathematically translates locations along the mapped region **655** to corresponding positions on the display plane **755**. Moreover, because the localization process at block **1010** occurs continually and frequently, the correlation **950** is calculated continually and frequently, resulting in accurate and near real-time tracking of the hand **650** relative to the eyewear **100**.

[0116] Block **1014** describes an example step of detecting a series of bimanual hand shapes **670** in the captured frames of video data **900** with the image processing system **920**. The image processing system **920** analyzes the pixel-level data in the captured frames of video data **900** to track the motion of both the second hand **652** and the first hand **650**. The series of bimanual hand shapes **670** in some implementations includes the detected first hand **650** and a series of current fingertip locations **681** (i.e., the fingertip **680** of the second hand **652**). The process in some implementations includes detecting the series of current fingertip locations **681** in three-dimensional coordinates relative to the target icon position **740** or to another known position, such as the mapped region **655** or the display plane **755**.

[0117] The fingertip **680** may be associated with any finger or thumb of the second hand **652**. In a relates aspect, the fingertip **680** operates as a second mapped region associated with the second hand **652**. In some implementations, other surfaces of the second hand **652** may be defined as the second mapped region (e.g., knuckles, joints, sides of the fingers or hand) and tracked using the processes described herein.

[0118] FIG. **8** is a perspective illustration of an example bimanual hand gesture in which the hands perform a touching gesture (e.g., the fingertip **680** is touching ulnar side of the first hand **650** near the target icon **710**). In this example, the detecting a series of bimanual hand shapes **670** includes one or more frames of video data **900** in which at least one of the series of current fingertip locations **681** is detected within a predefined threshold distance of the target icon position **740**.

[0119] The example process at block **1016** includes determining whether the detected series of bimanual hand shapes **670** matches any one of a plurality of predefined hand gestures **850** stored in the hand gesture library **480**. The data stored in the captured frames of video data **900** is compared to the predefined hand gestures **650** stored in the library of hand gestures **480**. Any of a variety of other predefined hand gestures **850** may be established and stored in the hand gesture library **480**.

[0120] In the example shown in FIG. **8**, the image processing system **920** analyzes the pixel-level data in the captured frames of video data **900** to determine whether the fingertip **680** is performing a touching gesture. The predefined touching gesture, in this example, includes a sequences of hand poses in which a fingertip is intersecting a surface of another hand, such as the ulnar side of the palmar surface.

[0121] The hand gesture library **480** includes a large number of poses and gestures, including descriptions of a hand in various positions and orientations. The stored poses and gestures are suitable for ready comparison to a hand shape that is detected in an image. A hand gesture record stored in the library **480** in some implementations includes three-dimensional coordinates for a number of landmarks on the hand, including the wrist, the fifteen interphalangeal joints, and the five fingertips, as well as other skeletal and soft-tissue landmarks. A hand gesture record stored in the library **480** may also include text identifiers, point of view annotations, directional references (e.g., palmar, dorsal, lateral), rotational references (e.g., stable, flexing, extending, pronating, supinating), and other data and descriptors related to each predefined hand gesture **850**. Each hand gesture record stored in the library **480** may include a set of exemplary three-dimensional coordinates for each joint and the tip, a hand position identifier (e.g., neutral hand), and a finger position identifier (e.g., index, flexed, partial). For a hand gesture (e.g., a series of hand poses observed over time), a hand gesture record stored in the library **480** may include a set of exemplary three-dimensional coordinates for each joint and the tip at each location of the index finger, over a particular time interval (e.g., two seconds or longer), a hand motion identifier (e.g., pronating, supinating, stable), and a finger motion identifier (e.g., index flexing and extending continually).

