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Gaze Tracking Circuitry with Optical Range Finders

Abstract

Eyewear such as a head-mounted device may include adjustable prescription lenses and/or may include displays. The eyewear may include gaze tracking circuitry that tracks a gaze direction of a user. The gaze tracking circuitry may include a range finder that uses phase-based optical coherence tomography to determine eye distance. The range finder may include one or more emitters such as lasers that emit infrared light into a beam splitter that splits the light into signal light that travels a free space path to the eye and reference light that travels a fixed reference path towards multiple image sensors located around the periphery of the eye. The signal light specularly reflects off of the eye (creating an eye glint) and the reflected signal light combines with the reference light, creating an interference pattern that can be detected by the image sensors and analyzed to determine eye distance.

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Background/Summary

[0001] This application claims the benefit of provisional patent application No. 63/551,876, Feb. 9, 2024, which is hereby incorporated by reference herein in its entirety.

FIELD

[0002] This relates generally to electronic devices, and, more particularly, to wearable electronic devices such as head-mounted devices.

BACKGROUND

[0003] Head-mounted devices and other eyewear may use gaze tracking circuitry to track a user's gaze.

[0004] It can be challenging to design gaze tracking circuitry that performs satisfactorily. If care is not taken, the gaze tracking circuitry may produce inaccurate measurements or may exhibit other performance limitations such as excessive power consumption.

SUMMARY

[0005] Eyewear such as a head-mounted device may include adjustable prescription lenses and/or may include displays. The lenses and displays may be mounted to a support structure such as supporting frames or other head-mounted support structures.

[0006] The eyewear may include gaze tracking circuitry that tracks a gaze direction of a user. The gaze tracking circuitry may include a camera, a light source, and a range finder, or the gaze tracking circuitry may include only a range finder.

[0007] The range finder may use phase-based optical coherence tomography to determine eye distance. The range finder may include one or more emitters that each include one or more lasers or other coherent light sources. The lasers may emit infrared light of known, time-dependent wavelength into a beam splitter that splits the light into signal light that travels a free space path length to the eye and reference light that travels a fixed reference path length towards multiple image sensors. The signal light specularly reflects off of the eye (creating an eye glint) and the reflected signal light combines with the reference light, creating an interference pattern that can be captured by the image sensor and analyzed to determine glint location, eye distance, eye velocity, and eye acceleration.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a top view of an illustrative head-mounted device that may include gaze tracking circuitry in accordance with an embodiment.

[0009] FIG. **2** is a rear view of an illustrative head-mounted device that may include gaze tracking circuitry in accordance with an embodiment.

[0010] FIG. **3** is a schematic diagram of an illustrative head-mounted device that may include gaze tracking circuitry in accordance with an embodiment.

[0011] FIG. **4** is a top view of illustrative gaze tracking circuitry being used to track a gaze direction of a user in accordance with an embodiment.

[0012] FIG. **5** is a schematic diagram of an illustrative range finder that uses optical coherent tomography to determine eye distance in accordance with an embodiment.

[0013] FIG. **6** is a rear view of an illustrative head-mounted device having a range finder of the type shown in FIG. **5** in accordance with an embodiment.
[0014] FIG. **7** is a side view of an illustrative range finder having an image sensor that includes a pixel array, a holographic optical element, a phase grating, and a lens in accordance with an embodiment.
[0015] FIG. **8** is a side view of an illustrative phase grating having edges that are offset from the vertex of an overlapping lens in accordance with an embodiment.
[0016] FIG. **9** is a front view of an illustrative image captured by a pixel array and having two focal spots that are slightly out of phase with one another in accordance with an embodiment.

DETAILED DESCRIPTION

[0017] Eyewear such as a pair of glasses or other head-mounted device may include one or more eye monitoring components such as gaze tracking circuitry for determining the direction of a user's gaze. The gaze tracking circuitry may include one or more range finders (e.g., distance sensors) that use optical coherence tomography to measure the path lengths of specular reflections off of the sclera and cornea of the eye (sometimes referred to as glints). This path length information may in turn be used to determine the direction of a user's gaze. The gaze tracking circuitry may rely entirely on distance sensing to track the direction of the user's gaze, or the gaze tracking circuitry may use both distance sensors and one or more cameras for capturing images of the pupil and one or more glints in a hybrid graze tracking approach.
[0018] A distance sensor based on optical coherence tomography may include one or more coherent light sources such as lasers that emit beams of infrared light into a beam splitter. The beams of infrared light may have a wavelength that changes slightly over time in a known or measured way. The beam splitter may include a star coupler that allows light from each laser to be detected by multiple sensors in different locations around the periphery of the eye. The beam splitter may split the infrared light into signal light that travels a free space path to the eye and reference light that travels a fixed reference path to one or more image sensors. The signal light that is emitted toward the eye creates a specular reflection (e.g., a glint) on the eye and is reflected toward the image sensor. The reflected signal light from the eye combines with the reference light from the fixed reference path and a corresponding interference pattern is captured by the image sensor. If the free space path length to the eye is equal to the fixed reference path length, the image of the glint will appear unchanged. If the two path lengths are different, a corresponding interference pattern may be captured by the image sensor and analyzed to determine glint location, eye distance, as well as eye velocity and acceleration (e.g., the first two derivatives of eye distance).
[0019] In a hybrid gaze tracking arrangement, a range finder based on optical coherence tomography may be combined with a light source and camera for determining pupil location and glint location. For example, a light source such as a light-emitting diode may create a glint on the user's eye and/or may illuminate the user's pupil and iris. Pupil location and glint location may be determined based on the eye images captured by the camera. The range finder may use phase-based optical coherence tomography to determine a distance to the eye (sometimes referred to as eye distance). The gaze direction of the user may be determined based on the location of the glint, the location of the pupil, and the distance to the eye.
[0020] Using hybrid gaze tracking circuitry that includes both a camera and light source for glint detection and a range finder for distance sensing may allow gaze direction to be determined using fewer glints (e.g., using only a single glint from a single light-emitting diode, if desired). This may be beneficial in arrangements where fewer light sources are desired and/or in scenarios where multiple glints cannot be obtained from a particular user's eye. In some arrangements, the camera, light source, and range finder may remain powered on during operation of device **10** and may continuously or periodically be used to track gaze direction. In other arrangements, power savings may be achieved by keeping the camera and/or the light source off (or otherwise in a low-power state) until the range finder detects a change in eye distance, which may be indicative of a change

in gaze direction. Upon detecting the change in eye distance with the range finder, the camera and light source may be switched on to help determine the new gaze direction of the user.

[0021] In some arrangements, glint detection may not be necessary to determine gaze direction. For example, a camera can be used to capture information about the pupil, iris, eyelids, and/or other features of the eye, and this information can be supplemented with one or more range measurements from an optical coherence tomographic measurement of a path length of a specular reflection off of the surface of the user's eye.

