US 20170246070A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2017/0246070 A1

Osterhout et al. (43) Pub. Date: Aug. 31, 2017

(54) **RADAR IMAGERY IN HEAD-WORN COMPUTING**

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(21) Appl. No.: **15/063,714**

(22) Filed: **Mar. 8, 2016**

Related U.S. Application Data

(63) Continuation of application No. 15/056,573, filed on Feb. 29, 2016.

Publication Classification

(51) **Int. Cl.**

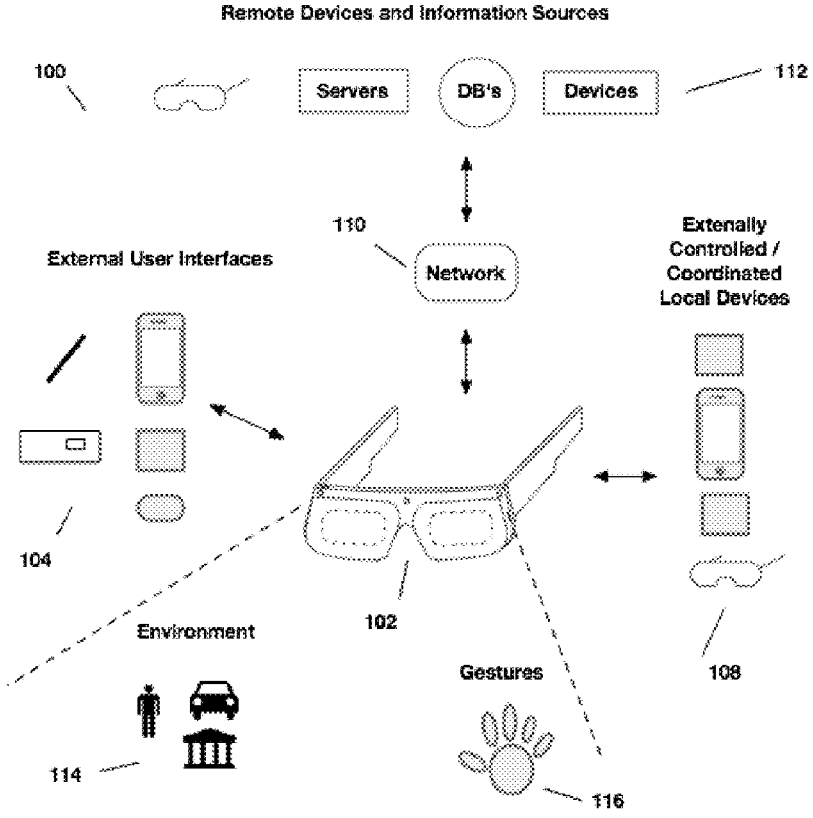
A61H 3/06	(2006.01)
G02B 27/01	(2006.01)
H04N 5/232	(2006.01)
G06F 3/00	(2006.01)
H04N 5/33	(2006.01)
G06F 3/01	(2006.01)

(52) **U.S. Cl.**

CPC ***A61H 3/061*** (2013.01); ***H04N 5/332*** (2013.01); ***G06F 3/012*** (2013.01); ***G06F 3/013*** (2013.01); ***G06F 3/017*** (2013.01); ***H04N 5/23296*** (2013.01); ***H04N 5/23264*** (2013.01); ***G06F 3/005*** (2013.01); ***G02B 27/0101*** (2013.01); ***G02B 27/0149*** (2013.01); ***G02B 27/0172*** (2013.01); *G02B 2027/0127* (2013.01); *G02B 2027/0138* (2013.01); *G02B 2027/014* (2013.01); *G02B 2027/0156* (2013.01); *G02B 2027/0178* (2013.01)

(57) **ABSTRACT**

Aspects of the present disclosure relate aids for the visually impaired. An apparatus to assist a visually impaired person in navigating an environment includes a head-worn computer, a radar system mounted on the head-worn computer and positioned to measure distances to objects in the environment within an angular field in front of the visually impaired person wearing the head-worn computer, and a processor adapted to process the measured distances from the radar system and to identify objects in the environment that are within the angular field in front of the visually impaired person. The processor is further adapted to generate feedback cues to the visually impaired person in correspondence to the measured distances within the angular field in front of the visually impaired person as the visually impaired person moves his head from side to side while navigating the environment.



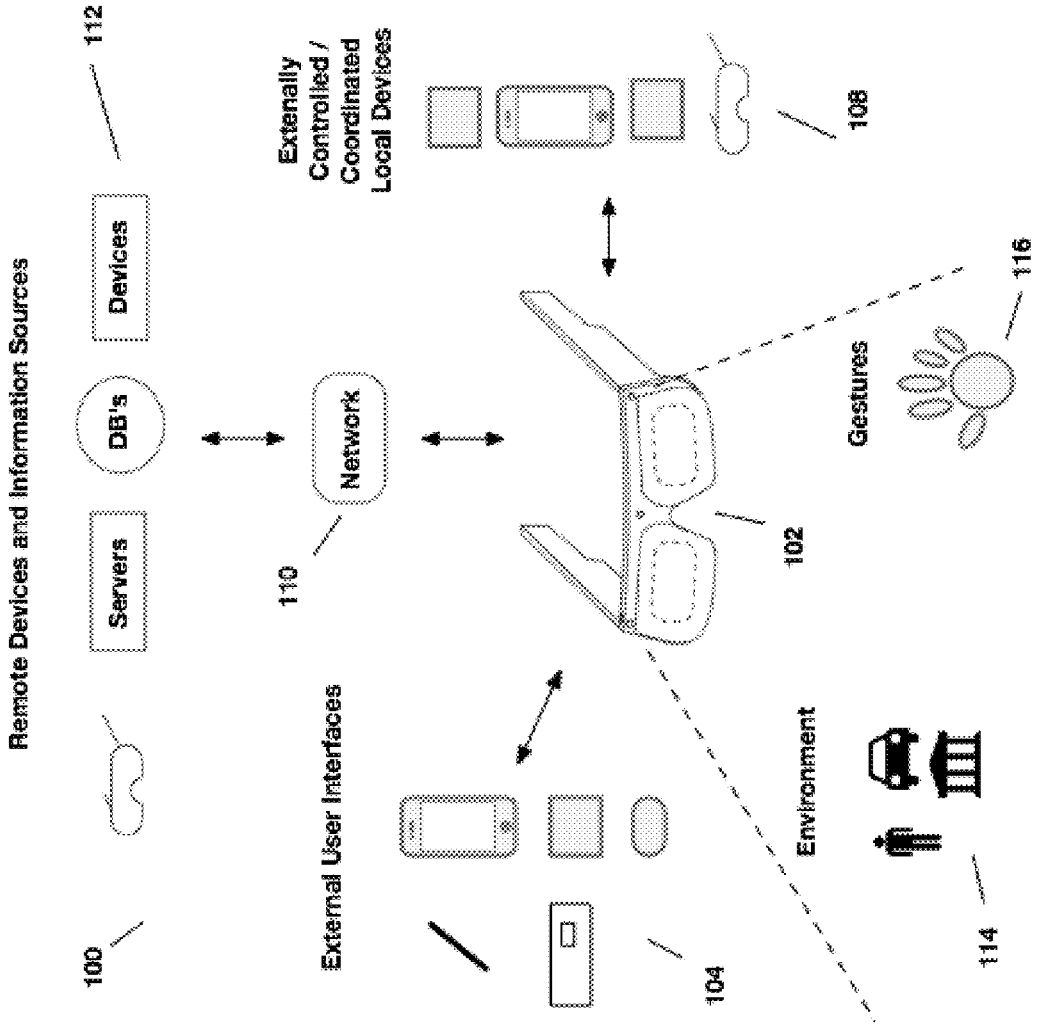

Remote Devices and Information Sources
100
Servers
DB's
Devices
112
Network
110
Externally Controlled / Coordinated Local Devices
108
External User Interfaces
104
102
Gestures
116
Environment
114