[0122] For the touching gesture, the record stored in the hand gesture library **480**, in some implementations, includes a gesture identifier (e.g., touching), a first motion identifier (e.g., fingertip detected within a predefined threshold distance of a defined surface on another hand), a minimum pressing duration (e.g., one second), and a subsequent motion identifier (e.g., removing the fingertip away from the other hand)—along with a series of exemplary three-dimensional coordinates for each hand and finger landmark during the time interval (e.g., twenty coordinate sets, every five milliseconds).

[0123] Other selecting gestures, in some implementations, include tapping the fingertip, sliding the fingertip along the hand, and hovering the fingertip for a predefined or configurable time duration. Moreover, although the gestures are described herein with reference to a single finger of the second hand, one or more fingers may be used to execute a selected hand gesture.

[0124] Referring again to FIG. **10**, the example process at block **1018** includes executing a selecting action **800** in accordance with the matching predefined hand gesture (e.g., touching, pressing, tapping). In some implementations, the selecting action **800** includes presenting on the display **180**B one or more graphical elements **700** at a first position **701** relative to the defined first mapped region **655** and in accordance with the calculated correlation **950**. The first position **701** in some implementations is a predefined default position near the top of the display **180**B, as shown in FIG. **8**. The first position **701** is defined relative to the defined first mapped region **655** so that the elements **700** at the first position **701** appear to move as the first hand **650** moves. In this aspect, the graphical elements **700** are apparently anchored to the first hand **650** (as opposed to remaining anchored to the display plane **755** for the display **180**B). The elements **700** are presented in accordance with the calculated correlation **950**, so that the elements **700** have a size and shape which is correlated with the relative distance between the current eyewear location **840** and the current location of the first mapped region **655** on the first hand **650**.

[0125] As used herein, the one or more graphical elements **700** means and includes any collection of graphical elements presented on a display, including but not limited to virtual objects associated with VR experiences and graphical elements such as icons, thumbnails, taskbars, and menu items. For example, the graphical elements **700** in FIG. **8** represent selectable menu items including friends, maps, and photos.

[0126] In a broader context, the process steps and methods may be executed in relation to another system or application that is currently running on the eyewear device **100**. Such an application may include a series of actions which logically proceed to an option of presenting one or more graphical elements on the display. At such a point, the running application may access the process described herein, starting in some implementations with presenting a target icon **710** on the ulnar side of the detected first hand **650**. After presenting the graphical elements **700**, the running application may then include processes and tools for executing additional actions or otherwise facilitating additional interactions with the graphical elements **700**. The process steps and methods described herein may be terminated when the first hand **650** is detected in a palm down position (e.g., revealing the distal surface of the hand), when one or both hands **650**, **652** is partly or completely removed from the field of view **904**, or when a predefined stopping gesture is detected.

[0127] In some implementations, the selecting action **800** at block **1018** includes generating a response to determining at block **1016** that the detected series of bimanual hand shapes **670** matches one of the predefined hand gestures **850**. The response includes an indicator or signal designed to inform the user that the input has been received; preferably at a time that nearly coincides with the physical experience of the fingertip touching the hand. The response indicator, in some implementations, includes one or more of presenting visual indicia, playing a sound, and generating a vibration. Visual indicia, for example, may include a color change, highlight, flash, or other change associated with one or more items presented on the display, such as the target icon **710** or the mapped region **655**. For example, when the target icon comprises a button, the visual indicia may include presenting the button cap in an actuated position. In another example, the response indicator includes playing a sound through a loudspeaker (e.g., a loudspeaker coupled to the eyewear device **100** or a loudspeaker coupled to a separate device). In yet another example, the response indicator includes generating a vibration using a vibrating actuator (e.g., an actuator coupled to the eyewear device **100** or an actuator coupled to a separate device).