[0022] A top view of an illustrative head-mounted device or other eyewear is shown in FIG. **1**. As shown in FIG. **1**, head-mounted devices such as electronic device **10** may have head-mounted support structures such as housing **12**. Housing **12** may include portions (e.g., support structures **12**T) to allow device **10** to be worn on a user's head. Support structures **12**T may be formed from fabric, polymer, metal, and/or other material. Support structures **12**T may form a strap or other head-mounted support structures to help support device **10** on a user's head. A main support structure (e.g., main housing portion **12**M) of housing **12** may support electronic components such as displays **14**. Main housing portion **12**M may include housing structures formed from metal, polymer, glass, ceramic, and/or other material. For example, housing portion **12**M may have housing walls on front face F and housing walls on adjacent top, bottom, left, and right side faces that are formed from rigid polymer or other rigid support structures and these rigid walls may optionally be covered with electrical components, fabric, leather, or other soft materials, etc. The walls of housing portion **12**M may enclose internal components **38** in interior region **34** of device **10** and may separate interior region **34** from the environment surrounding device **10** (exterior region **36**). Internal components **38** may include integrated circuits, actuators, batteries, sensors, and/or other circuits and structures for device **10**. Housing **12** may be configured to be worn on a head of a user and may form glasses, a hat, a helmet, goggles, and/or other head-mounted device. Configurations in which housing **12** forms goggles may sometimes be described herein as an example.

[0023] Front face F of housing **12** may face outwardly away from a user's head and face. Opposing rear face R of housing **12** may face the user. Portions of housing **12** (e.g., portions of main housing **12**M) on rear face R may form a cover such as cover **12**C (sometimes referred to as a curtain). The presence of cover **12**C on rear face R may help hide internal housing structures, internal components **38**, and other structures in interior region **34** from view by a user.

[0024] Device **10** may have left and right optical modules **40**. Each optical module may include a respective display **14**, lens **30**, and support structure **32**. Support structures **32**, which may sometimes be referred to as lens barrels or optical module support structures, may include hollow cylindrical structures with open ends or other supporting structures to house displays **14** and lenses **30**. Support structures **32** may, for example, include a left lens barrel that supports a left display **14** and left lens **30** and a right lens barrel that supports a right display **14** and right lens **30**.

[0025] Displays **14** may include arrays of pixels or other display devices to produce images. Displays **14** may, for example, include organic light-emitting diode pixels formed on substrates with thin-film circuitry and/or formed on semiconductor substrates, pixels formed from crystalline semiconductor dies, liquid crystal display pixels, scanning display devices, and/or other display devices for producing images.

[0026] Lenses **30** may include one or more lens elements for providing image light from displays **14** to respective eyes boxes **13**. Lenses **30** may be implemented using refractive glass lens elements, using mirror lens structures (catadioptric lenses), using Fresnel lenses, using holographic lenses, and/or other lens systems.

[0027] When a user's eyes are located in eye boxes **13**, displays (display panels) **14** operate together to form a display for device **10** (e.g., the images provided by respective left and right optical modules **40** may be viewed by the user's eyes in eye boxes **13** so that a stereoscopic image is created for the user). The left image from the left optical module fuses with the right image from a right optical module while the display is viewed by the user.

[0028] If desired, device **10** may include additional lenses such as lenses **50**. Lenses **50** may be fixed lenses or may be adjustable lenses such as liquid crystal lenses, fluid-filled lenses, or other suitable adjustable lenses. Lenses **50** may be configured to accommodate different focal ranges and/or to correct for vision defects such as myopia, hyperopia, presbyopia, astigmatism, higher-order aberrations, and/or other vision defects. For example, lenses **50** may be adjustable prescription lenses having a first set of optical characteristics for a first user with a first prescription and a second set of optical characteristics for a second user with a second prescription. Lenses **50** may be removably or permanently attached to housing **12**. In arrangements where lenses **50** are removable, lenses **50** may have mating engagement features, magnets, clips, or other attachment structures that allow lenses **50** to be attached to housing **12** (e.g., individually or as a pair).

[0029] If desired, device **10** may be used purely for vision correction (e.g., device **10** may be a pair of spectacles, glasses, etc.) and some of the other components in FIG. **1** such as displays **14**, lenses **30**, and optical modules **40** may be omitted. In other arrangements, device **10** (sometimes referred to as eyewear **10**, glasses **10**, head-mounted device **10**, etc.) may include displays that display virtual reality, mixed reality, and/or augmented reality content. With this type of arrangement, lenses **50** may be prescription lenses and/or may be used to move content between focal planes from the perspective of the user. If desired, lenses **50** may be omitted. Arrangements in which device **10** is a head-mounted device with one or more displays are sometimes described herein as an illustrative example.

[0030] It may be desirable to monitor the user's eyes while the user's eyes are located in eye boxes **13**. For example, it may be desirable to use a camera to capture images of the user's irises (or other portions of the user's eyes) for user authentication. It may also be desirable to monitor the direction of the user's gaze. Gaze tracking information may be used as a form of user input and/or may be used to determine where, within an image, image content resolution should be locally enhanced in a foveated imaging system. To ensure that device **10** can capture satisfactory eye images while a user's eyes are located in eye boxes **13**, each optical module **40** may be provided with gaze tracking circuitry **62**. Gaze tracking circuitry **62** may include one or more cameras such as camera **42**, one or more light sources such as light source **44** (e.g., light-emitting diodes, lasers, lamps, etc.), and one or more range finders such as range finder **48**. Device **10** may include gaze tracking circuitry **62** for each eye (e.g., a left eye and a right eye), or device **10** may include gaze tracking circuitry **62** for a single eye.

[0031] Cameras **42** and light-emitting diodes **44** may operate at any suitable wavelengths (visible, infrared, and/or ultraviolet). With an illustrative configuration, which may sometimes be described herein as an example, diodes **44** emit infrared light that is invisible (or nearly invisible) to the user. This allows eye monitoring operations to be performed continuously without interfering with the user's ability to view images on displays **14**.

[0032] Range finder **48** (sometimes referred to as depth sensor **48**) may be any suitable range finder such as an optical range finder (e.g., a light source and light sensor that gather time-of-flight measurements, phase-based measurements, self-mixing sensors, light detection and ranging (lidar) sensors, structured light sensors, and/or depth sensors based on stereo imaging devices that capture three-dimensional images, etc.), an ultrasonic range finder (e.g., one or more capacitive micromachined ultrasonic transducers, piezoelectric micromachined transducers, and/or other suitable ultrasonic transducers for emitting and/or detecting acoustic signals), and/or any other suitable range finder.

[0033] In some arrangements, range finder **48** may use phase-based optical coherence tomography to determine a distance to the eye. With this type of arrangement, range finder **48** may include one or more coherent light sources such as wavelength-tunable lasers that emit light into a beam splitter while sweeping a wavelength of the emitted light across a given range of tunability. Laser light that is emitted with this type of wavelength sweep may sometimes be referred to as a laser chirp. The beam splitter splits the light into a signal arm that creates a specular reflection (e.g., a glint) on the user's eye and a local oscillator arm that will interfere with the light collected from the signal arm. Range finder **48** may include one or more image sensors (e.g., arrays of pixels) that capture an image of the signal light and reference light, which may include an interference pattern based on the constructive and destructive interference between the signal light from the eye and the reference light from the local oscillator arm. The captured images may be processed to determine the path length of the specular reflection and the corresponding distance to the eye. If desired, only a portion of the pixel array that includes the glint image may be read out for processing (e.g., to save processing power). In particular, a first laser chirp may be used to identify the portion of the pixel array that includes the glint, and a second laser chirp may be used to determine a distance to the glint using only that portion of the pixel array (e.g., by only reading out a subset of the pixels that includes the glint). If desired, a third laser chirp may be used to determine the first temporal derivative of the distance to the eye (e.g., eye velocity). If desired, third and fourth laser chirps may be used to determine the first two temporal derivatives of the distance to the eye (e.g., eye velocity and eye acceleration).