Figure 1

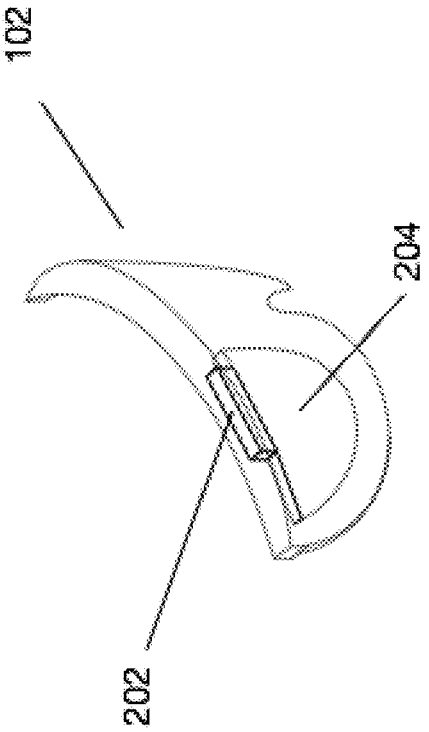


Figure 2

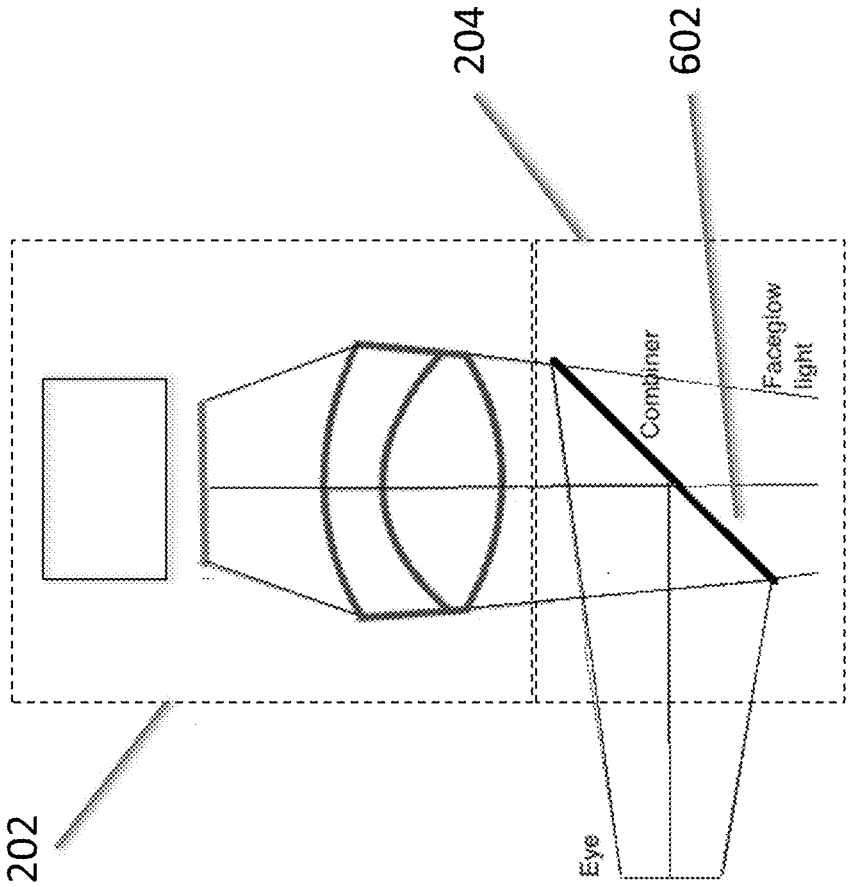


Figure 3

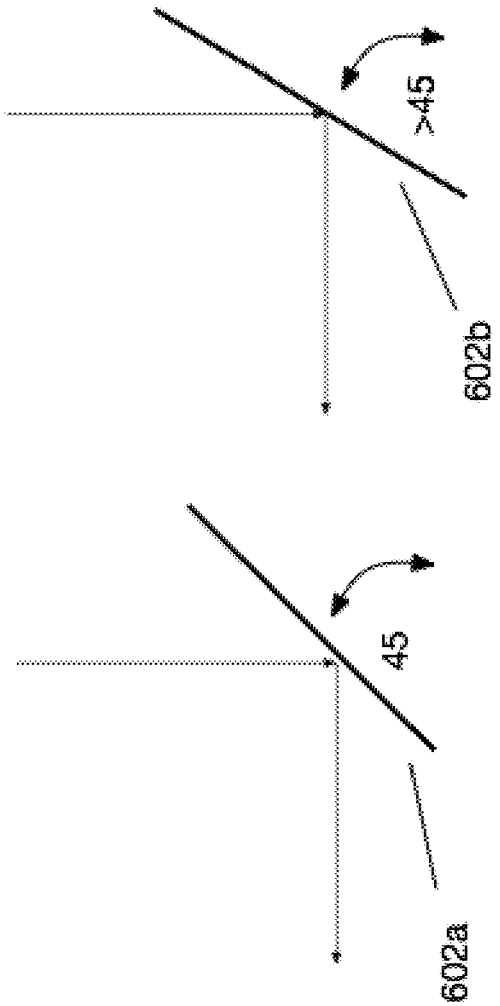


Figure 4

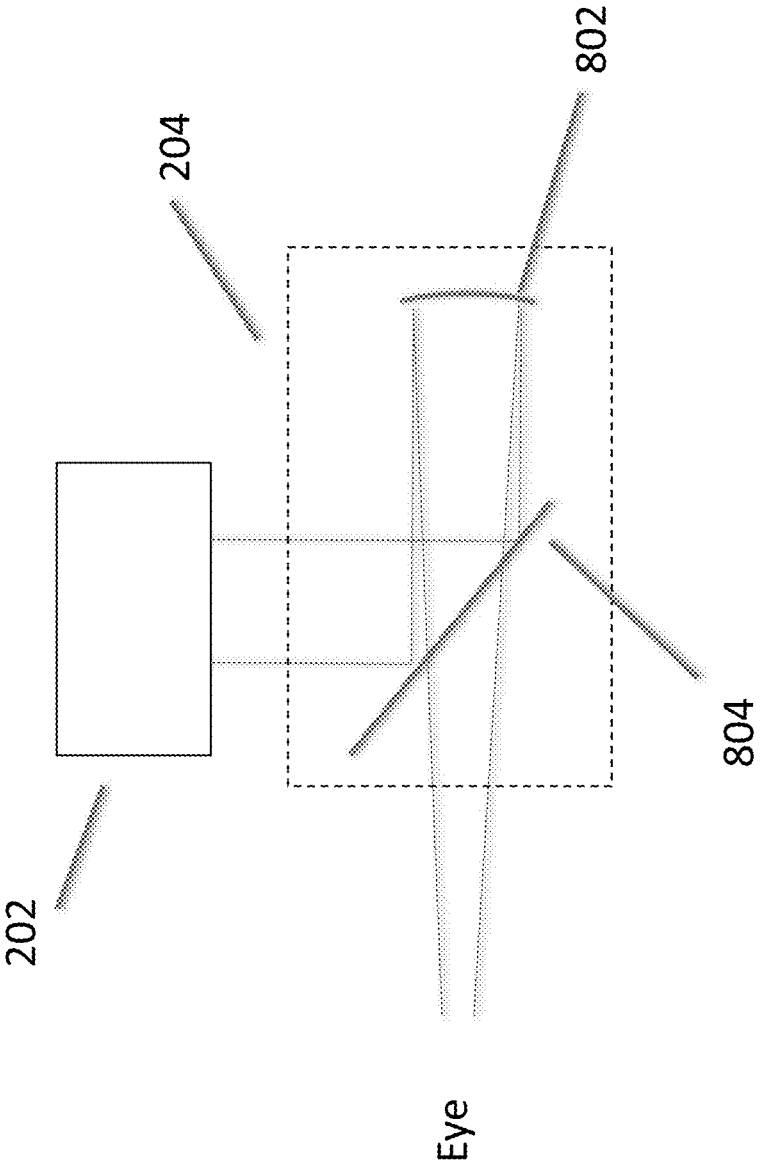


Figure 5

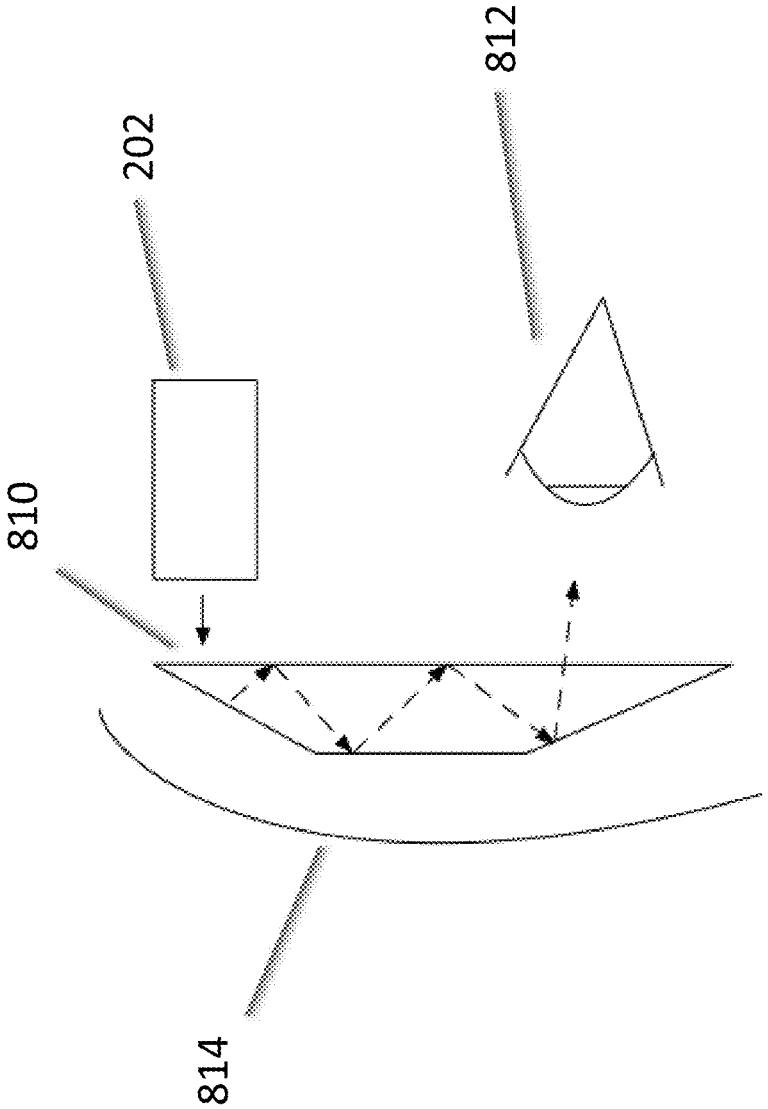


Figure 6

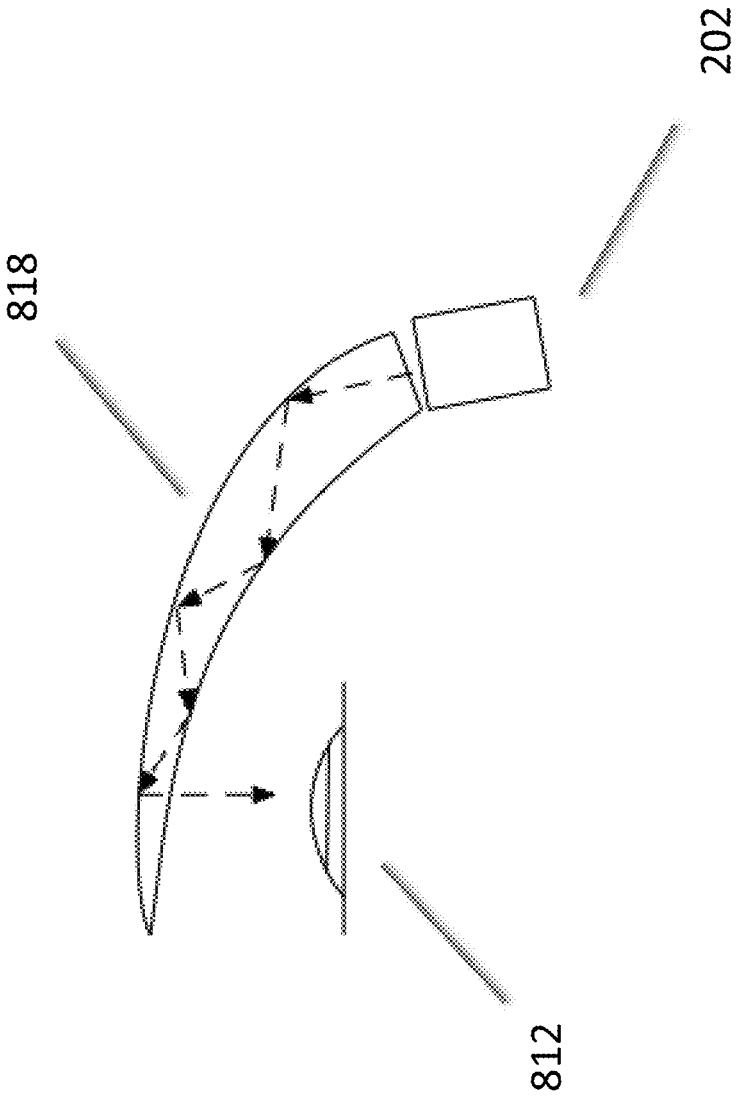


Figure 7

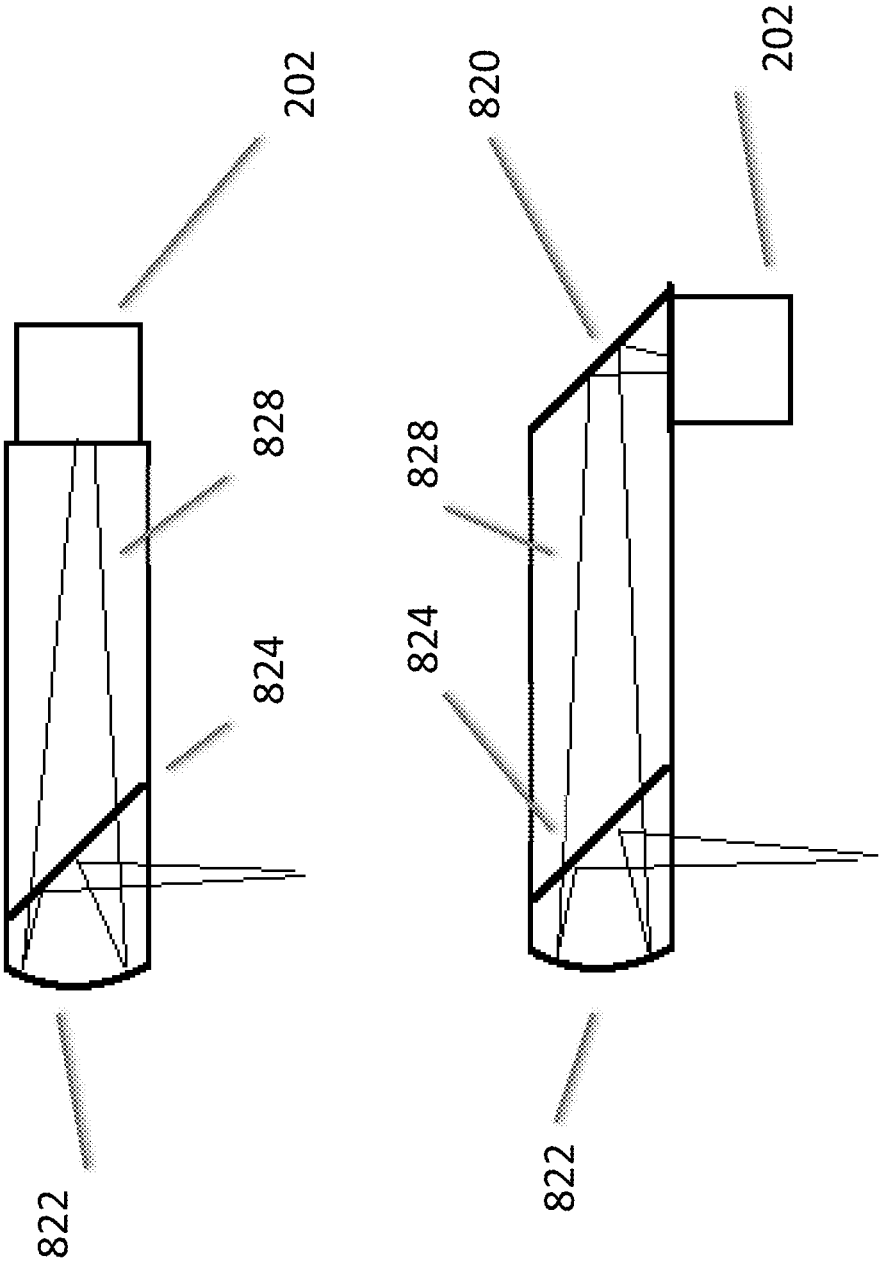


Figure 8

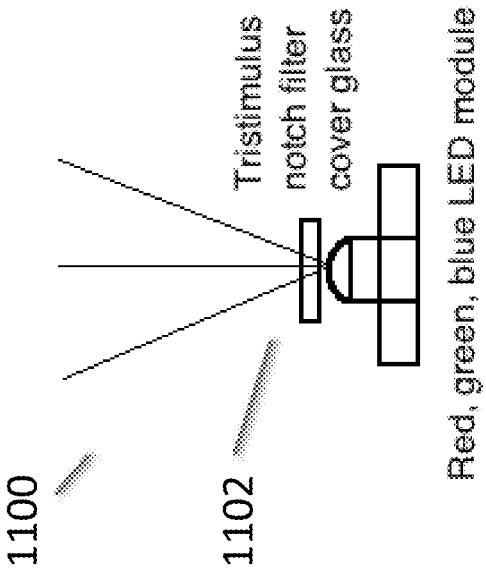

1100
1102
Tristimulus
notch filter
cover glass
Red, green, blue LED module

Figure 9

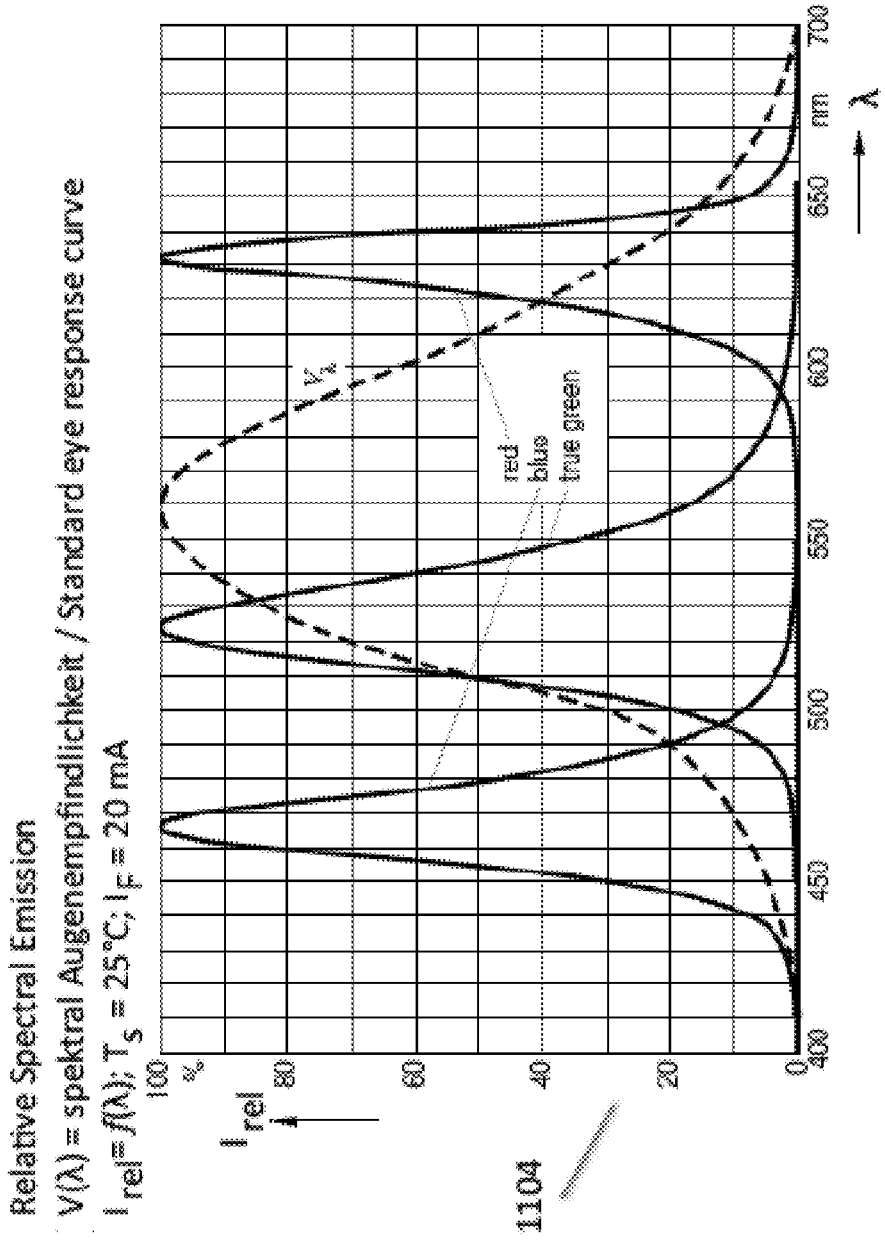

Relative Spectral Emission
V(λ) = spektral Augenempfindlichkeit / Standard eye response curve
I rel = f(λ); T S = 25°C; I F = 20 mA
1104
I rel
%
100
80
60
40
20
0
400
450
500
550
600
650
700
nm
λ
V λ
red
blue
true green