[0128] The target icon **710** in some implementation includes a virtual button having a button cap supported by a housing. The button cap may be movable from a default position to an actuated position and may include a spring that urges the cap toward its default position. As described briefly above, the responds indicator includes presenting the button cap in an actuated position in accordance with the matching predefined hand gesture so that the apparent motion of the cap is correlated with the detected series of fingertip locations **681**. In this aspect, the cap moves at an apparent speed that is correlated with the detected speed of the fingertip **680** in motion. Upon release or removal of the fingertip **680**, the button cap may return to its default position, as illustrated in FIG. **9**. As shown, the graphical elements **700** may be persistently presented on the display **180**B after the fingertip **680** is no longer detected near the target icon position **740**. In a related aspect, the target icon **710** may be configured to act as a toggle switch; alternatively presenting or removing the graphical elements **700** from the display in response to subsequent touches by the fingertip **680**.

[0129] In another example implementation, the process at block **1016** of determining whether a detected series of bimanual hand shapes **670** matches a predefined hand gesture **850** involves using a machine-learning algorithm to compare the pixel-level data about the hand shape in one or more captured frames of video data to a collection of images that include hand gestures.

[0130] Machine learning refers to an algorithm that improves incrementally through experience. By processing a large number of different input datasets, a machine-learning algorithm can develop improved generalizations about particular datasets, and then use those generalizations to produce an accurate output or solution when processing a new dataset. Broadly speaking, a machine-learning algorithm includes one or more parameters that will adjust or change in response to new experiences, thereby improving the algorithm incrementally; a process similar to learning.

[0131] In the context of computer vision, mathematical models attempt to emulate the tasks accomplished by the human visual system, with the goal of using computers to extract information from an image and achieve an accurate understanding of the contents of the image. Computer vision algorithms have been developed for a variety of fields, including artificial intelligence and autonomous navigation, to extract and analyze data in digital images and video.

[0132] Deep learning refers to a class of machine-learning methods that are based on or modeled after artificial neural networks. An artificial neural network is a computing system made up of a number of simple, highly interconnected processing elements (nodes), which process information by their dynamic state response to external inputs. A large artificial neural network might have hundreds or thousands of nodes.

[0133] A convolutional neural network (CNN) is a type of neural network that is frequently applied to analyzing visual images, including digital photographs and video. The connectivity pattern between nodes in a CNN is typically modeled after the organization of the human visual cortex, which includes individual neurons arranged to respond to overlapping regions in a visual field. A neural network that is suitable for use in the determining process described herein is based on one of the following architectures: VGG16, VGG19, ResNet50, Inception V3, Xception, or other CNN-compatible architectures.

[0134] In the machine-learning example, at block **1016**, the processor **432** determines whether a detected series of bimanual hand shapes substantially matches a predefined hand gesture using a machine-trained algorithm referred to as a hand feature model. The processor **432** is configured to access the hand feature model, trained through machine learning, and applies the hand feature model to identify and locate features of the hand shape in one or more frames of the video data.

[0135] In one example implementation, the trained hand feature model receives a frame of video data which contains a detected hand shape and abstracts the image in the frame into layers for analysis. Data in each layer is compared to hand gesture data stored in the hand gesture library **480**, layer by layer, based on the trained hand feature model, until a good match is identified.

[0136] In one example, the layer-by-layer image analysis is executed using a convolutional neural network. In a first convolution layer, the CNN identifies learned features (e.g., hand landmarks, sets of joint coordinates, and the like). In a second convolution layer, the image is transformed into a plurality of images, in which the learned features are each accentuated in a respective sub-image. In a pooling layer, the sizes and resolution of the images and sub-images are reduced in order isolation portions of each image that include a possible feature of interest (e.g., a possible palm shape, a possible finger joint). The values and comparisons of images from the non-output layers are used to classify the image in the frame. Classification, as used herein, refers to the process of using a trained model to classify an image according to the detected hand shape. For example, an image may be classified as a "touching action" if the detected series of bimanual hand shapes matches the touching gesture stored in the library **480**.