[0034] Not all users have the same interpupillary distance IPD. To provide device **10** with the ability to adjust the interpupillary spacing between modules **40** along lateral dimension X and thereby adjust the spacing IPD between eye boxes **13** to accommodate different user interpupillary distances, device **10** may be provided with actuators **43**. Actuators **43** can be manually controlled and/or computer-controlled actuators (e.g., computer-controlled motors) for moving support structures **32** relative to each other. Information on the locations of the user's eyes may be gathered using, for example, cameras **42**. The locations of eye boxes **13** can then be adjusted accordingly.

[0035] As shown in FIG. **2**, cover **12**C may cover rear face F while leaving lenses **30** of optical modules **40** uncovered (e.g., cover **12**C may have openings that are aligned with and receive modules **40**). As modules **40** are moved relative to each other along dimension X to accommodate different interpupillary distances for different users, modules **40** move relative to fixed housing structures such as the walls of main portion **12**M and move relative to each other.

[0036] A schematic diagram of an illustrative electronic device such as a head-mounted device or other wearable device is shown in FIG. **3**. Device **10** of FIG. **3** may be operated as a stand-alone device and/or the resources of device **10** may be used to communicate with external electronic equipment. As an example, communications circuitry in device **10** may be used to transmit user input information, sensor information, and/or other information to external electronic devices (e.g., wirelessly or via wired connections). Each of these external devices may include components of the type shown by device **10** of FIG. **3**.

[0037] As shown in FIG. **3**, a head-mounted device such as device **10** may include control circuitry **20**. Control circuitry **20** may include storage and processing circuitry for supporting the operation of device **10**. The storage and processing circuitry may include storage such as nonvolatile memory (e.g., flash memory or other electrically-programmable-read-only memory configured to form a solid state drive), volatile memory (e.g., static or dynamic random-access-memory), etc. Processing circuitry in control circuitry **20** may be used to gather input from sensors and other input devices and may be used to control output devices. The processing circuitry may be based on one or more microprocessors, microcontrollers, digital signal processors, baseband processors and other wireless communications circuits, power management units, audio chips, application specific integrated circuits, etc. During operation, control circuitry **20** may use display(s) **14** and other output devices in providing a user with visual output and other output.

[0038] To support communications between device **10** and external equipment, control circuitry **20** may communicate using communications circuitry **22**. Circuitry **22** may include antennas, radio-frequency transceiver circuitry, and other wireless communications circuitry and/or wired communications circuitry. Circuitry **22**, which may sometimes be referred to as control circuitry and/or control and communications circuitry, may support bidirectional wireless communications between device **10** and external equipment (e.g., a companion device such as a computer, cellular telephone, or other electronic device, an accessory such as a point device, computer stylus, or other input device, speakers or other output devices, etc.) over a wireless link. For example, circuitry **22** may include radio-frequency transceiver circuitry such as wireless local area network transceiver circuitry configured to support communications over a wireless local area network link, near-field communications transceiver circuitry configured to support communications over a near-field communications link, cellular telephone transceiver circuitry configured to support communications over a cellular telephone link, or transceiver circuitry configured to support communications over any other suitable wired or wireless communications link. Wireless communications may, for example, be supported over a Bluetooth® link, a WiFi® link, a wireless link operating at a frequency between 10 GHz and 400 GHz, a 60 GHz link, or other millimeter wave link, a cellular telephone link, or other wireless communications link. Device **10** may, if desired, include power circuits for transmitting and/or receiving wired and/or wireless power and may include batteries or other energy storage devices. For example, device **10** may include a coil and rectifier to receive wireless power that is provided to circuitry in device **10**.

[0039] Device **10** may include input-output devices such as devices **24**. Input-output devices **24** may be used in gathering user input, in gathering information on the environment surrounding the user, and/or in providing a user with output. Devices **24** may include one or more displays such as display(s) **14**. Display(s) **14** may include one or more display devices such as organic light-emitting diode display panels (panels with organic light-emitting diode pixels formed on polymer substrates or silicon substrates that contain pixel control circuitry), liquid crystal display panels, microelectromechanical systems displays (e.g., two-dimensional mirror arrays or scanning mirror display devices), display panels having pixel arrays formed from crystalline semiconductor light-emitting diode dies (sometimes referred to as microLEDs), and/or other display devices.

[0040] Sensors **16** in input-output devices **24** may include force sensors (e.g., strain gauges, capacitive force sensors, resistive force sensors, etc.), audio sensors such as microphones, touch and/or proximity sensors such as capacitive sensors such as a touch sensor that forms a button, trackpad, or other input device), and other sensors. If desired, sensors **16** may include optical sensors such as optical sensors that emit and detect light, ultrasonic sensors, optical touch sensors, optical proximity sensors, and/or other touch sensors and/or proximity sensors, monochromatic and color ambient light sensors, image sensors, fingerprint sensors, iris scanning sensors, retinal scanning sensors, and other biometric sensors, temperature sensors, sensors for measuring three-dimensional non-contact gestures ("air gestures"), pressure sensors, sensors for detecting position, orientation, and/or motion (e.g., accelerometers, magnetic sensors such as compass sensors, gyroscopes, and/or inertial measurement units that contain some or all of these sensors), health sensors such as blood oxygen sensors, heart rate sensors, blood flow sensors, and/or other health sensors, radio-frequency sensors, depth sensors (e.g., structured light sensors and/or depth sensors based on stereo imaging devices that capture three-dimensional images), optical sensors such as self-mixing sensors and light detection and ranging (lidar) sensors that gather time-of-flight measurements, humidity sensors, moisture sensors, gaze tracking sensors, electromyography sensors to sense muscle activation, facial sensors, and/or other sensors. In some arrangements, device **10** may use sensors **16** and/or other input-output devices to gather user input. For example, buttons may be used to gather button press input, touch sensors overlapping displays can be used for gathering user touch screen input, touch pads may be used in gathering touch input, microphones may be used for gathering audio input, accelerometers may be used in monitoring when a finger contacts an input surface and may therefore be used to gather finger press input, etc.

[0041] If desired, electronic device **10** may include additional components (see, e.g., other devices **18** in input-output devices **24**). The additional components may include haptic output devices, actuators for moving movable housing structures, audio output devices such as speakers, light-emitting diodes for status indicators, light sources such as light-emitting diodes that illuminate portions of a housing and/or display structure, other optical output devices, and/or other circuitry for gathering input and/or providing output. Device **10** may also include a battery or other energy storage device, connector ports for supporting wired communication with ancillary equipment and for receiving wired power, and other circuitry.