Figure 10a

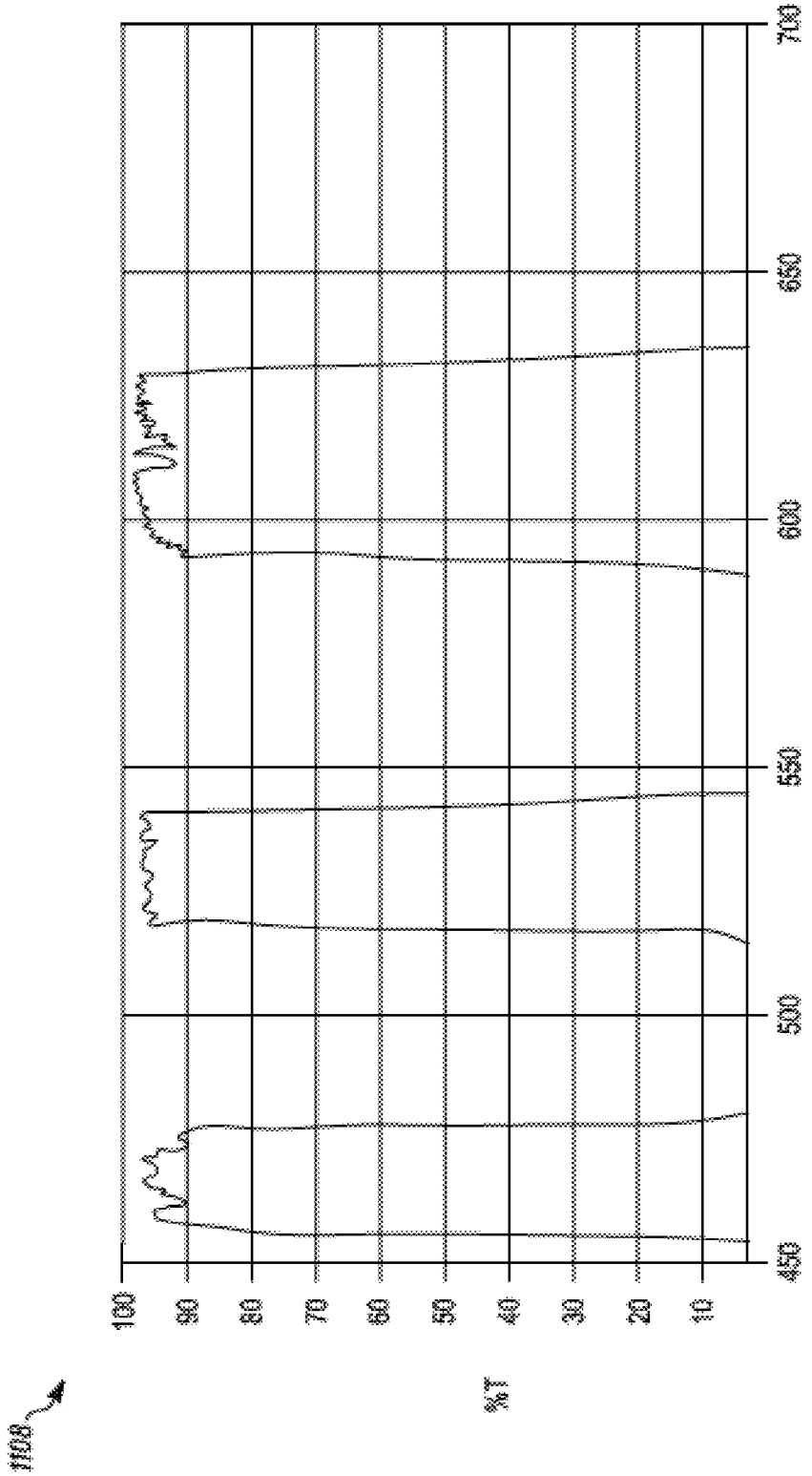


Figure 10b

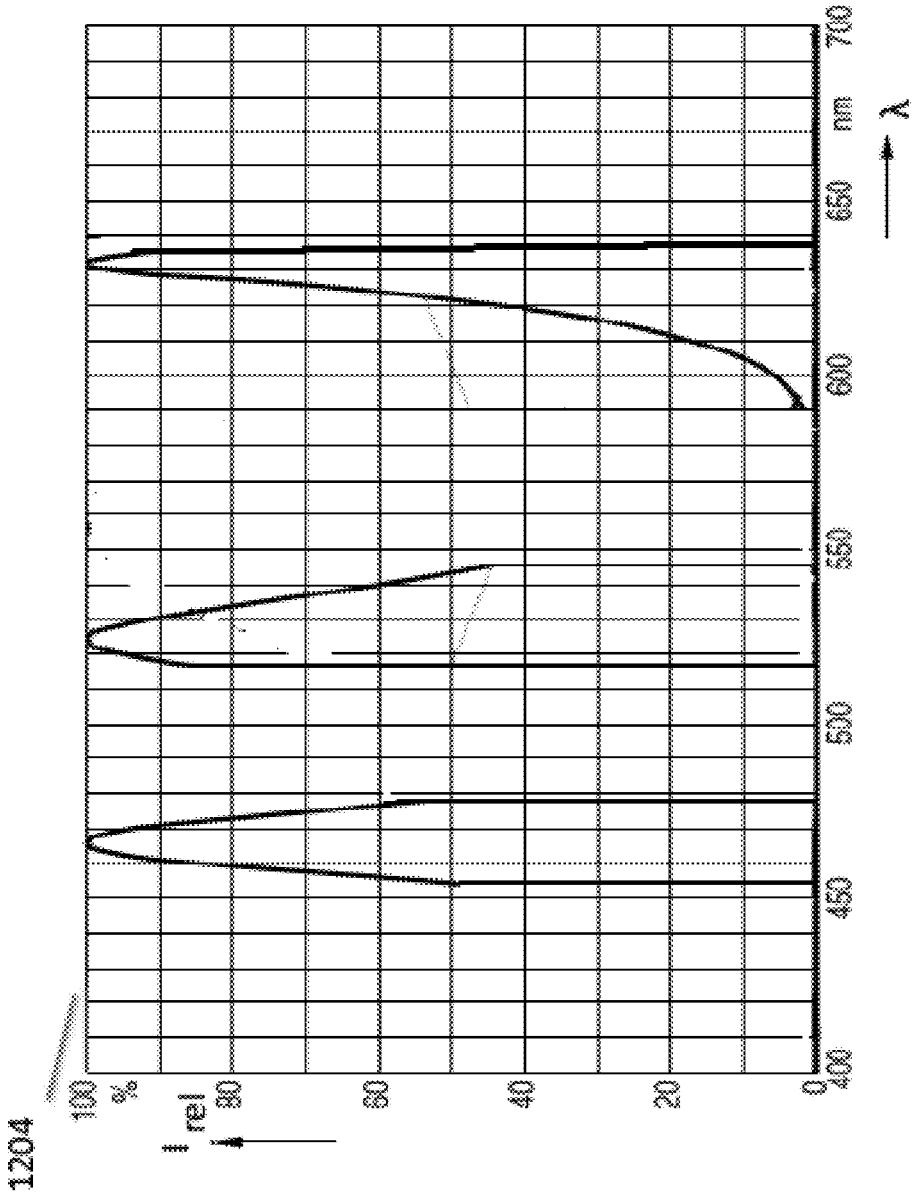


Figure 11

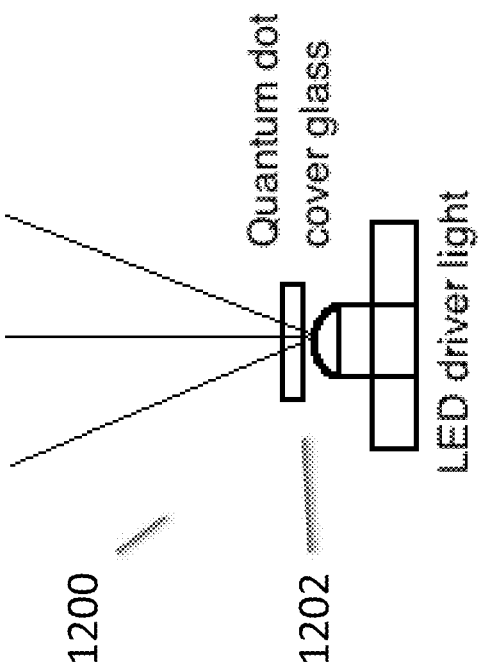


Figure 12a

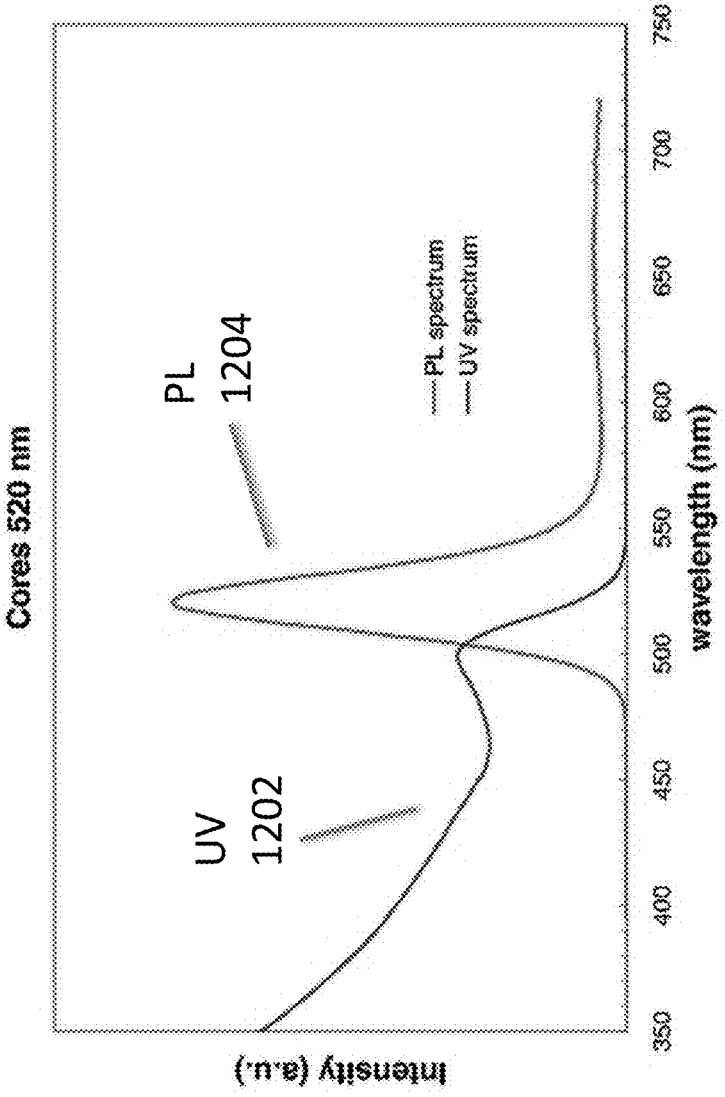

Cores 520 nm
PL
1204
UV
1202
PL spectrum
UV spectrum
Intensity (a.u.)
wavelength (nm)
350
400
450
500
550
600
650
700
750

Figure 12b

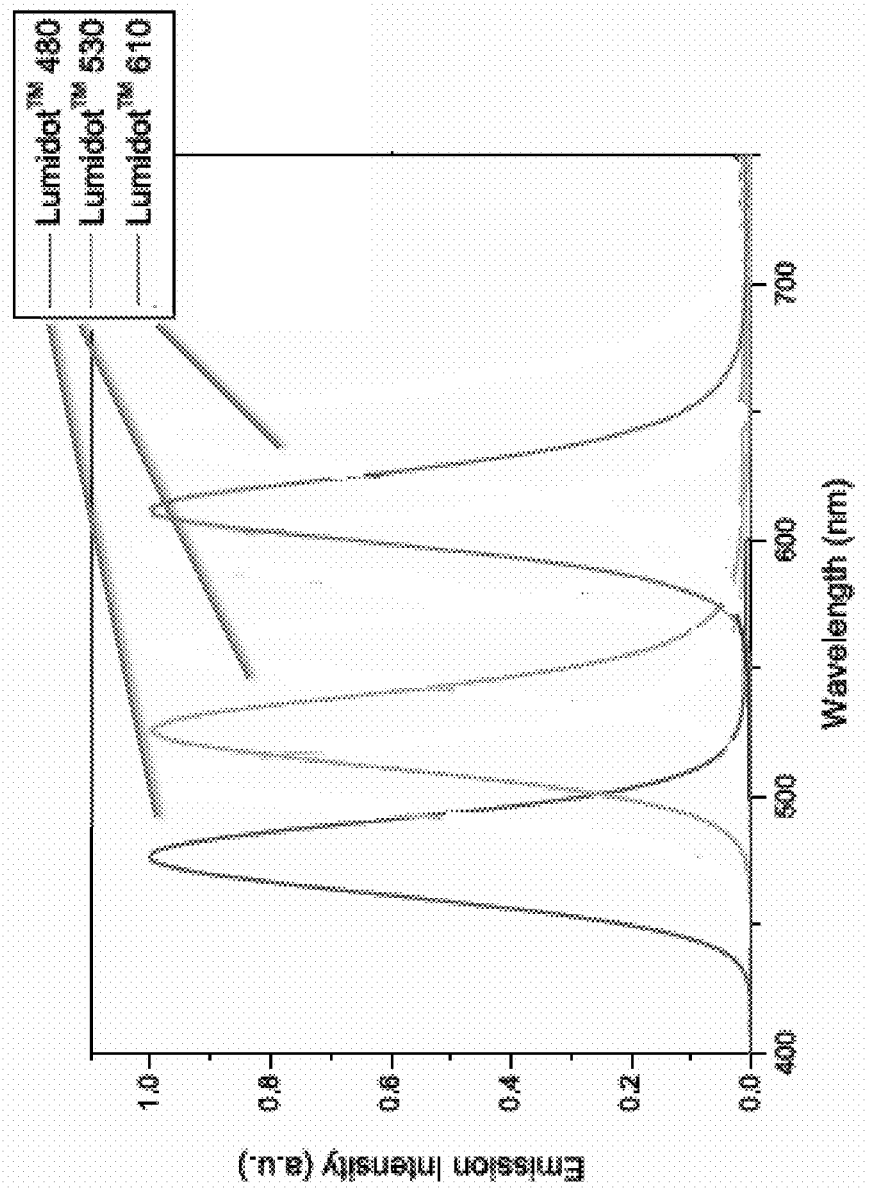

Lumidot™ 480
Lumidot™ 530
Lumidot™ 610
Emission Intensity (a.u.)
0.0
0.2
0.4
0.6
0.8
1.0
400
500
600
700
Wavelength (nm)

Figure 12c

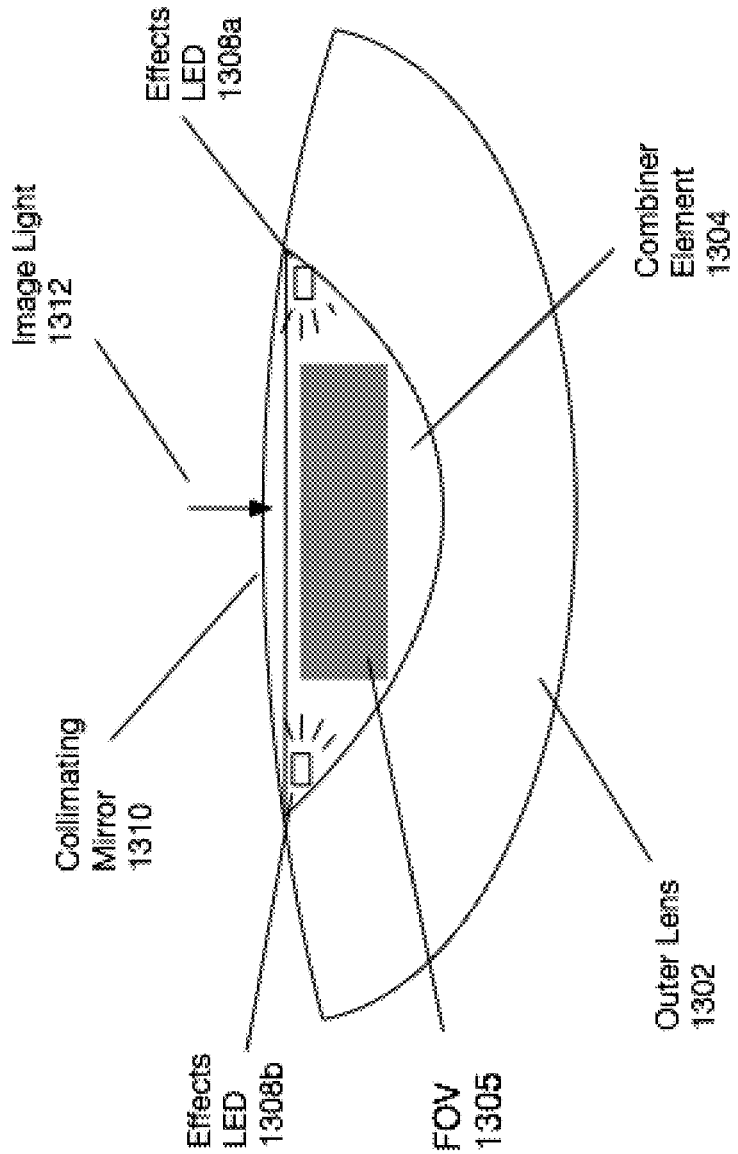

Effects LED 1308a
Image Light 1312
Combiner Element 1304
Collimating Mirror 1310
Effects LED 1308b
FOV 1305
Outer Lens 1302

Figure 13a

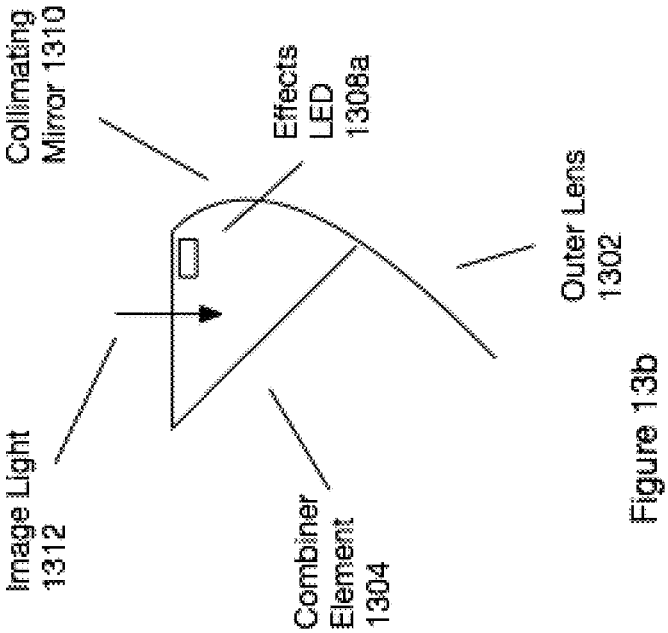

Collimating Mirror 1310
Effects LED 1308a
Outer Lens 1302
Image Light 1312
Combiner Element 1304