[0137] Any of the functionality described herein for the eyewear device **100**, the mobile device **401**, and the server system **498** can be embodied in one or more computer software applications or sets of programming instructions, as described herein. According to some examples, "function," "functions," "application," "applications," "instruction," "instructions," or "programming" are program(s) that execute functions defined in the programs. Various programming languages can be employed to develop one or more of the applications, structured in a variety of manners, such as object-oriented programming languages (e.g., Objective-C, Java, or C++) or procedural programming languages (e.g., C or assembly language). In a specific example, a third-party application (e.g., an application developed using the ANDROID™ or IOS™ software development kit (SDK) by an entity other than the vendor of the particular platform) may include mobile software running on a mobile operating system such as IOS™, ANDROID™, WINDOWS® Phone, or another mobile operating system. In this example, the third-party application can invoke API calls provided by the operating system to facilitate functionality described herein.

[0138] Hence, a machine-readable medium may take many forms of tangible storage medium. Non-volatile storage media include, for example, optical or magnetic disks, such as any of the storage devices in any computer devices or the like, such as may be used to implement the client device, media gateway, transcoder, etc. shown in the drawings. Volatile storage media include dynamic memory, such as main memory of such a computer platform. Tangible transmission media include coaxial cables; copper wire and fiber optics, including the wires that comprise a bus within a computer system. Carrier-wave transmission media may take the form of electric or electromagnetic signals, or acoustic or light waves such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media therefore include for example: a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD or DVD-ROM, any other optical medium, punch cards paper tape, any other physical storage medium with patterns of holes, a RAM, a PROM and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave transporting data or instructions, cables or links transporting such a carrier wave, or any other medium from which a computer may read programming code or data. Many of these forms of computer readable media may be involved in carrying one or more sequences of one or more instructions to a processor for execution.

[0139] Except as stated immediately above, nothing that has been stated or illustrated is intended or should be interpreted to cause a dedication of any component, step, feature, object, benefit, advantage, or equivalent to the public, regardless of whether it is or is not recited in the claims.

[0140] It will be understood that the terms and expressions used herein have the ordinary meaning as is accorded to such terms and expressions with respect to their corresponding respective areas of inquiry and study except where specific meanings have otherwise been set forth herein. Relational terms such as first and second and the like may be used solely to distinguish one entity or action from another without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms "comprises," "comprising," "includes," "including," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises or includes a list of elements or steps does not include only those elements or steps but may include other elements or steps not expressly listed or inherent to such process, method, article, or apparatus. An element preceded by "a" or "an" does not, without further constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises the element.

[0141] Unless otherwise stated, any and all measurements, values, ratings, positions, magnitudes, sizes, and other specifications that are set forth in this specification, including in the claims that follow, are approximate, not exact. Such amounts are intended to have a reasonable range that is consistent with the functions to which they relate and with what is customary in the art to which they pertain. For example, unless expressly stated otherwise, a parameter value or the like may vary by as much as plus or minus ten percent from the stated amount or range.

[0142] In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in various examples for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed examples require more features than are expressly recited in each claim. Rather, as the following claims reflect, the subject matter to be protected lies in less than all features of any single disclosed example. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

[0143] While the foregoing has described what are considered to be the best mode and other examples, it is understood that various modifications may be made therein and that the subject matter disclosed herein may be implemented in various forms and examples, and that they may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all modifications and variations that fall within the true scope of the present concepts.

What is claimed is:

1. A method of presenting a graphical element on a display coupled to an eyewear device, the method comprising:

capturing frames of video data using a camera system coupled to the eyewear device;

detecting a hand in a physical environment using the frames of video data;

generating a mapped region relative to one or more physical landmarks associated with the hand;

determining a current eyewear location relative to the mapped region;

presenting on the display a virtual target icon at a target position relative to the mapped region in accordance with the current eyewear location, wherein the virtual target icon comprises a highlight extending along the mapped region;

iteratively detecting according to a configurable time interval, using the frames of video data, a series of current fingertip locations associated with a fingertip of a second hand relative to the virtual target icon;

detecting a bimanual gesture based on the series of current fingertip locations, wherein the bimanual gesture comprises an interaction selected from a group consisting of the fingertip physically touching the hand, the fingertip tapping relative to the hand, the fingertip sliding relative to the mapped region, and the fingertip hovering within a threshold distance of the mapped region for a configurable duration;

presenting on the display an indicator in response to detecting the gesture; and

executing an action associated with the virtual target icon in accordance with the bimanual gesture, wherein the action comprises presenting on the display a graphical element at a first position relative to the virtual target icon in accordance with the current eyewear location.