[0042] FIG. **4** is a top view of illustrative gaze tracking circuitry **62**. As shown in FIG. **4**, gaze tracking circuitry **62** may include one or more cameras such as camera **42**, one or more light sources such as light source **44**, and one or more range finders such as range finder **48**. Range finder **48** may be configured to measure the distance to eye **58** (e.g., the distance to the point of specular reflection on the cornea, sometimes referred to as eye distance), sometimes referred to as eye distance). As the user's gaze moves around (e.g., from position P**1** to position P**2**), the distance to eye **58** may change. At position P**1**, range finder **48** may measure a distance D**1** to eye **58**. At position P**2**, range finder **48** may measure a distance D**2** to eye **58**.

[0043] Range finder **48** may include one or more transmitters such as transmitter **48**T and one or more receivers such as receiver **48**R. Transmitter **48**T may be configured to emit signal **56** toward the user's eye **58**. Signal **56** may reflect off of eye **58** and reflected signal **54** may be detected by receiver **48**R. If desired, range finder **48** may include more than one transmitter **48**T and/or more than one receiver **48**R. For example, range finder **48** may include a second transmitter **48**T and a second receiver **48**R for redundancy. Arrangements in which range finder **48** includes three or more transmitters **48**T and/or three or more receivers **48**R may also be used.

[0044] In some arrangements, one device may serve as both transmitter **48**T and receiver **48**R. For example, a flexible membrane in a transducer may be used to detect ultrasonic signals (when serving as receiver **48**R) and may also be used to emit ultrasonic signals (when serving as transmitter **48**T). As another example, a self-mixing interferometer may also serve as both transmitter **48**T and receiver **48**R.

[0045] Range finder **48** may be any suitable sensor configured to measure distance. In arrangements where range finder **48** is an optical sensor (e.g., an optical sensor that gathers time-of-flight measurements, a self-mixing sensor, a light detection and ranging (lidar) sensor, a structured light sensor, a phased-based optical coherence tomography sensor, and/or a depth sensor based on a stereo imaging device that captures three-dimensional images, etc.), emitted signal **56** and reflected signal **54** may be optical signals. When range finder **48** is formed from a phased-based sensor such as an optical sensor based on optical coherence tomography, range finder **48** may be configured to achieve smaller resolvable time intervals than time-of-flight based sensors. In arrangements where range finder **48** is an ultrasonic sensor (e.g., one or more capacitive micromachined ultrasonic transducers, piezoelectric micromachined transducers, and/or other suitable ultrasonic transducers for emitting and/or detecting acoustic signals), emitted signal **56** and reflected signal **54** may be ultrasonic signals.

[0046] If desired, transmitter **48**T may be co-located with receiver **48**R. In other arrangements, transmitter **48**T and receiver **48**R may be mounted in different locations. Camera **42** and light source **44** may be co-located with one another or may be mounted in different locations. One or both of transmitter **48**T and receiver **48**R may be co-located with camera **42** and/or light source **44**, or transmitter **48**T and receiver **48**R may be mounted separately from camera **42** and/or light source **44**.

[0047] During operation, light source **44** may be used to emit light **50** toward eye **58**. Light **50** may reflect off of eye **58** and reflected light **52** may be detected by camera **42**. Emitted light **50** may create a glint on eye **58**. Camera **42** may capture images of eye **58** including the glint created by light **50**. Based on the captured images, gaze tracking circuitry **62** may determine the location of the glint and the location of the user's pupil. In some arrangements, there may be multiple light sources **44** that produce multiple glints on the user's eye. If there are a sufficient number of glints produced on eye **58**, gaze control circuitry **62** can determine the shape and/or the location of the user's eye or a part of the user's eye (e.g., the user's cornea), which in turn can be used to determine gaze direction (e.g., without requiring range finder **48**).

[0048] In some arrangements, such as when fewer light sources **44** are desired, or when a sufficient number of glints cannot be captured due to the shape of a particular user's eye, gaze control circuitry **62** may combine glint detection with distance sensing to determine gaze direction. In this type of scenario, a single light source **44** may produce a single glint on eye **58**, and camera **42** may capture images of eye **58** including the single glint. Based on the captured images, gaze tracking control circuitry **62** may determine a position of the glint and a position of the pupil. Because the eye is mostly spherical (e.g., to first order), the glint on eye **58** will remain mostly in the same place as the eye moves around, but the position of the pupil relative to the glint will change as the gaze direction changes. In particular, as the eyeball moves around to different gaze directions (e.g., from position to P**1** to position P**2**), the position of the pupil relative to the glint will change by a scaling factor that depends on the distance to the eyeball. By using range finder **48** to determine a distance to the eyeball at positions P**1** and P**2**, gaze tracking circuitry **62** can determine this scaling factor and can therefore map the pupil and glint positions at P**1** to a first gaze direction (e.g., based on distance D**1**) and the pupil and glint positions at P**2** to a second gaze direction (e.g., based on distance D**2**). In scenarios where no glints are visible to camera **42**, multiple range finders **48** or a single range finder **48** can be combined with image information from camera **42** (e.g., eye features and/or facial features) which together enable an accurate assessment of the location and orientation of eye **58**.

[0049] FIG. **5** is a schematic diagram of an illustrative range finder **48** that uses phase-based optical coherence tomography to determine the distance to a user's eye (e.g., as discussed in connection with FIG. **4**). As shown in FIG. **5**, range finder **48** may include one or more light sources such as transmitter **48**T. Transmitter **48**T may include one or more coherent light sources such as coherent light sources **74** on an integrated circuit such as integrated circuit die **72**. Coherent light sources **74** may include one or more lasers such as lasers **74**A, **74**B, **74**C, and **74**D. Lasers **74** may be vertical cavity surface emitting lasers, distributed feedback (DFB) lasers, distributed Bragg reflector (DBR) lasers, microelectromechanical systems (MEMs) tunable lasers, thermally tuned lasers, or any other suitable coherent light source. Lasers **74** may be wavelength-tunable lasers configured to emit light while sweeping the wavelength of the light across a given range of tunability. For example, lasers **74** may be configured to emit light centered at 905 nm with 1.8 nm of tunability (e.g., from 904.1 nm to 905.9 nm). This example is merely illustrative. If desired, light emitted from lasers **74** may be centered around other wavelengths and/or may have other ranges of tunability.

[0050] Each laser **74** may emit a laser chirp with a given frequency sweep into a respective input of a beam splitter such as beam splitter **102**. Beam splitter **102** may be a planar lightwave circuit (e.g., one or more passive optical components) or other suitable beam splitter for splitting light from lasers **72** into signal light such as signal light **56** and reference light such as reference light **106**. Laser **72**A may emit light into input **76-1** of beam splitter **102**, laser **72**B may emit light into input **76-2** of beam splitter **102**, laser **74**C may emit light into input **76-3** of beam splitter **102**, and laser **74**D may emit light into input **76-4** of beam splitter **102**.