Figure 13b

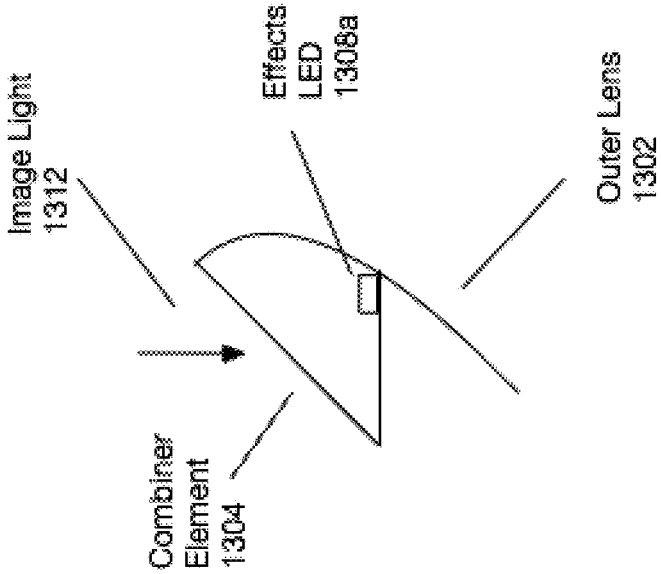

Image Light
1312
Effects
LED
1308a
Outer Lens
1302
Combiner
Element
1304

Figure 13c

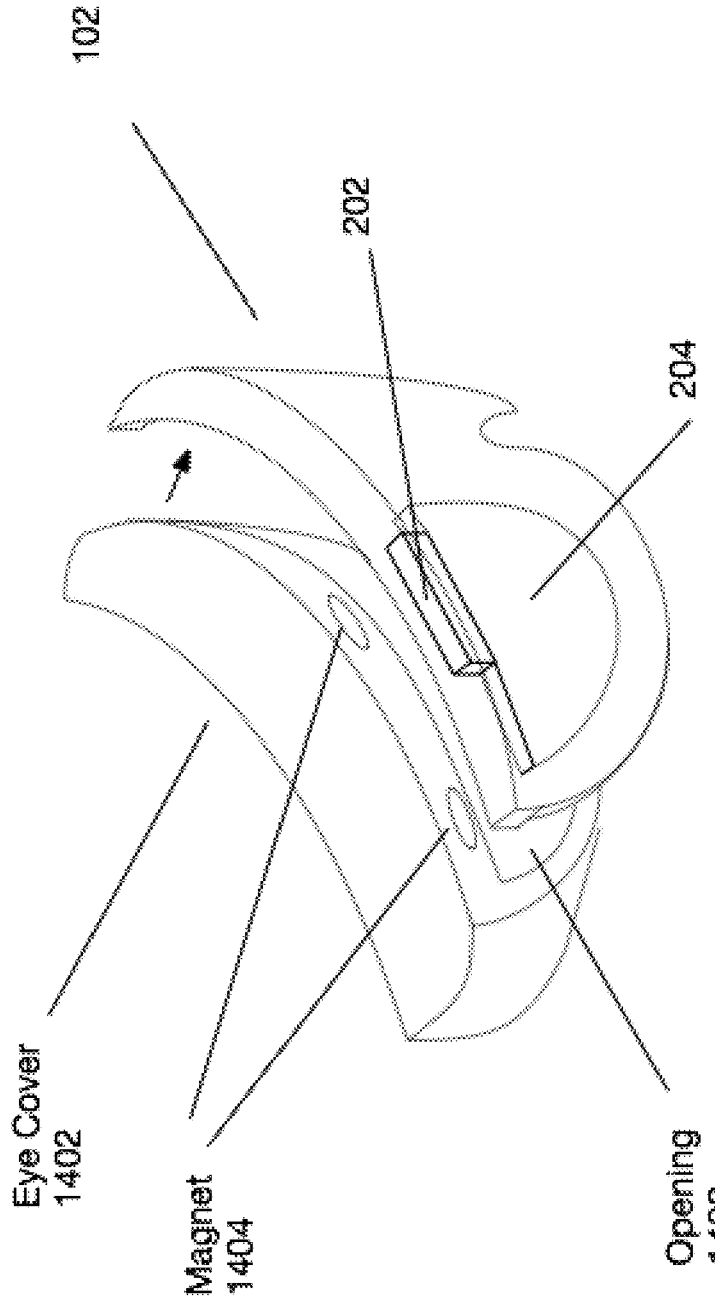


Figure 14a

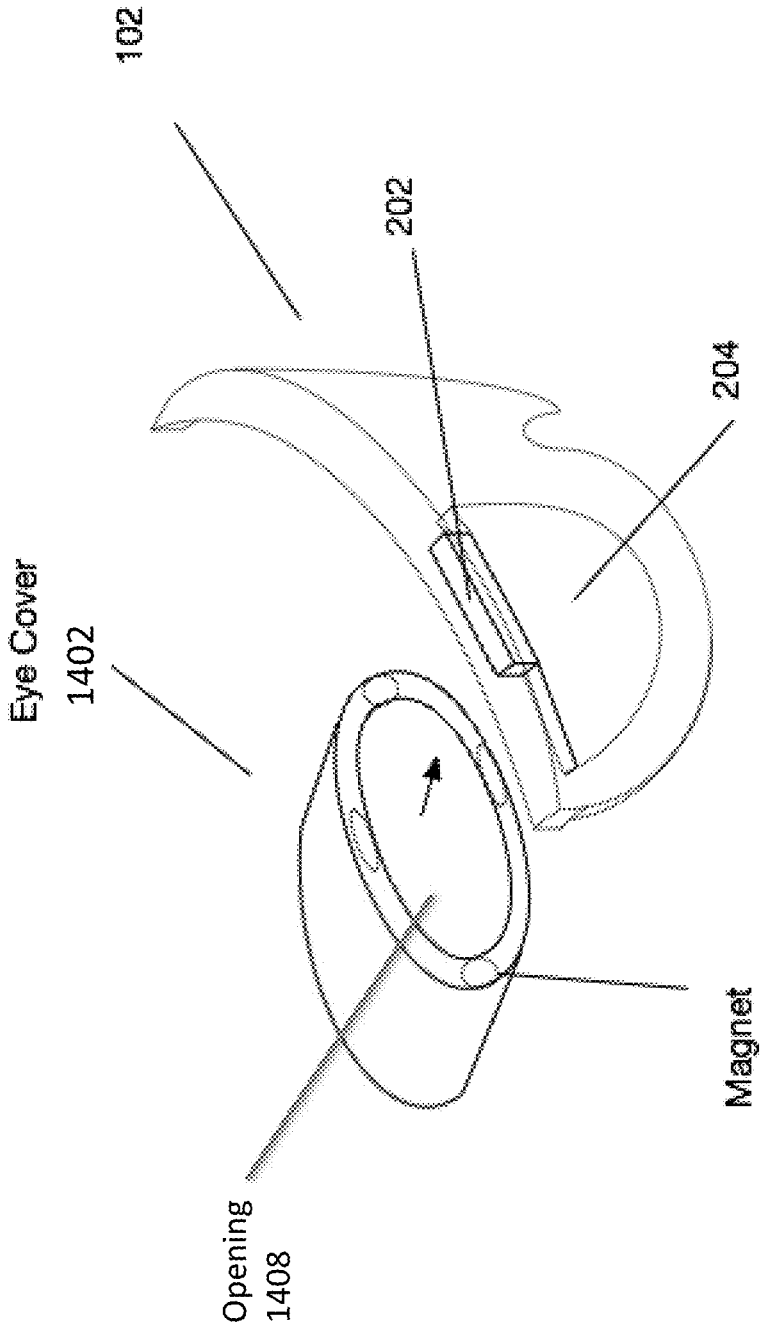


Figure 14b

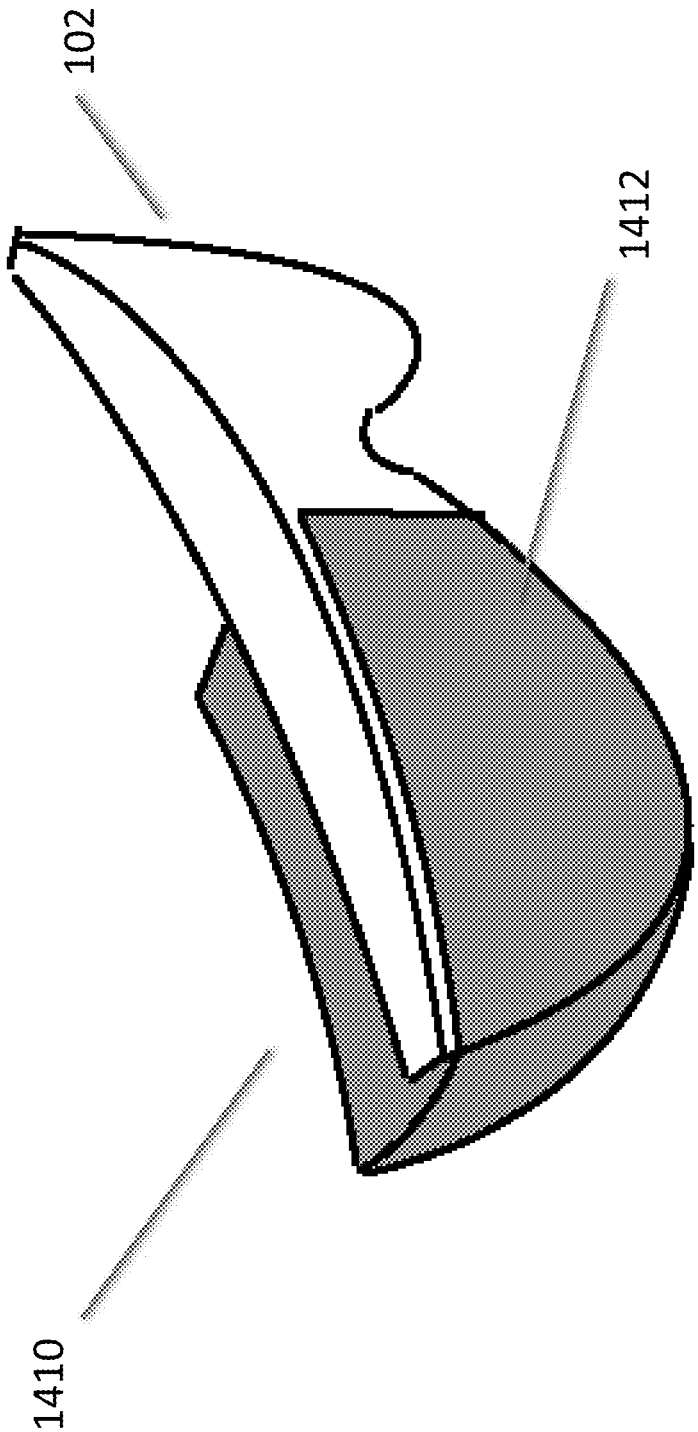


Figure 14c

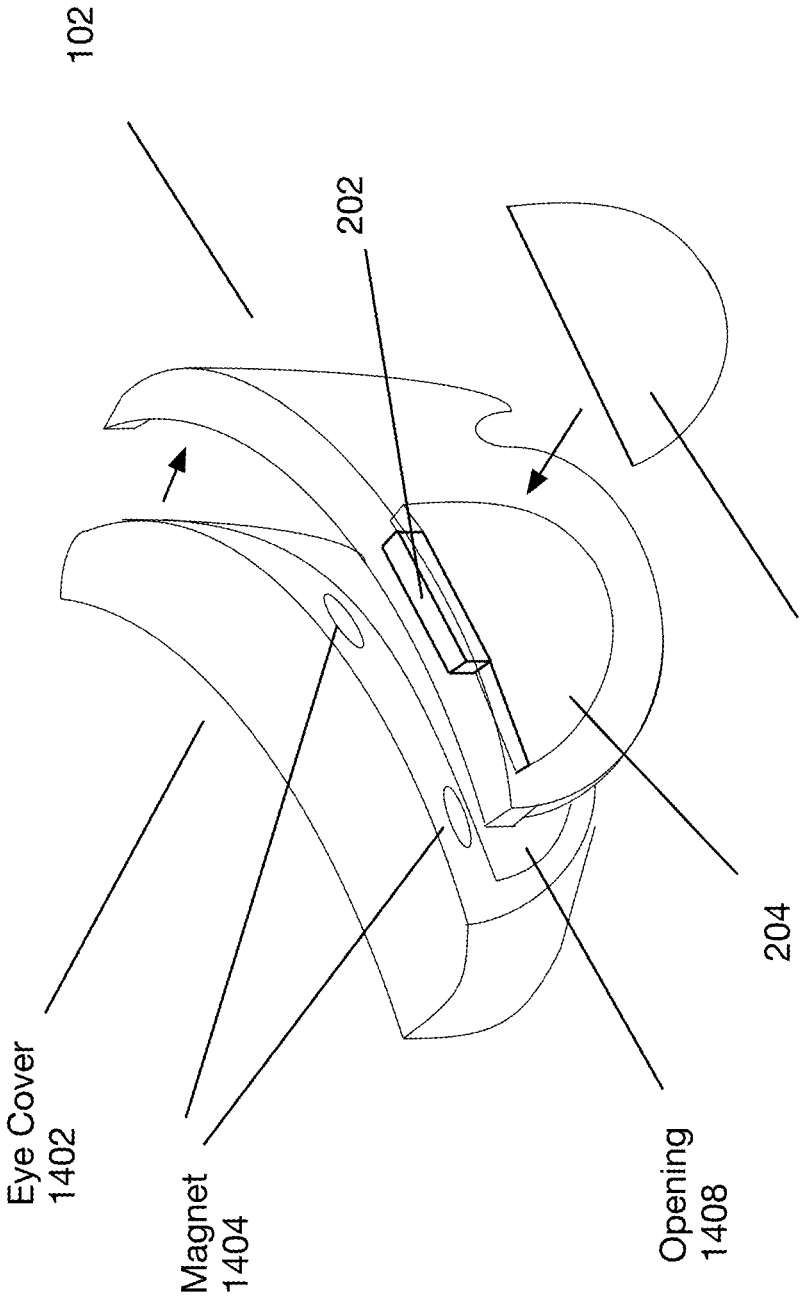

102
202
Eye Cover
1402
Magnet
1404
Opening
1408
204
Removable
Outer Lens
1414

Figure 14d