2. The method of claim **1**, wherein detecting the hand comprises detecting a palmar surface, and wherein generating the mapped region comprises:

identifying a palmar landmark associated with the palmar surface; and

generating the mapped region relative to the palmar landmark.

3. The method of claim **1**, further comprising:

determining whether the hand matches a start shape selected from a plurality of predefined starting hand shapes; and

generating the mapped region in response to the start shape.

4. The method of claim **1**, wherein presenting the virtual target icon comprises presenting a virtual switch apparently movable between a default position and an activated position, and

wherein detecting the series of current fingertip locations comprises detecting the fingertip intersecting at least one of the default position or the activated position, wherein the activated position is characterized by the fingertip physically touching the hand.

5. The method of claim **4**, wherein executing the action comprises presenting the virtual switch in a series of switch positions in accordance with the bimanual gesture, such that the series of switch positions is correlated with the series of current fingertip locations.

6. The method of claim **1**, wherein detecting the bimanual gesture comprises detecting the fingertip within a threshold distance of the virtual target icon.

7. The method of claim **1**, wherein presenting the indicator comprises at least one of presenting on the display visual indicia associated with the target icon, playing a sound through a loudspeaker, or generating a vibration using an actuator.

8. The method of claim **1**, further comprising:

calculating a correlation between the mapped region and a plane associated with the display, in accordance with the current eyewear location;

translating the series of current fingertip locations to corresponding positions relative to the plane, based on the correlation; and

executing the action in accordance with the correlation.

9. A bimanual control system, comprising:

an eyewear device comprising a processor, a memory, a camera system, and a display; and

programming in the memory, wherein execution of the programming by the processor configures the eyewear device to perform functions, including functions to:

capture frames of video data using a camera system coupled to the eyewear device;

detect a hand in a physical environment using the frames of video data;

generate a mapped region relative to one or more physical landmarks associated with the hand;

determine a current eyewear location relative to the mapped region;

present on the display a virtual target icon at a target position relative to the mapped region in accordance with the current eyewear location, wherein the virtual target icon comprises a highlight extending along the mapped region;

iteratively detect according to a configurable time interval, using the frames of video data, a series of current fingertip locations associated with a fingertip of a second hand relative to the virtual target icon;

detect a bimanual gesture based on the series of current fingertip locations, wherein the bimanual gesture comprises an interaction selected from a group consisting of the fingertip physically touching the hand, the fingertip tapping relative to the hand, the fingertip sliding relative to the mapped region, and the fingertip hovering within a threshold distance of the mapped region for a configurable duration;

present on the display an indicator in response to detecting the gesture; and

execute an action associated with the virtual target icon in accordance with the bimanual gesture, wherein the function to execute the action comprises a function to present on the display a graphical element at a first position relative to the virtual target icon in accordance with the current eyewear location.

10. The bimanual control system of claim **9**, wherein the function to detect the hand comprises a function to detect a palmar surface, and

wherein the function to generate the mapped region comprises functions to:

identify a palmar landmark associated with the palmar surface; and

generate the mapped region relative to the palmar landmark.

11. The bimanual control system of claim **9**, wherein the execution of the programming further configures the eyewear device to perform additional functions, including functions to:

determine whether the hand matches a start shape selected from a plurality of predefined starting hand shapes; and

generate the mapped region in response to the start shape.