[0051] Beam splitter **102** may be configured to split light from lasers **74** into a signal arm headed toward eye **58** and a local oscillator arm that will interfere with the light collected from the signal arm. As shown in FIG. **5**, beam splitter **102** may direct half of light from laser **74**A to path **84-1** and the other half to path **104-1**; may direct half of light from laser **74**B to path **84-2** and the other half to path **104-2**; may direct half of light from laser **74**C to path **84-3** and the other half to path **104-3**; and may direct half of light from laser **84**D to path **84-4** and the other half to path **104-4**. Light that is directed to paths **104-1**, **104-2**, **104-3**, and **104-4** may serve as reference light (e.g., in the local oscillator arm that forms the fixed reference path), whereas light that is directed to paths **84-1**, **84-2**, **84-3**, and **84-4** may serve as signal light (e.g., in the signal arm that forms the free space path to eye **58**).

[0052] Paths **104-1**, **104-2**, **104-3**, and **104-4** may serve as inputs to an optical coupler such as star coupler **82** for coupling reference light **106** from respective lasers **74** to one or more sensors such as image sensors **70**. Star coupler **82** may have one or more outputs such as outputs **78**. Star coupler **82** may have more outputs than inputs, if desired. For example, star coupler **82** may have four inputs and twelve outputs, may have eight inputs and twelve outputs, may have two inputs and ten outputs, and/or may have any other suitable number of inputs and outputs. Star coupler **82** may be configured to couple reference light **106** from inputs **104-1**, **104-2**, **104-3**, and **104-4** to outputs **78**. Outputs **78** may direct reference light **106** toward one or more image sensors **70**. There may be one, two, three, ten, twelve, more than twelve, or less than twelve image sensors **70** in range finder **48**. Each image sensor **70** may have a two-dimensional array of pixels. If desired, star coupler **82** may include an additional output **78** coupled to wavelength reference circuit **80** (e.g., for measuring the actual wavelength of each laser chirp).

[0053] Paths **84-1**, **84-2**, **84-3**, and **84-4** may be configured to couple signal light **56** to a given emission aperture such as emission apertures **68-1** and **68-2** (sometimes referred to as exit apertures). If desired, range finder **48** may have more than two emission apertures (e.g., three, four, or more than four emission apertures). Emission apertures **68-1** and **68-2** may be positioned in different locations with respect to eye **58**. Signal light **56** from paths **84-1** and **84-2** is coupled out of aperture **68-1** toward eye **58**. Signal light **56** from paths **84-3** and **84-4** is coupled out of aperture **68-2** toward eye **58**. Signal light **56** creates a specular reflection (e.g., a glint) on the user's eye and reflected signal light **54** is reflected toward one or more sensors **70** where it combines with reference light **106**.

[0054] Each image sensor **70** may capture an image of the glint that is produced on eye **58** by signal light **56** from a given laser **74**. If the free space path length to eye **58** is equal to the reference path length, then there will be no change to the image of the glint captured by image sensor **70**. If the two path lengths are different, then constructive interference will occur at some frequencies of light and destructive interference will occur at other frequencies of light. The frequency at which the signal modulates between constructive and destructive interference is proportional to the difference in path length between the free space path that reflects off of eye **58** and the fixed reference path that has a known path length. In this way, the distance to eye **58** (e.g., distance D**1** or distance D**2** of FIG. **4**) may be determined based on the interference pattern (e.g., the pattern of fringes) that is produced on image sensors **70**.

[0055] In the example of FIG. **5**, range finder **48** includes first and second emitters **48**T that each include first and second lasers. For example, a first emitter **48**T-**1** having exit aperture **68-1** may include lasers **74**A and laser **74**B, and a second emitter **48**T-**2** having exit aperture **68-2** may include laser **74**C and laser **74**D. The use of multiple emitters **48**T may allow for a diversity of path length measurements. If desired, there may be three, four, or more than four emitters **48**T. Some of emitters **48**T may be used for direct path measurements in which emitter **48**T emits light on a free space path directly toward sensor **70** (e.g., without reflecting off of eye **58**) in order to monitor for changes in the shape of glasses **10**, which may be subject to daily wear and tear. In an arrangement with four emitters **48**T, for example, range finder **48** may be configured to determine the x, y, and z location coordinates of each emitter **48**T using direct path measurements.

[0056] The example of FIG. **5** in which each emitter **48**T includes two lasers is merely illustrative. If desired, each emitter **48**T may include three, four, or more than four lasers, or may include only one laser. The use of multiple lasers **74** in each emitter **48**T allows for multiple laser chirps to be emitted in sequence during a given measurement, while allowing lasers **74** to have a rest period such as 1 ms of rest period after firing (e.g., for thermal management). Emitting multiple laser chirps in a given measurement may allow a first of the chirps to be used for determining glint location and subsequent chirps to be used for determining eye distance and its first one or two temporal derivatives (eye velocity and eye acceleration).

[0057] For example, during a given measurement, laser **74**A may fire a first chirp having a first frequency sweep (e.g., a sweep from 905.9 nm to 904.1 nm) across a first sweep duration (e.g., 2 ms or other suitable duration). Beam splitter **102** may split the first chirp from laser **74**A into signal light **56** which exits aperture **68-1** and reference light **106** which exits outputs **78** toward sensors **70**. Image sensors **70** may capture one or more images of reflected signal light **54** and reference light **106**. Based on the captured images, range finder **48** may determine the location of the glint (e.g., may determine which group of pixels on image sensor **70** includes the glint). This allows range finder **48** to only read out the particular group of pixels where the glint is located during subsequent chirps. For example, if sensor **70** includes an array of 50 pixels by 50 pixels, a subset region of 2 pixels by 4 pixels (corresponding to the glint location) may be read out in subsequent chirps for measuring path length and its derivatives (as an example).

[0058] After the first chirp, laser **74**B may fire a second chirp having a second frequency sweep (e.g., from 904.1 nm to 905.9 nm) across a second sweep duration different from the first sweep duration (e.g., 0.5 ms or other suitable duration). Beam splitter **102** may split the first chirp from laser **74**B into signal light **56** which exits aperture **68-1** and reference light **106** which exits outputs **78** toward sensors **70**. Image sensors **70** may capture one or more images of reflected signal light **54** and reference light **106**. If desired, only the subset of pixels where the glint is located (e.g., the subset of pixels identified from the first chirp) may be read out to measure the second chirp. Based on the captured images, range finder **48** may determine the free space path length and the corresponding distance to eye **58**.

[0059] After the second chirp, laser **74**A may again fire a third chirp having a third frequency sweep (e.g., from 905.9 nm to 904.1 nm) across a third sweep duration different from the first sweep duration (e.g., 1.5 ms or other suitable duration). Beam splitter **102** may split the third chirp from laser **74**A into signal light **56** which exits aperture **68-1** and reference light **106** which exits outputs **78** toward sensors **70**. Image sensors **70** may capture one or more images of reflected signal light **54** and reference light **106**. If desired, only the subset of pixels where the glint is located (e.g., the subset of pixels identified from the first chirp) may be read out to measure the third chirp. Based on the captured images, range finder **48** may determine the first temporal derivative of the free space path length (e.g., eye velocity).