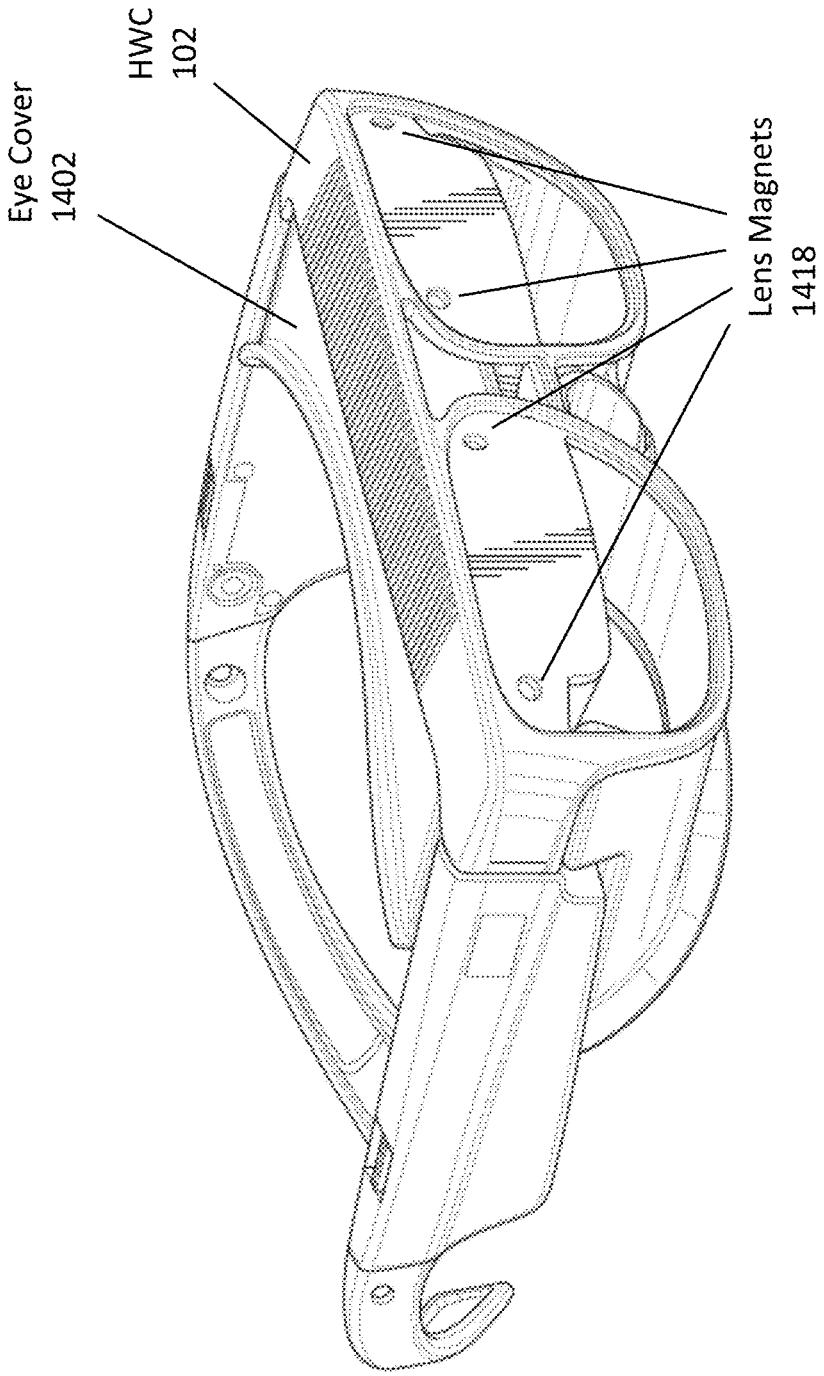


Figure 14e

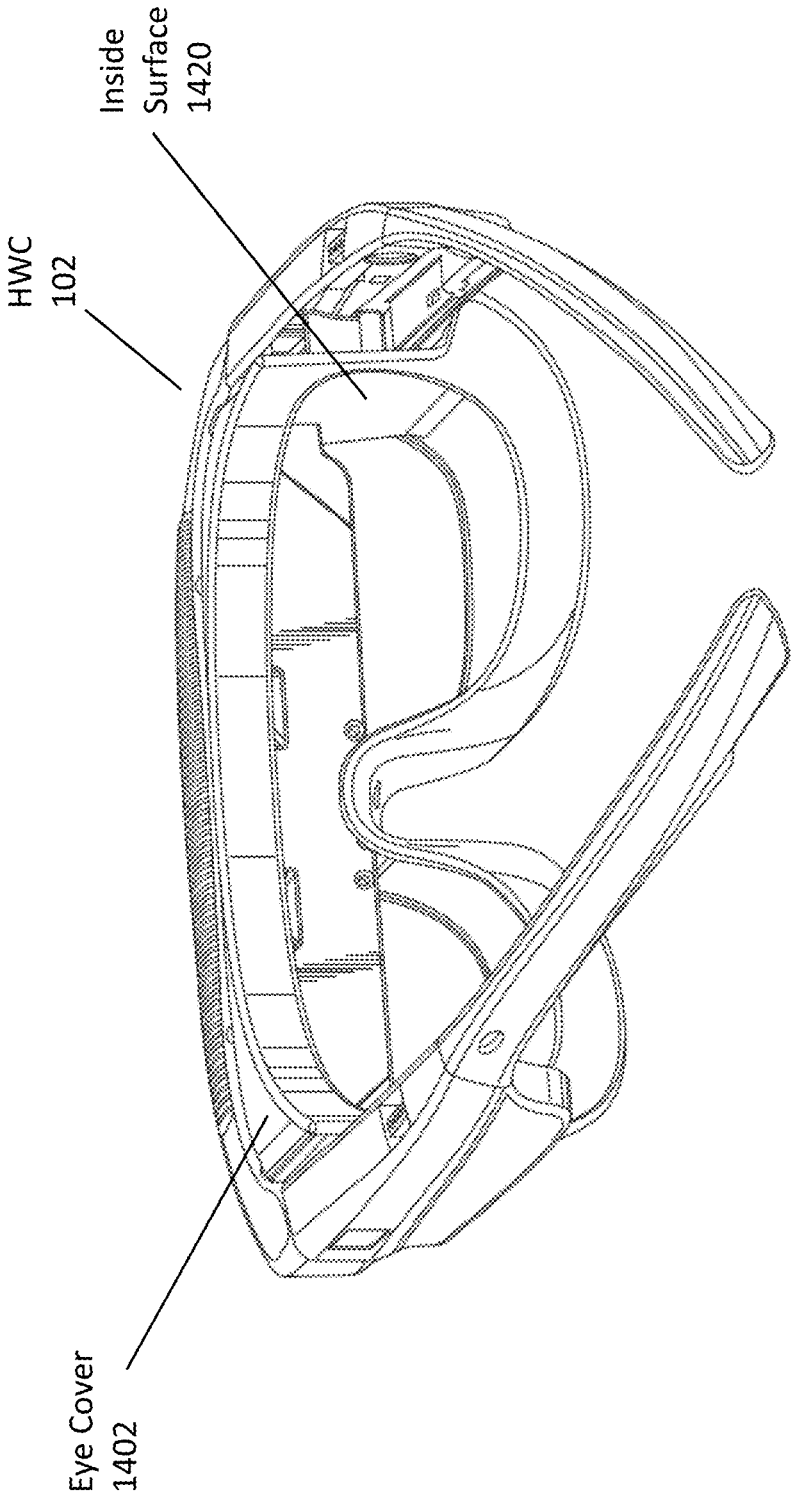


Figure 14f

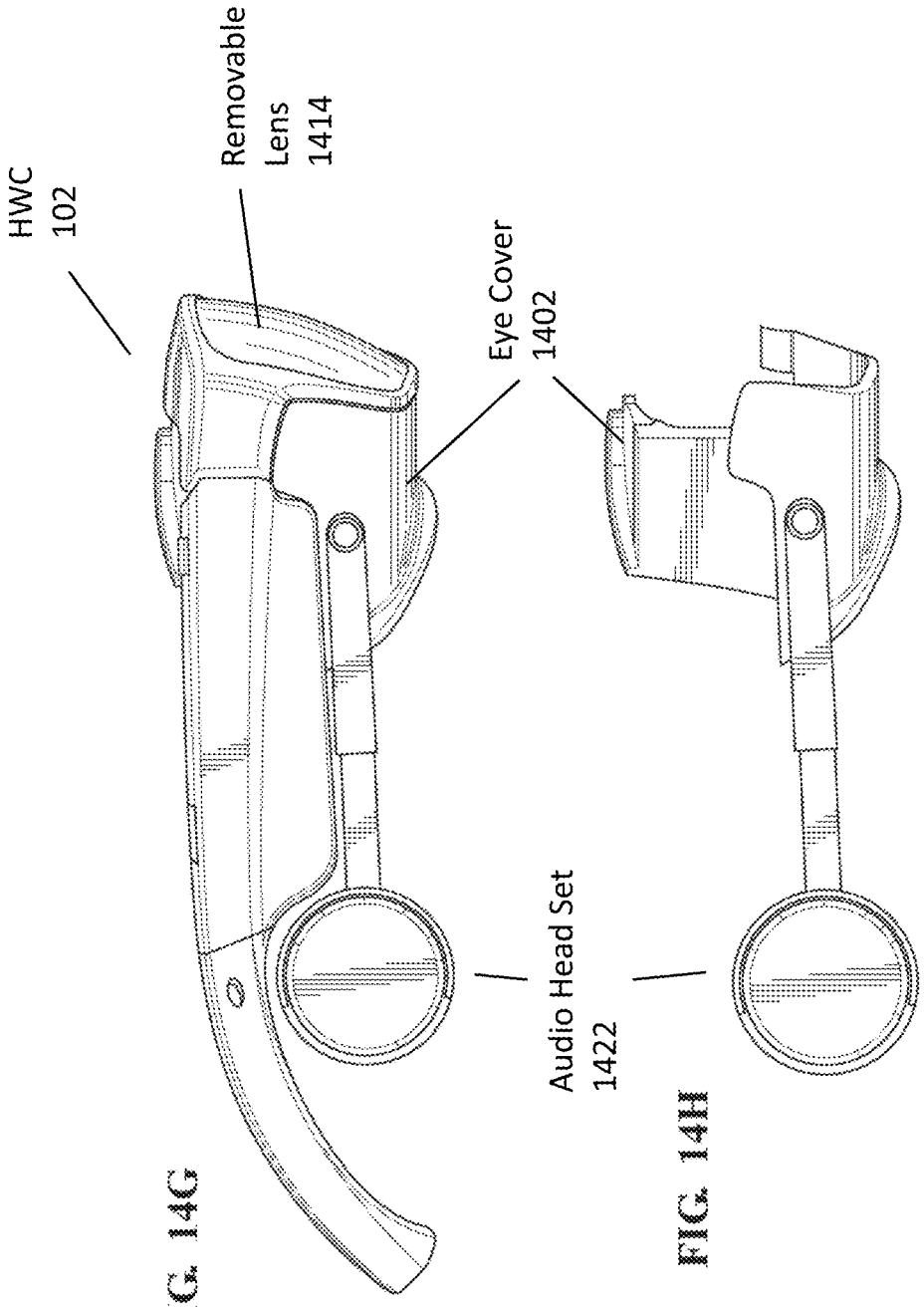


FIG. 14G

FIG. 14H

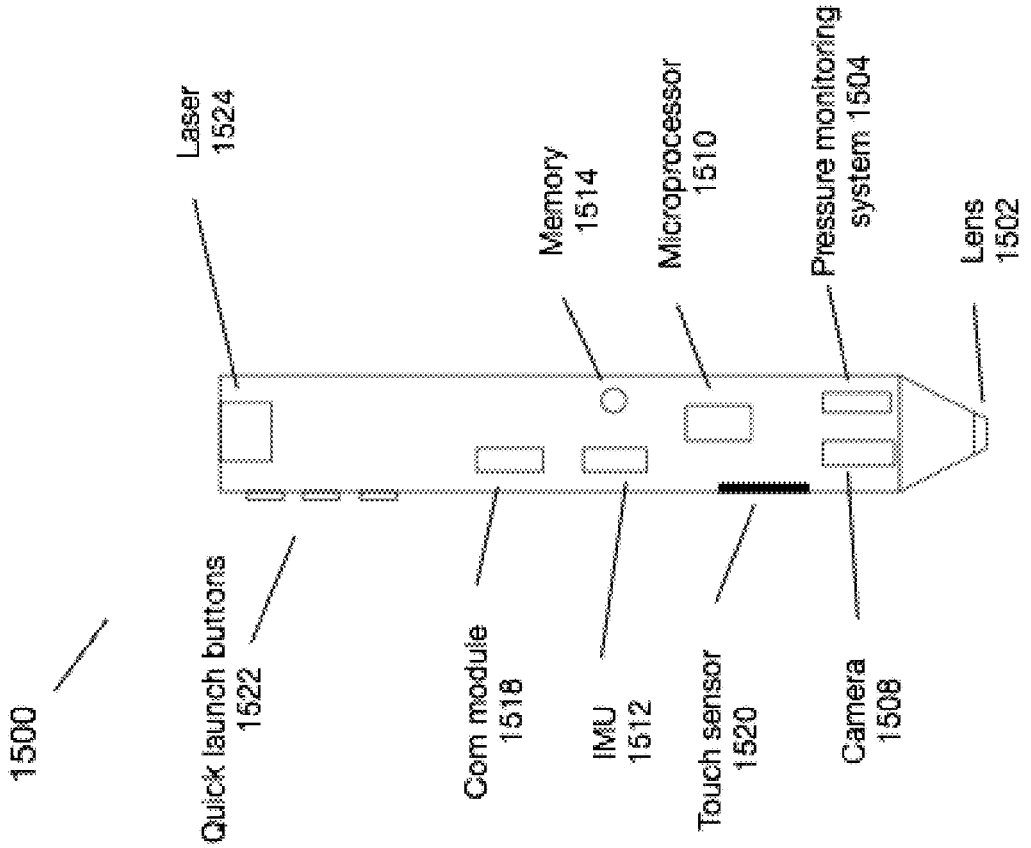
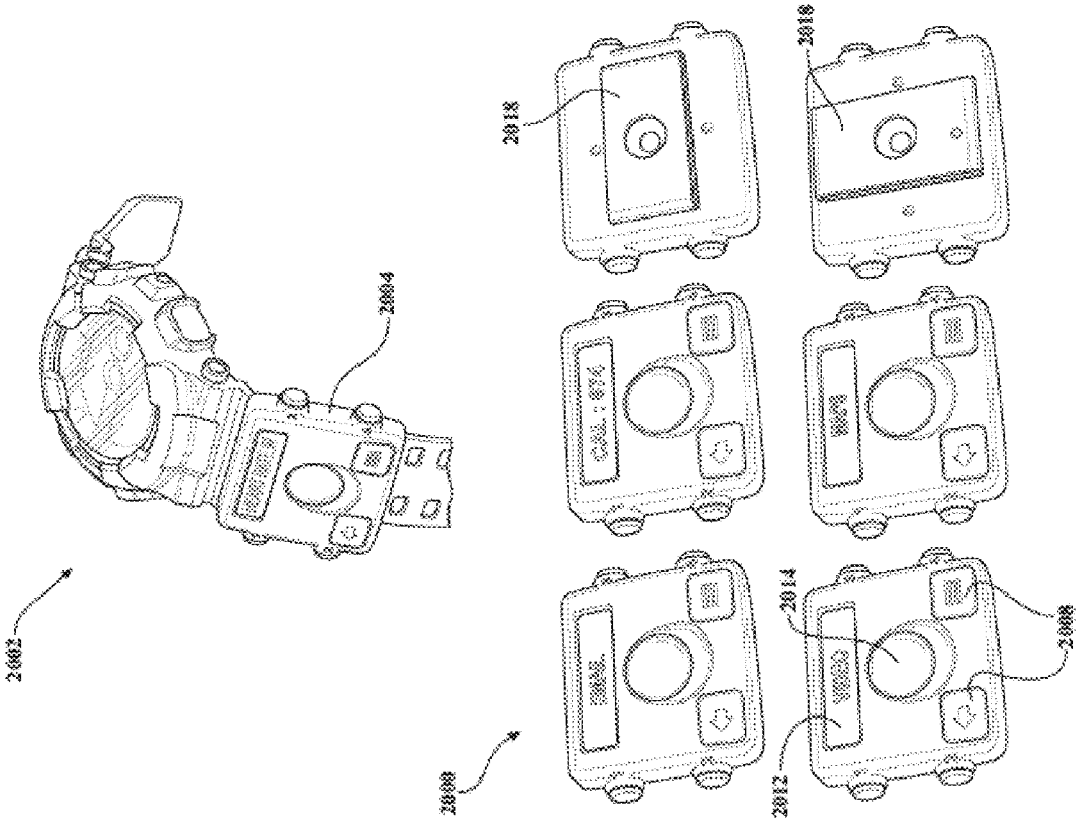

1500
Quick launch buttons 1522
Com module 1518
IMU 1512
Touch sensor 1520
Camera 1508
Laser 1524
Memory 1514
Microprocessor 1510
Pressure monitoring system 1504
Lens 1502