12. The bimanual control system of claim **9**, wherein the function to present the virtual target icon comprises a function to present a virtual switch apparently movable between a default position and an activated position,

wherein the function to detect the series of current fingertip locations comprises a function to detect the fingertip intersecting at least one of the default position or the activated position, wherein the activated position is characterized by the fingertip physically touching the hand, and

wherein the function to execute the action comprises a function to present the virtual switch in a series of switch positions in accordance with the bimanual gesture, such that the series of switch positions is correlated with the series of current fingertip locations.

13. The bimanual control system of claim **9**, wherein the function to detect the bimanual gesture comprises a function to detect the fingertip within a threshold distance of the virtual target icon.

14. The bimanual control system of claim **9**, wherein the function to present the indicator comprises at least one of a function to present on the display visual indicia associated with the target icon, a function to play a sound through a loudspeaker, or a function to generate a vibration using an actuator.

15. The bimanual control system of claim **9**, wherein the execution of the programming further configures the eyewear device to perform additional functions, including functions to:

calculate a correlation between the mapped region and a plane associated with the display, in accordance with the current eyewear location;

translate the series of current fingertip locations to corresponding positions relative to the plane, based on the correlation; and

execute the action in accordance with the correlation.

16. A non-transitory computer-readable medium storing program code which, when executed, is operative to cause an electronic processor to perform the steps of:

capturing frames of video data using a camera system coupled to an eyewear device;

detecting a hand in a physical environment using the frames of video data;

generating a mapped region relative to one or more physical landmarks associated with the hand;

determining a current eyewear location relative to the mapped region;

presenting, on a display coupled to the eyewear device, a virtual target icon at a target position relative to the mapped region in accordance with the current eyewear location, wherein the virtual target icon comprises a highlight extending along the mapped region;

iteratively detecting according to a configurable time interval, using the frames of video data, a series of current fingertip locations associated with a fingertip of a second hand relative to the virtual target icon;

detecting a bimanual gesture based on the series of current fingertip locations, wherein the bimanual gesture comprises an interaction selected from a group consisting of the fingertip physically touching the hand, the fingertip tapping relative to the hand, the fingertip sliding relative to the mapped region, and the fingertip hovering within a threshold distance of the mapped region for a configurable duration;

presenting on the display an indicator in response to detecting the gesture; and

executing an action associated with the virtual target icon in accordance with the bimanual gesture, wherein the action comprises presenting on the display a graphical element at a first position relative to the virtual target icon in accordance with the current eyewear location.

17. The non-transitory computer-readable medium storing program code of claim **16**, wherein detecting the hand comprises detecting a start shape characterized by an exposed palmar surface, and

wherein generating the mapped region comprises:

identifying a palmar landmark associated with the exposed palmar surface; and

generating the mapped region relative to the palmar landmark.

18. The non-transitory computer-readable medium storing program code of claim **16**, wherein presenting the virtual target icon comprises presenting a virtual switch apparently movable between a default position and an activated position,

wherein detecting the series of current fingertip locations comprises detecting the fingertip intersecting at least one of the default position or the activated position, wherein the activated position is characterized by the fingertip physically touching the hand, and

wherein executing the action comprises presenting the virtual switch in a series of switch positions in accordance with the bimanual gesture, such that the series of switch positions is correlated with the series of current fingertip locations.

19. The non-transitory computer-readable medium storing program code of claim **16**, wherein presenting the indicator comprises at least one of presenting on the display visual indicia associated with the target icon, playing a sound through a loudspeaker coupled to the eyewear device, or generating a vibration using an actuator coupled to the eyewear device.

20. The non-transitory computer-readable medium storing program code of claim **16**, wherein the program code, when executed, is operative to cause an electronic processor to perform the steps of:

calculating a correlation between the mapped region and a plane associated with the display, in accordance with the current eyewear location;

translating the series of current fingertip locations to corresponding positions relative to the plane, based on the correlation; and

executing the action in accordance with the correlation.

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