[0060] After the third chirp, laser **74**B may again fire a fourth chirp having a fourth frequency sweep (e.g., from 904.1 nm to 905.9 nm) across a fourth sweep duration different from the first sweep duration (e.g., 0.5 ms or other suitable duration). Beam splitter **102** may split the fourth chirp from laser **74**B into signal light **56** which exits aperture **68-1** and reference light **106** which exits outputs **78** toward sensors **70**. Image sensors **70** may capture one or more images of reflected signal light **54** and reference light **106**. If desired, only the subset of pixels where the glint is located (e.g., the subset of pixels identified from the first chirp) may be read out to measure the fourth chirp. Based on the captured images, range finder **48** may determine the second temporal derivative of the free space path length (e.g., eye acceleration).

[0061] In arrangements where range finder **48** includes multiple emitters **48**T, emitters **48**T may be active in alternate measurements. For example, lasers **74**A and **74**B of emitter **48**T-**1** may fire four chirps as described above in a first measurement, while lasers **74**C and **74**D of emitter **48**T-**2** are not active (e.g., not emitting light). In a second subsequent measurement, lasers **74**C and **74**D of emitter **48**T-**2** may fire four chirps (as described above for lasers **74**A and **74**B) while lasers **74**A and **74**B of emitter **48**T-**1** are not emitting light.

[0062] If desired, range finder **48** may use a signal processing technique such as PROFIT to process signals from sensor **70**. With this type of technique, range finder **48** may determine the frequency of an isolated sinusoidal signal by taking N+1 data samples, then performing fast Fourier transforms on the first N samples and the last N samples. Each will show a peak around the location of the sinusoidal signal, but with a different phase. The frequency of the signal may be estimated based on the difference in phase alone (e.g., rather than using amplitude in bins outside the peak). This is merely illustrative, however. If desired, other signal processing techniques may be used to process signals from image sensor **70**.

[0063] FIG. **6** is a rear view of device **10** showing illustrative locations for some of the components of FIG. **5**. Image sensors **70** and emission apertures **68-1** and **68-2** may face the eye box and may be mounted to a support structure such as support structure **66**. Support structure **66** may be a ring-shaped frame member that extends around the periphery of a user's eye. Support structure **66** may be part of housing **12** of device **10**, part of optical module **40** of device **10**, and/or may be a dedicated support structure for gaze tracking circuitry **62**. In arrangements where device **10** includes a display such as display **14**, support structure **66** may extend around some or all of the periphery of display **14**, or support structure **66** may be mounted elsewhere in device **10** (e.g., surrounding lens **30** of FIG. **1**, surrounding lens **50** of FIG. **1**, etc.). Support structure **66** may have apertures for allowing emitted signal light **56** from emission apertures **68-1** and **68-2** to exit support structure **66** and may include apertures for allowing reflected signal light **54** to be detected by image sensors **70**.
[0064] Range finder **48** may include one or more optical fibers such as optical fibers **64** in support structure **66**. Optical fibers **64** may be configured to guide laser light (e.g., via total internal reflection) from beam splitter **102** to the desired location within support structure **66**. For example, a first set of optical fibers **64** may be configured to guide reference light **106** from beam splitter **102** (e.g., from a given output **78** of star coupler **82**) to respective image sensors **70**. A second set of optical fibers **64** may be configured to guide signal light **56** from beam splitter **102** (e.g., from a respective one of paths **84-1**, **84-2**, **84-3**, and **84-4**) to respective emission apertures such as exit apertures **68-1** and **68-2**. Reflected signal light **54** may interfere with reference light **106** and the corresponding interference pattern captured by image sensors **70** can be analyzed to determine glint location, eye speed, eye velocity, and/or eye acceleration as discussed in connection with FIG. **5**.
[0065] FIG. **7** is a side view of an illustrative image sensor **70** that may be used in range finder **48**. As shown in FIG. **7**, image sensor **70** may include a two-dimensional array of pixels **96** on a substrate such as semiconductor substrate **94**. Image sensor **70** may be a complementary metal-oxide-semiconductor (CMOS) image sensor or other suitable image sensor. If desired, image sensor **70** may include one or more additional optical components overlapping pixels **96** such as lens **86**, phase grating **88**, and holographic optical element **90**. Lens **86** may be used to focus reflected signal light **54** onto pixels **96**. Phase grating **88** (sometimes referred to as diffraction grating **88**) may be interposed between holographic optical element **90** and lens **86**.
[0066] Holographic optical element **90** may be configured to couple reference light out of output **78** at an angle that is mostly parallel to incoming reflected signal light **54**. Holographic optical element **90** may be a relatively sparse hologram with a small duty cycle (e.g., a metal pattern with 5% density or other suitable density). Making the reference wavefront parallel or mostly parallel to the signal wavefront reduces the spatial frequency of fringes between the two light paths and helps ensure that the interference pattern can be captured by pixels **96** even when pixels **96** are not overly small (e.g., 3 microns by 3 microns or other suitable size). Permitting relatively large pixels can help reduce the number of pixels that need to be digitized, thus saving power.
[0067] Phase grating **88** may be configured to split the specular reflection (e.g., the glint) on eye **58** into two spots on image pixels **96**. Depending on whether the free space path is longer or shorter than the fixed reference path, one of the spots will lead the other (e.g., by 160 degrees of phase). Range finder **48** can therefore disambiguate the sign (e.g., positive or negative) associated with the difference in path length between the free space path and the fixed reference path. For example, if range finder **48** measures a one millimeter difference in path length, phase grating **88** may be used to determine if the free space path is one millimeter shorter or one millimeter longer than the fixed reference path based on which spot leads the other on pixels **96**.
[0068] FIG. **8** is a side view of phase grating **88** and lens **86** of range finder **48**. Phase grating **88** may be a surface relief grating formed from modulations in the thickness of a medium (e.g., having ridges **108** and troughs **110** in the medium that form fringes). If desired, phase grating **88** may be formed from two different types of plastic having a known etch depth and known refractive indices.