Figure 15

Fig. 16



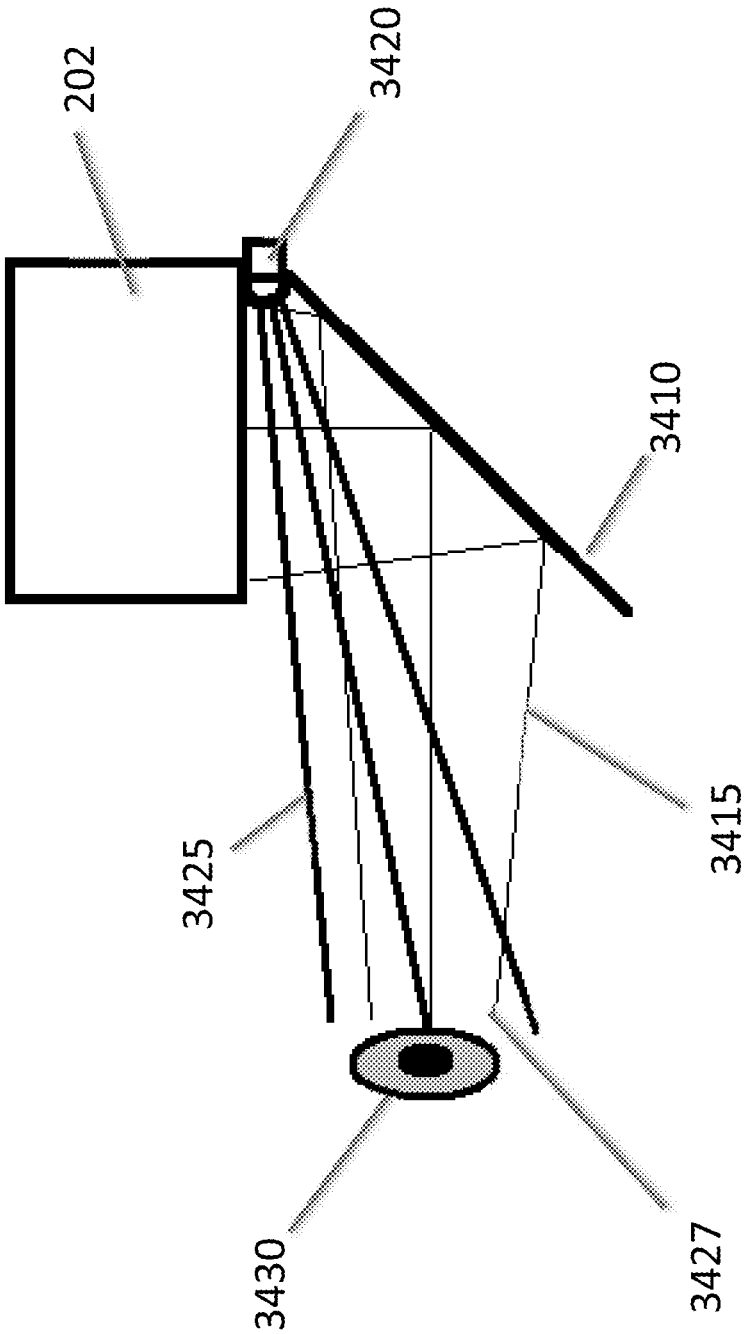


Figure 17

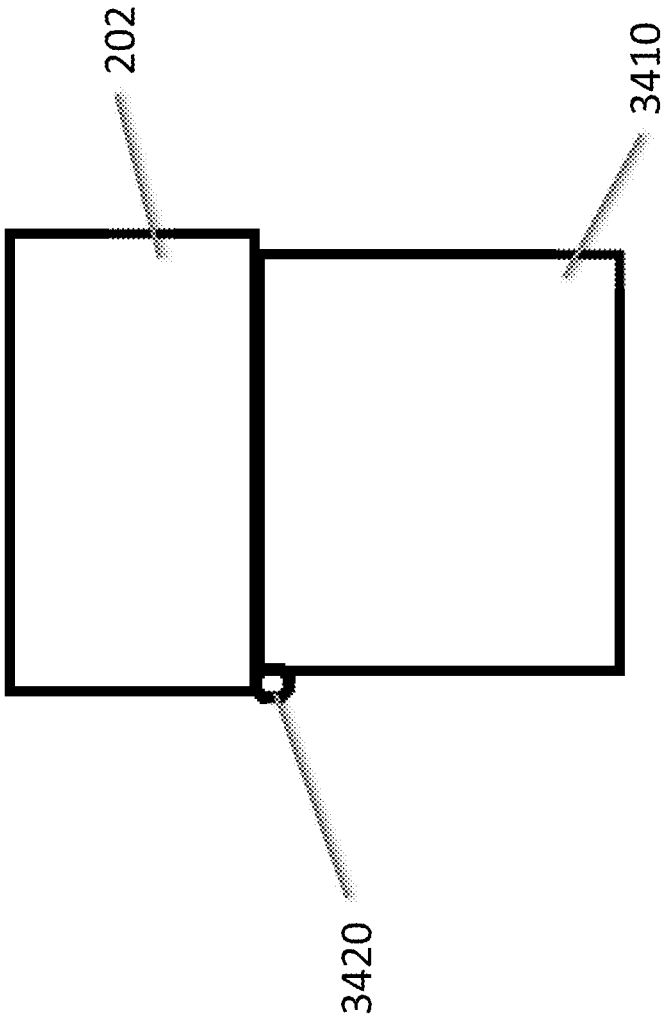


Figure 18

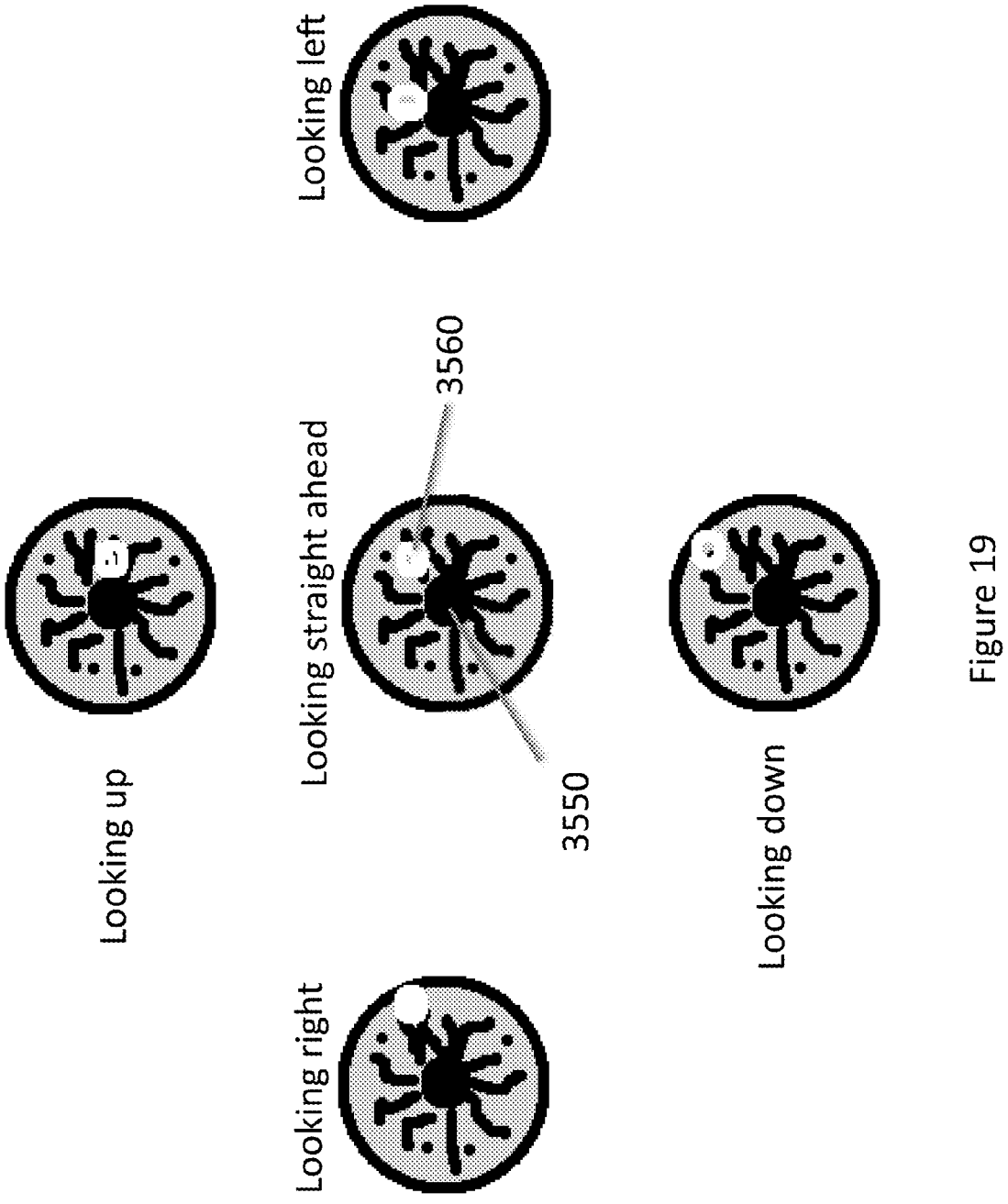

Looking left
Looking up
Looking straight ahead
3560
3550
Looking down
Looking right

Figure 19

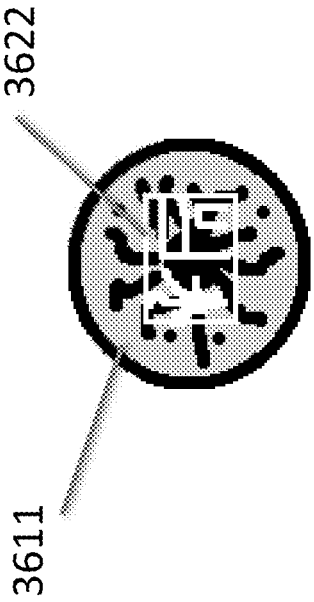


Figure 20b

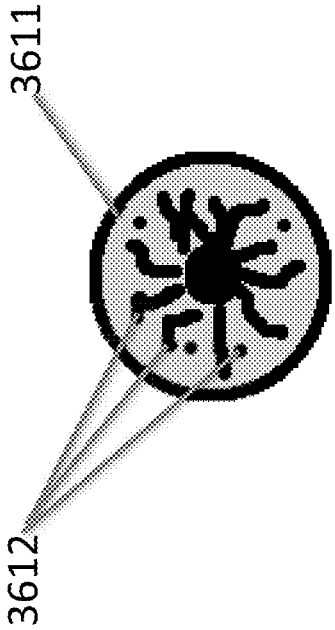


Figure 20a

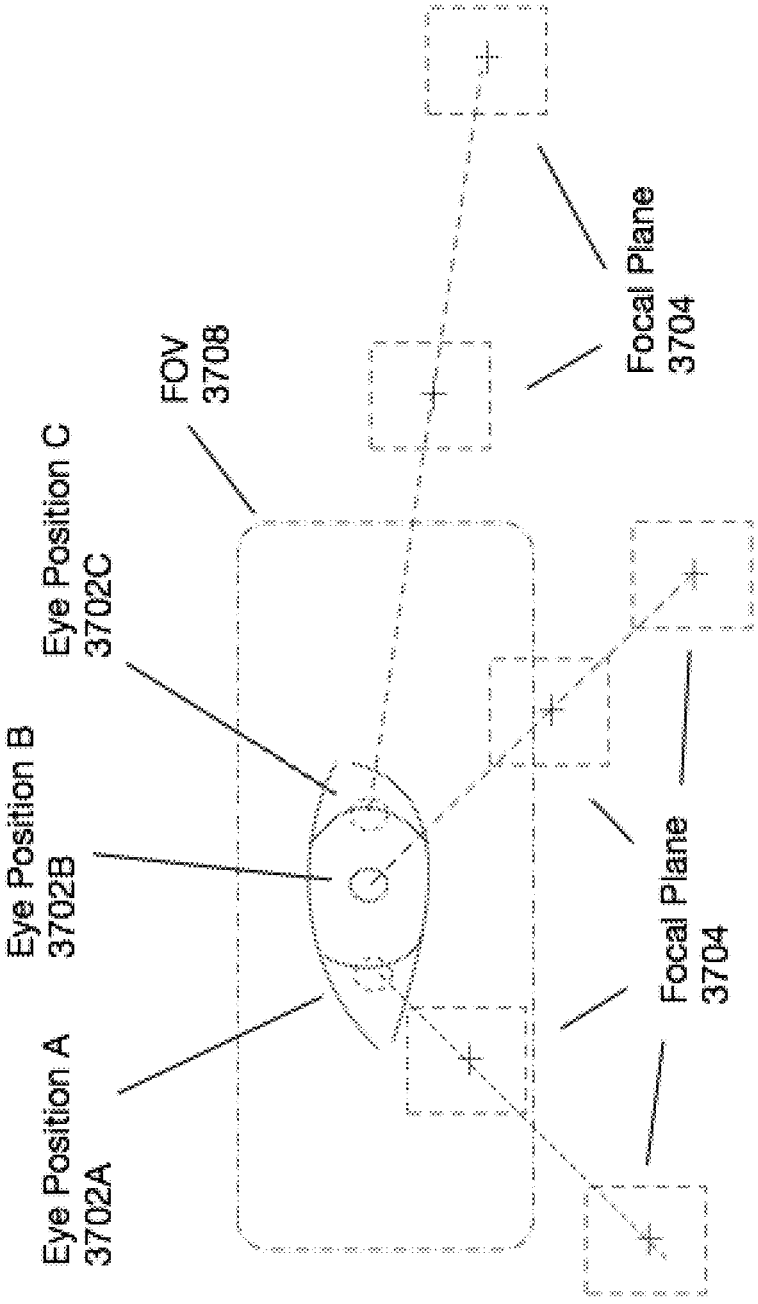

Eye Position A
3702A
Eye Position B
3702B
Eye Position C
3702C
FOV
3708
Focal Plane
3704
Focal Plane
3704

Figure 21

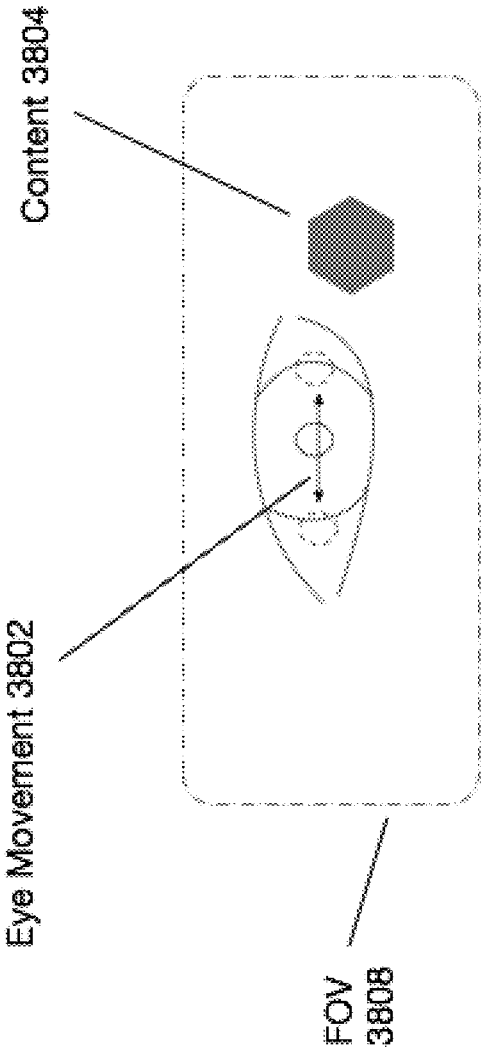


Figure 22

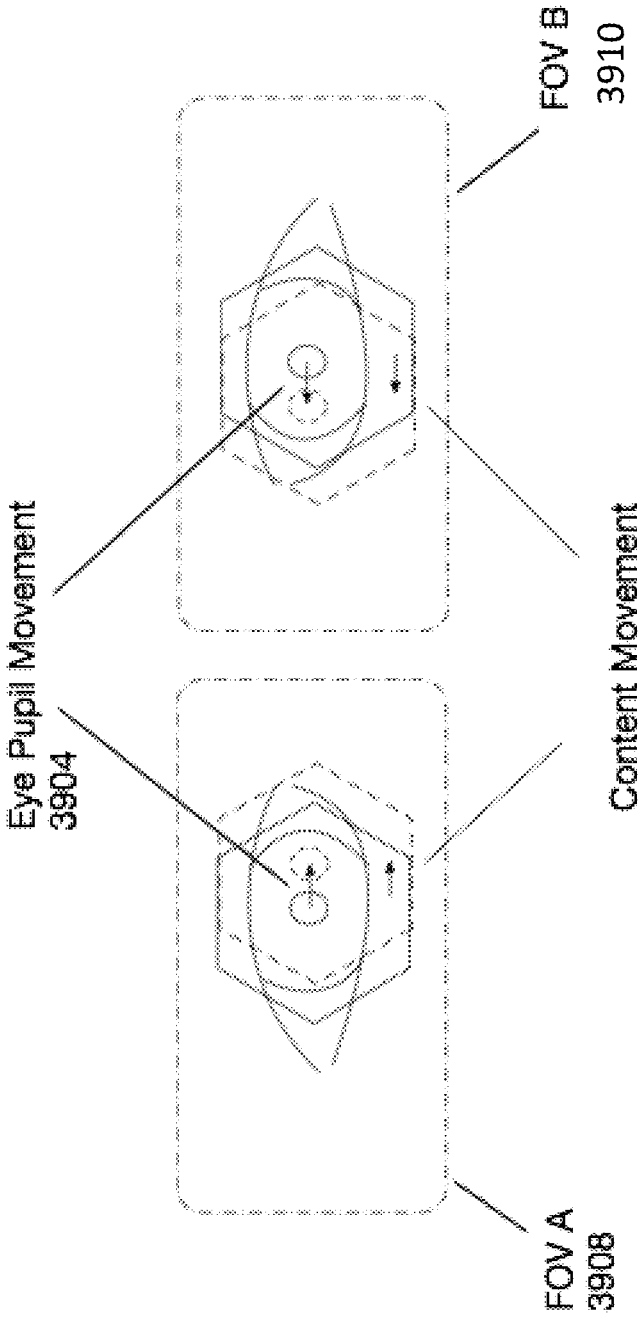

FOV B
3910
Eye Pupil Movement
3904
Content Movement
3902
FOV A
3908

Figure 23

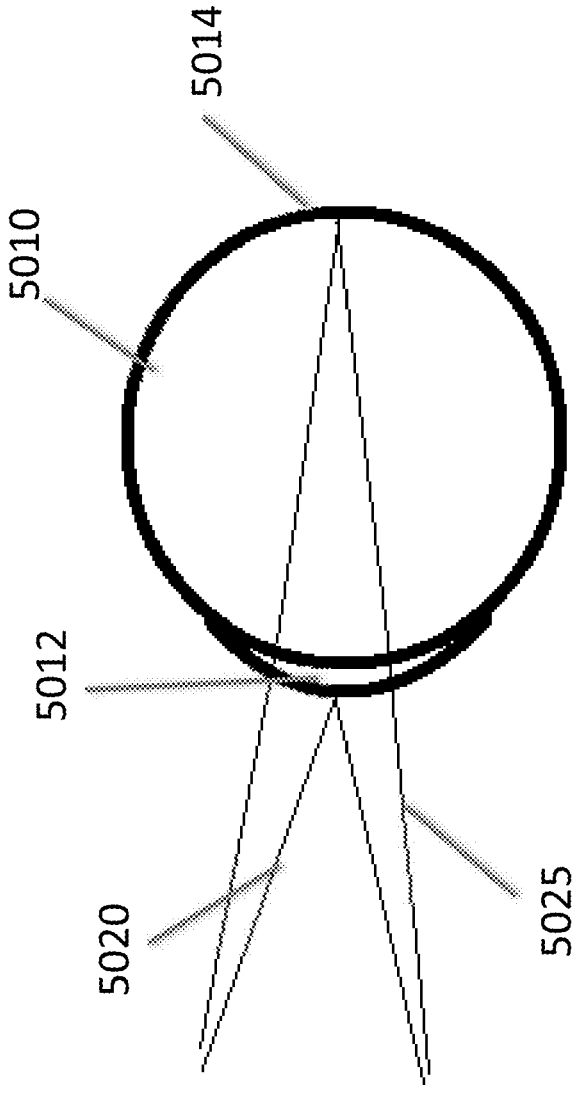


Figure 24

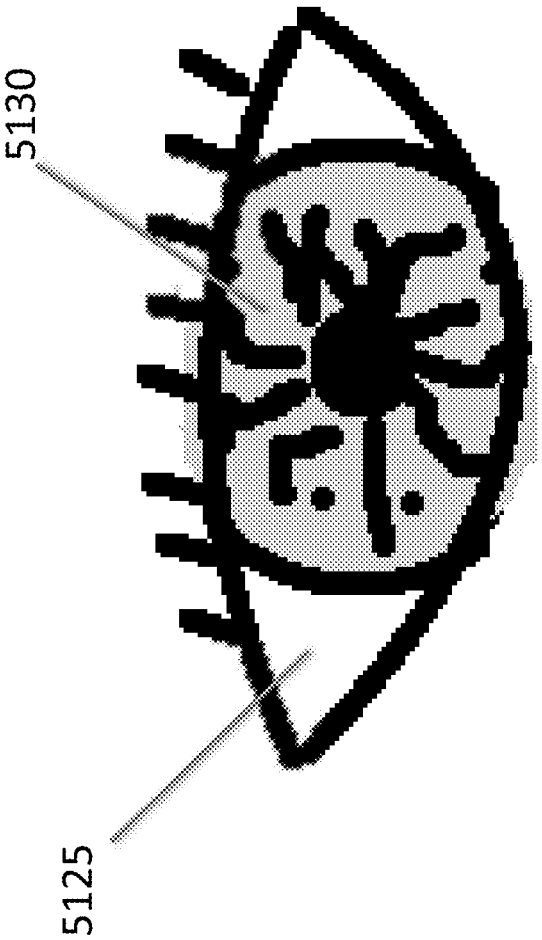


Figure 25

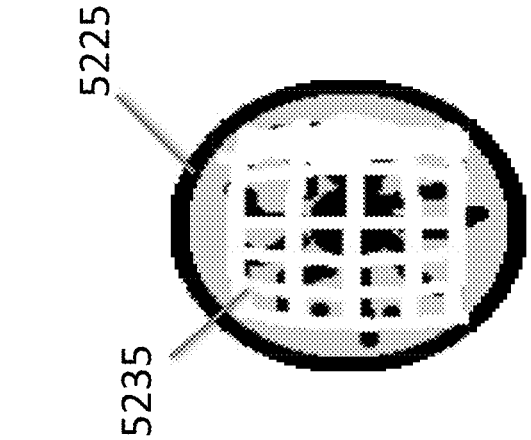


Figure 26b

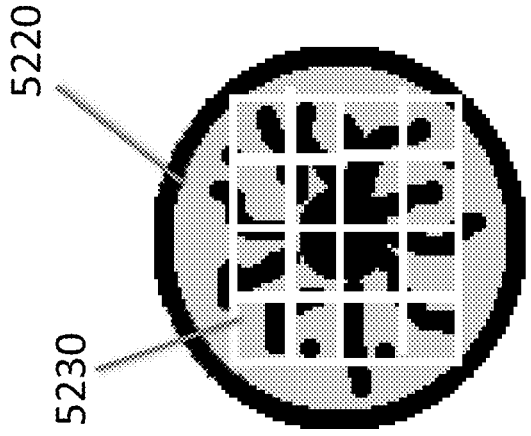


Figure 26a

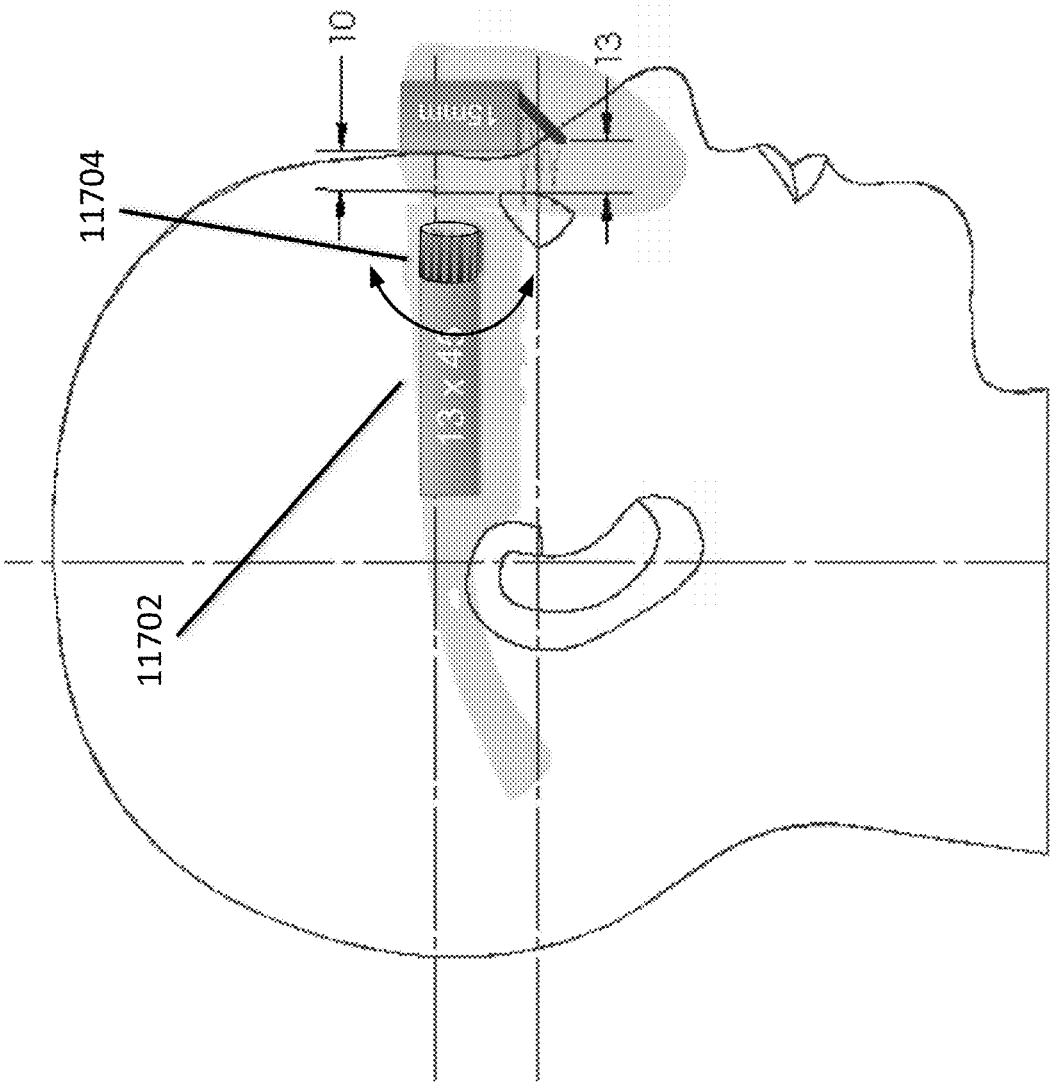


Figure 27

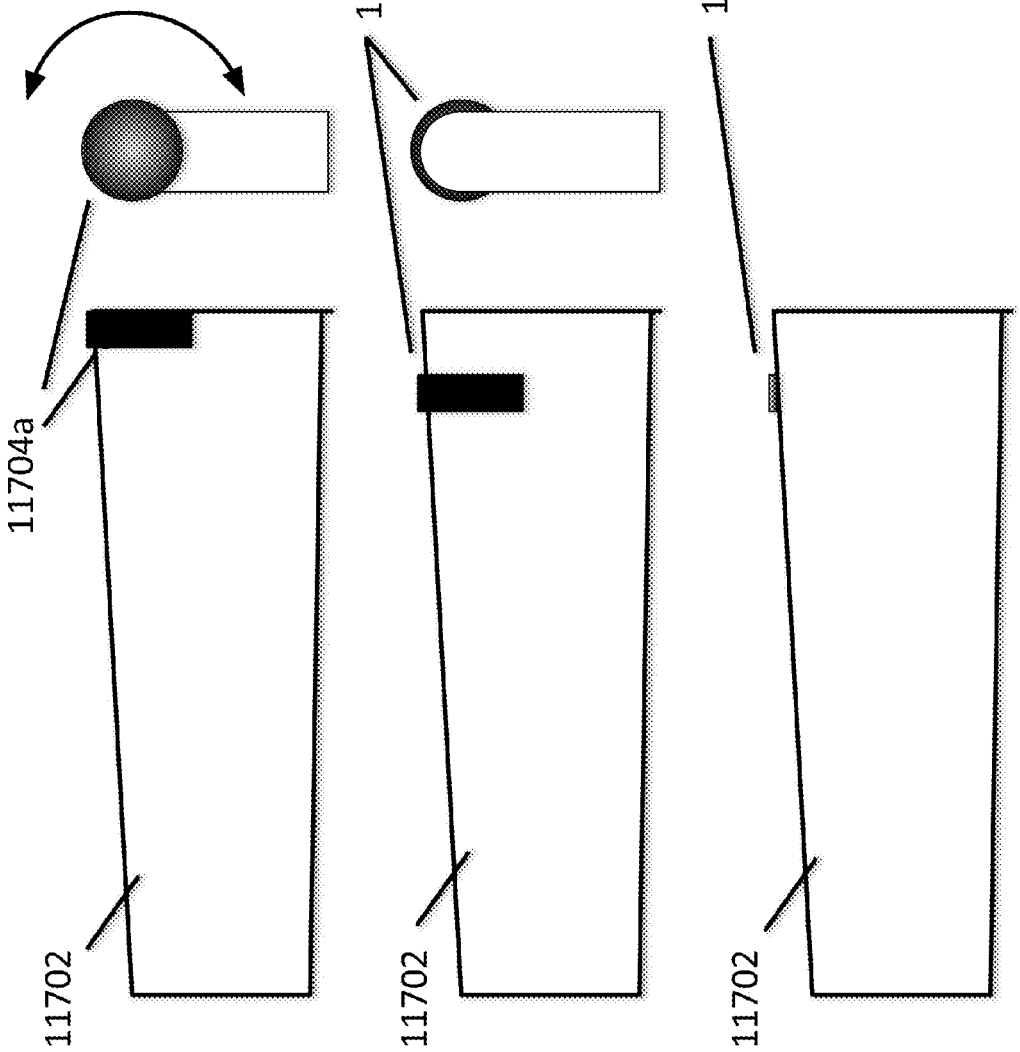


Figure 28

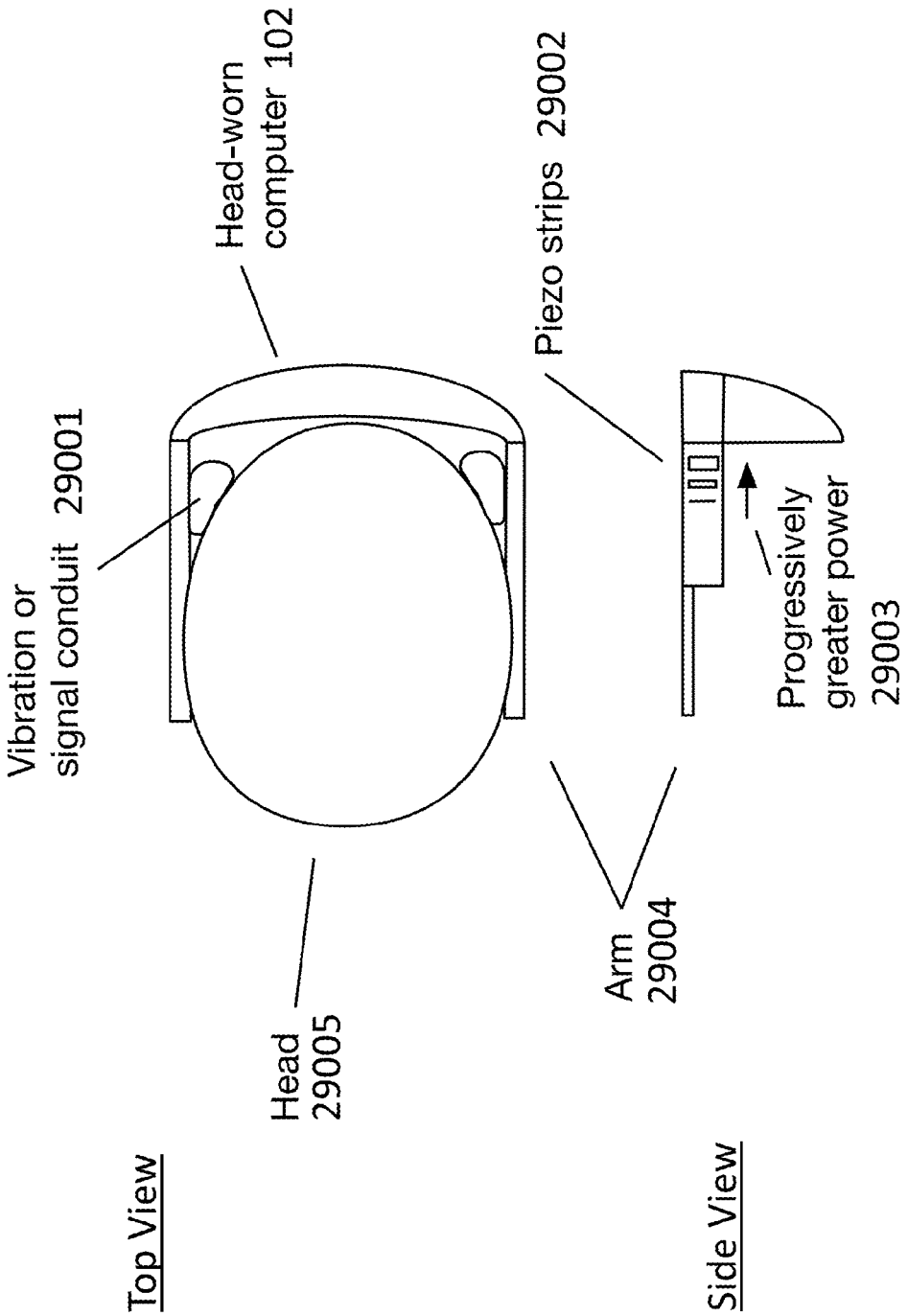

Head-worn computer 102
Piezo strips 29002
Vibration or signal conduit 29001
Progressively greater power 29003
Head 29005
Arm 29004
Top View
Side View