The height H of ridges **108** relative to troughs **110** may be equal to about one half of the wavelength of the signal light so that one of the spots produced on pixels **96** leads the other.
[0069] As shown in FIG. **8**, lens **86** may be laterally offset from the edges of phase grating **88**. In particular, the vertex of lens **86** is laterally offset from all edges of phase grating **88** such as edge **112** of ridge **108**. This lateral offset between lens **86** and phase grating **88** can be tuned to create asymmetry where one of spots on pixels **96** leads the other, as shown in FIG. **9**. As shown in FIG. **9**, phase grating **88** of FIG. **8** may split reflected signal light **54** into a double image, such as glint spot **98-1** and glint spot **98-2**. Depending on whether the free space path is longer or shorter than the fixed reference path, one of glint spots **98-1** and **98-2** will lead the other. For example, glint spot **98-1** may lead glint spot **98-2** when the free space path length is longer than the fixed reference path length, whereas glint spot **98-2** may lead glint spot **98-1** when the free space path length is shorter than the fixed reference path length. Range finder **48** may therefore disambiguate the sign (e.g., positive or negative) associated with the calculated path length difference based on which of glint spots **98-1** and **98-2** leads the other.
[0070] As described above, one aspect of the present technology is the gathering and use of information such as information from input-output devices. The present disclosure contemplates that in some instances, data may be gathered that includes personal information data that uniquely identifies or can be used to contact or locate a specific person. Such personal information data can include demographic data, location-based data, telephone numbers, email addresses, social media information, home addresses, data or records relating to a user's health or level of fitness (e.g., vital signs measurements, medication information, exercise information), date of birth, username, password, biometric information, or any other identifying or personal information.
[0071] The present disclosure recognizes that the use of such personal information, in the present technology, can be used to the benefit of users. For example, the personal information data can be used to deliver targeted content that is of greater interest to the user. Accordingly, use of such personal information data enables users to calculated control of the delivered content. Further, other uses for personal information data that benefit the user are also contemplated by the present disclosure. For instance, health and fitness data may be used to provide insights into a user's general wellness, or may be used as positive feedback to individuals using technology to pursue wellness goals.
[0072] The present disclosure contemplates that the entities responsible for the collection, analysis, disclosure, transfer, storage, or other use of such personal information data will comply with well-established privacy policies and/or privacy practices. In particular, such entities should implement and consistently use privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining personal information data private and secure. Such policies should be easily accessible by users, and should be updated as the collection and/or use of data changes. Personal information from users should be collected for legitimate and reasonable uses of the entity and not shared or sold outside of those legitimate uses. Further, such collection/sharing should occur after receiving the informed consent of the users. Additionally, such entities should consider taking any needed steps for safeguarding and securing access to such personal information data and ensuring that others with access to the personal information data adhere to their privacy policies and procedures. Further, such entities can subject themselves to evaluation by third parties to certify their adherence to widely accepted privacy policies and practices. In addition, policies and practices should be adapted for the particular types of personal information data being collected and/or accessed and adapted to applicable laws and standards, including jurisdiction-specific considerations. For instance, in the United States, collection of or access to certain health data may be governed by federal and/or state laws, such as the Health Insurance Portability and Accountability Act (HIPAA), whereas health data in other countries may be subject to other regulations and policies and should be handled accordingly. Hence different privacy practices should be maintained for different personal data types in each

country.
[0073] Despite the foregoing, the present disclosure also contemplates embodiments in which users selectively block the use of, or access to, personal information data. That is, the present disclosure contemplates that hardware and/or software elements can be provided to prevent or block access to such personal information data. For example, the present technology can be configured to allow users to select to “opt in” or “opt out” of participation in the collection of personal information data during registration for services or anytime thereafter. In another example, users can select not to provide certain types of user data. In yet another example, users can select to limit the length of time user-specific data is maintained. In addition to providing “opt in” and “opt out” options, the present disclosure contemplates providing notifications relating to the access or use of personal information. For instance, a user may be notified upon downloading an application (“app”) that their personal information data will be accessed and then reminded again just before personal information data is accessed by the app.
[0074] Moreover, it is the intent of the present disclosure that personal information data should be managed and handled in a way to minimize risks of unintentional or unauthorized access or use. Risk can be minimized by limiting the collection of data and deleting data once it is no longer needed. In addition, and when applicable, including in certain health related applications, data de-identification can be used to protect a user's privacy. De-identification may be facilitated, when appropriate, by removing specific identifiers (e.g., date of birth, etc.), controlling the amount or specificity of data stored (e.g., collecting location data at a city level rather than at an address level), controlling how data is stored (e.g., aggregating data across users), and/or other methods.
[0075] Therefore, although the present disclosure broadly covers use of information that may include personal information data to implement one or more various disclosed embodiments, the present disclosure also contemplates that the various embodiments can also be implemented without the need for accessing personal information data. That is, the various embodiments of the present technology are not rendered inoperable due to the lack of all or a portion of such personal information data.
[0076] Physical environment: A physical environment refers to a physical world that people can sense and/or interact with without aid of electronic systems. Physical environments, such as a physical park, include physical articles, such as physical trees, physical buildings, and physical people. People can directly sense and/or interact with the physical environment, such as through sight, touch, hearing, taste, and smell.
[0077] Computer-generated reality: in contrast, a computer-generated reality (CGR) environment refers to a wholly or partially simulated environment that people sense and/or interact with via an electronic system. In CGR, a subset of a person's physical motions, or representations thereof, are tracked, and, in response, one or more characteristics of one or more virtual objects simulated in the CGR environment are adjusted in a manner that comports with at least one law of physics. For example, a CGR system may detect a person's head turning and, in response, adjust graphical content and an acoustic field presented to the person in a manner similar to how such views and sounds would change in a physical environment. In some situations (e.g., for accessibility reasons), adjustments to characteristic(s) of virtual object(s) in a CGR environment may be made in response to representations of physical motions (e.g., vocal commands). A person may sense and/or interact with a CGR object using any one of their senses, including sight, sound, touch, taste, and smell. For example, a person may sense and/or interact with audio objects that create 3D or spatial audio environment that provides the perception of point audio sources in 3D space. In another example, audio objects may enable audio transparency, which selectively incorporates ambient sounds from the physical environment with or without computer-generated audio. In some CGR environments, a person may sense and/or interact only with audio objects. Examples of CGR include virtual reality and mixed reality.
[0078] Virtual reality: A virtual reality (VR) environment refers to a simulated environment that is

designed to be based entirely on computer-generated sensory inputs for one or more senses. A VR environment comprises a plurality of virtual objects with which a person may sense and/or interact. For example, computer-generated imagery of trees, buildings, and avatars representing people are examples of virtual objects. A person may sense and/or interact with virtual objects in the VR environment through a simulation of the person's presence within the computer-generated environment, and/or through a simulation of a subset of the person's physical movements within the computer-generated environment.

[0079] Mixed reality: In contrast to a VR environment, which is designed to be based entirely on computer-generated sensory inputs, a mixed reality (MR) environment refers to a simulated environment that is designed to incorporate sensory inputs from the physical environment, or a representation thereof, in addition to including computer-generated sensory inputs (e.g., virtual objects). On a virtuality continuum, a mixed reality environment is anywhere between, but not including, a wholly physical environment at one end and virtual reality environment at the other end. In some MR environments, computer-generated sensory inputs may respond to changes in sensory inputs from the physical environment. Also, some electronic systems for presenting an MR environment may track location and/or orientation with respect to the physical environment to enable virtual objects to interact with real objects (that is, physical articles from the physical environment or representations thereof). For example, a system may account for movements so that a virtual tree appears stationery with respect to the physical ground. Examples of mixed realities include augmented reality and augmented virtuality. Augmented reality: an augmented reality (AR) environment refers to a simulated environment in which one or more virtual objects are superimposed over a physical environment, or a representation thereof. For example, an electronic system for presenting an AR environment may have a transparent or translucent display through which a person may directly view the physical environment. The system may be configured to present virtual objects on the transparent or translucent display, so that a person, using the system, perceives the virtual objects superimposed over the physical environment. Alternatively, a system may have an opaque display and one or more imaging sensors that capture images or video of the physical environment, which are representations of the physical environment. The system composites the images or video with virtual objects, and presents the composition on the opaque display. A person, using the system, indirectly views the physical environment by way of the images or video of the physical environment, and perceives the virtual objects superimposed over the physical environment. As used herein, a video of the physical environment shown on an opaque display is called “pass-through video,” meaning a system uses one or more image sensor(s) to capture images of the physical environment, and uses those images in presenting the AR environment on the opaque display. Further alternatively, a system may have a projection system that projects virtual objects into the physical environment, for example, as a hologram or on a physical surface, so that a person, using the system, perceives the virtual objects superimposed over the physical environment. An augmented reality environment also refers to a simulated environment in which a representation of a physical environment is transformed by computer-generated sensory information. For example, in providing pass-through video, a system may transform one or more sensor images to impose a select perspective (e.g., viewpoint) different than the perspective captured by the imaging sensors. As another example, a representation of a physical environment may be transformed by graphically modifying (e.g., enlarging) portions thereof, such that the modified portion may be representative but not photorealistic versions of the originally captured images. As a further example, a representation of a physical environment may be transformed by graphically eliminating or obfuscating portions thereof. Augmented virtuality: an augmented virtuality (AV) environment refers to a simulated environment in which a virtual or computer generated environment incorporates one or more sensory inputs from the physical environment. The sensory inputs may be representations of one or more characteristics of the physical environment. For example, an AV park may have virtual trees and virtual buildings, but

people with faces photorealistically reproduced from images taken of physical people. As another example, a virtual object may adopt a shape or color of a physical article imaged by one or more imaging sensors. As a further example, a virtual object may adopt shadows consistent with the position of the sun in the physical environment.
[0080] Hardware: there are many different types of electronic systems that enable a person to sense and/or interact with various CGR environments. Examples include head mounted systems, projection-based systems, heads-up displays (HUDs), vehicle windshields having integrated display capability, windows having integrated display capability, displays formed as lenses designed to be placed on a person's eyes (e.g., similar to contact lenses), headphones/earphones, speaker arrays, input systems (e.g., wearable or handheld controllers with or without haptic feedback), smartphones, tablets, and desktop/laptop computers. A head mounted system may have one or more speaker(s) and an integrated opaque display. Alternatively, a head mounted system may be configured to accept an external opaque display (e.g., a smartphone). The head mounted system may incorporate one or more imaging sensors to capture images or video of the physical environment, and/or one or more microphones to capture audio of the physical environment. Rather than an opaque display, a head mounted system may have a transparent or translucent display. The transparent or translucent display may have a medium through which light representative of images is directed to a person's eyes. The display may utilize digital light projection, OLEDs, LEDs, uLEDs, liquid crystal on silicon, laser scanning light sources, or any combination of these technologies. The medium may be an optical waveguide, a hologram medium, an optical combiner, an optical reflector, or any combination thereof. In one embodiment, the transparent or translucent display may be configured to become opaque selectively. Projection-based systems may employ retinal projection technology that projects graphical images onto a person's retina. Projection systems also may be configured to project virtual objects into the physical environment, for example, as a hologram or on a physical surface.
[0081] The foregoing is merely illustrative and various modifications can be made to the described embodiments. The foregoing embodiments may be implemented individually or in any combination.

Claims

1. Eyewear, comprising: a support structure; first and second lenses mounted to the support structure; and gaze tracking circuitry configured to track gaze direction, wherein the gaze tracking circuitry comprises: a coherent light source configured to emit infrared light; a beam splitter configured to split the infrared light into signal light that travels a free space path and reference light that travels a fixed reference path, wherein the signal light creates an eye glint; and an image sensor configured to capture images of the reference light and the signal light including the eye glint, wherein eye distance is determined based on the captured images.
2. The eyewear defined in claim 1 wherein the coherent light source comprises a vertical cavity surface emitting laser and wherein the infrared light is swept across a range of wavelengths during emission.
3. The eyewear defined in claim 1 wherein the beam splitter comprises a planar lightwave circuit that splits the infrared light into the signal light and the reference light.
4. The eyewear defined in claim 1 wherein the beam splitter comprises a star coupler having an input that receives the reference light and an output that directs the reference light toward the image sensor.
5. The eyewear defined in claim 1 wherein the image sensor comprises a two-dimensional array of pixels.
6. The eyewear defined in claim 5 wherein the image sensor comprises a lens overlapping the two-dimensional array of pixels.

7. The eyewear defined in claim 6 wherein the image sensor comprises a phase grating interposed between the two-dimensional array of pixels and the lens and wherein a vertex of the lens is laterally offset from all edges of the phase grating.
8. The eyewear defined in claim 7 wherein the image sensor comprises a holographic optical element interposed between the phase grating and the array of pixels, wherein the holographic optical element is configured to redirect the reference light to be parallel to the signal light.
9. The eyewear defined in claim 1 wherein the coherent light source and the image sensor have different locations.
10. The eyewear defined in claim 1 wherein the image sensor is one of multiple image sensors that detect the signal light and the reference light from the coherent light source.
11. A distance sensor, comprising: first and second emitters, wherein each emitter comprises a first laser that fires a first chirp and a second laser that fires a second chirp after the first chirp; a beam splitter that splits the first and second chirps into signal light and reference light, wherein the signal light travels a free space path length and creates a specular reflection while the reference light travels a fixed reference path length; and an image sensor configured to capture images of the signal light and the reference light of the first and second chirps, wherein a location of the specular reflection is determined based on the first chirp and wherein a difference between the free space path length and the fixed reference path length is determined based on the second chirp.
12. The distance sensor defined in claim 11 wherein the first and second emitters are configured to be active during alternate measurements.
13. The distance sensor defined in claim 11 wherein the image sensor comprises a pixel array and a lens overlapping the pixel array.
14. The distance sensor defined in claim 13 further comprising a phase grating interposed between the lens and the pixel array, wherein the phase grating is configured to create a double image of the specular reflection on the pixel array that indicates whether the free space path length is longer or shorter than the fixed reference path length.
15. The distance sensor defined in claim 13 further comprising a holographic optical element interposed between the lens and the pixel array, wherein the holographic optical element is configured to redirect the reference light to be parallel to the signal light.
16. A head-mounted device, comprising: a display configured to present an image; a lens through which the image is viewable from an eye box; image sensors distributed around a periphery of the display; and first and second emitters configured to emit coherent infrared light that is split into signal light headed toward the eye box and reference light headed toward the image sensors, wherein the signal light is specularly reflected at the eye box and wherein the specularly reflected signal light combines with the reference light and creates a corresponding interference pattern that is captured by the image sensors and used to determine eye distance.
17. The head-mounted device defined in claim 16 wherein each of the first and second emitters comprises at least first and second lasers, the head-mounted device further comprising first optical fibers that guide the reference light from the first and second lasers to the image sensors and second optical fibers that guide the signal light from the first and second lasers to respective exit apertures facing the eye box.
18. The head-mounted device defined in claim 16 wherein the image sensors each comprise an array of pixels, wherein the first laser is configured to fire a first chirp of the coherent infrared light and the second laser is configured to fire a second chirp of the coherent infrared light after the first chirp, wherein the first chirp is used to identify a portion of the array of pixels that includes a glint created by the specularly reflected signal light, and wherein the second chirp is used to determine the eye distance.
19. The head-mounted device defined in claim 18 wherein only the portion of the array of pixels that includes the glint is read out for processing the second chirp.
20. The head-mounted device defined in claim 16 wherein at least one of the image sensors

comprises: a pixel array; a lens overlapping the pixel array; a phase grating interposed between the pixel array and the lens; and a holographic optical element interposed between the phase grating and the pixel array.