Figure 29

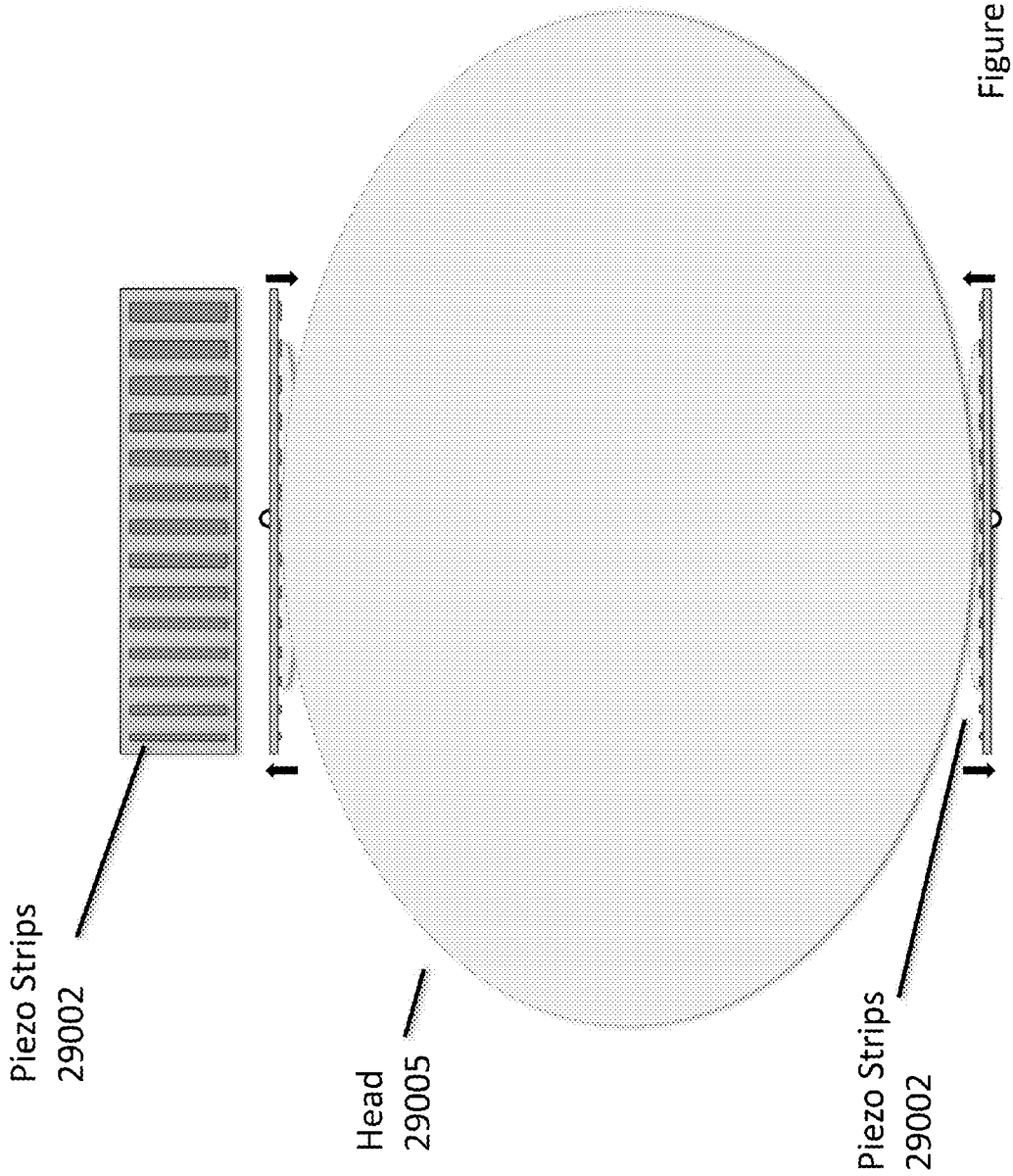


Figure 29a

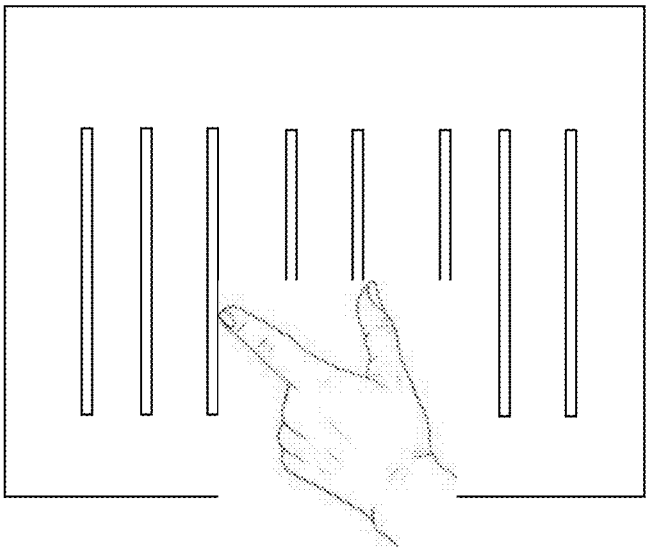


Figure 30b

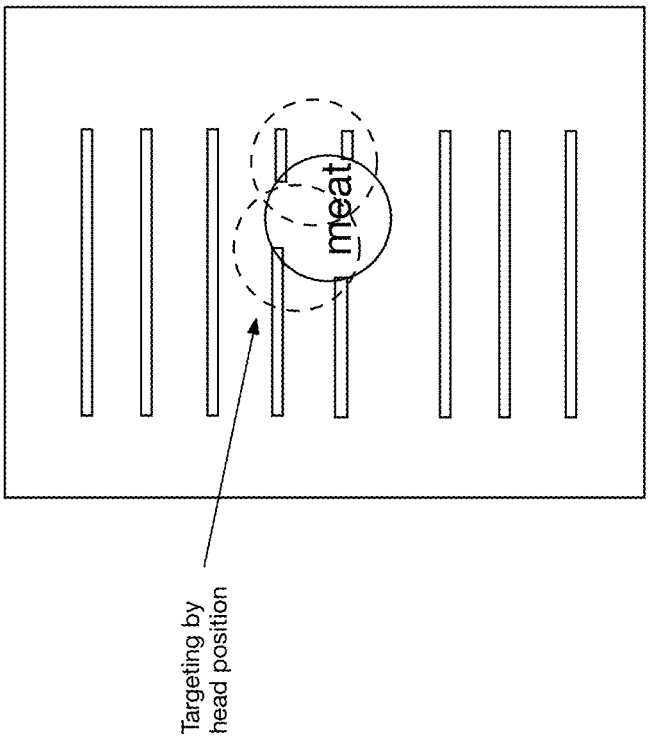


Figure 30a

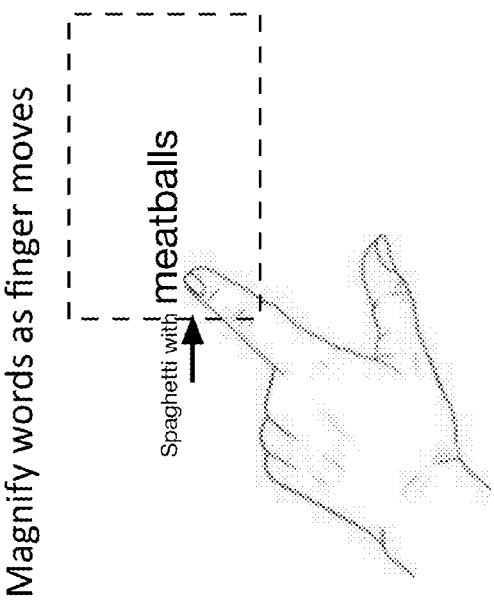


Figure 31a

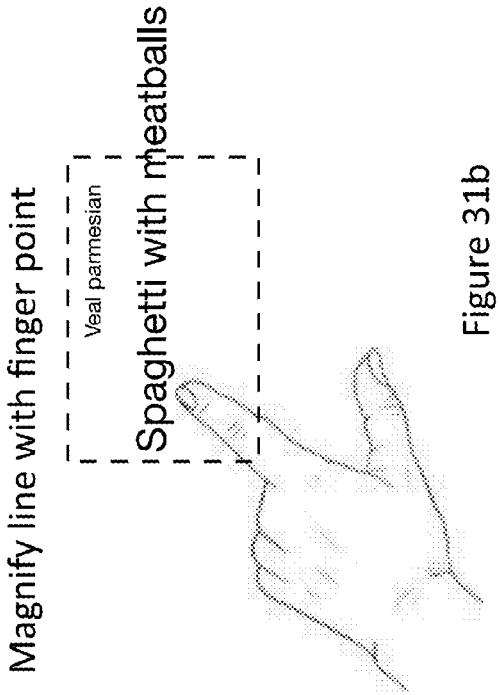


Figure 31b

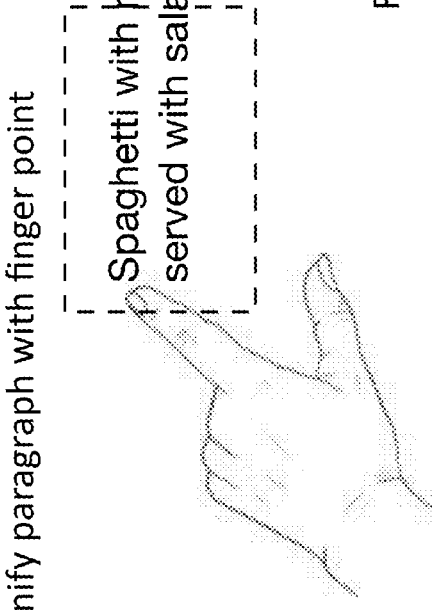


Figure 31c

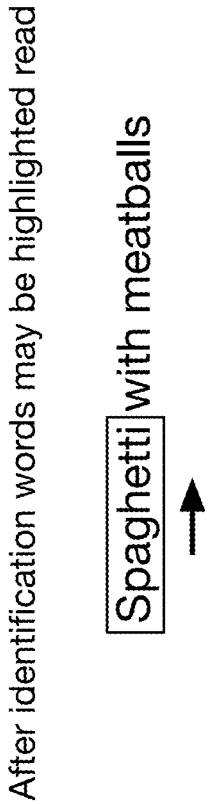

After identification words may be highlighted read
Spaghetti with meatballs

Figure 32

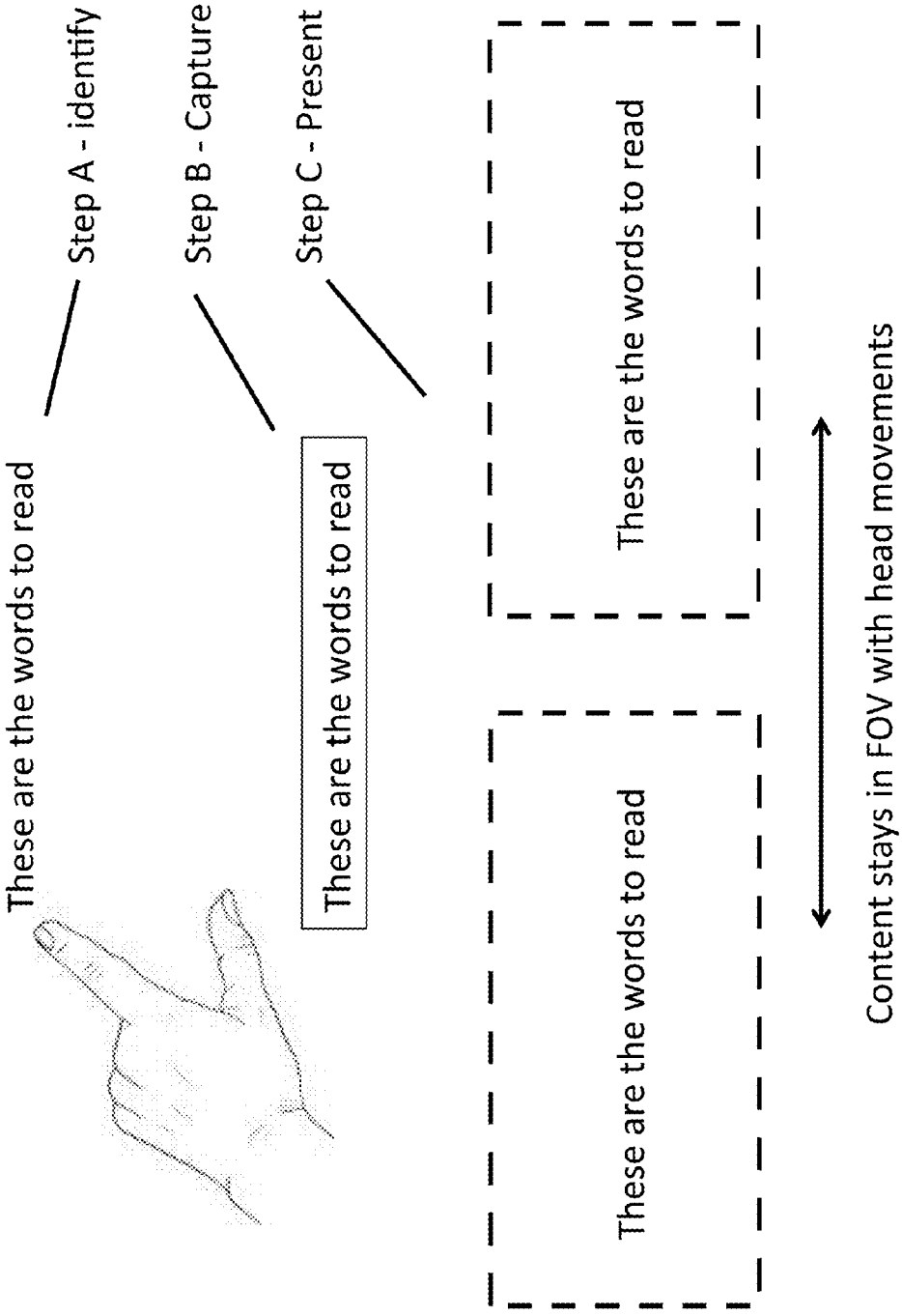

Step A - identify
Step B - Capture
Step C - Present
These are the words to read
These are the words to read
These are the words to read
These are the words to read
Content stays in FOV with head movements

Figure 33

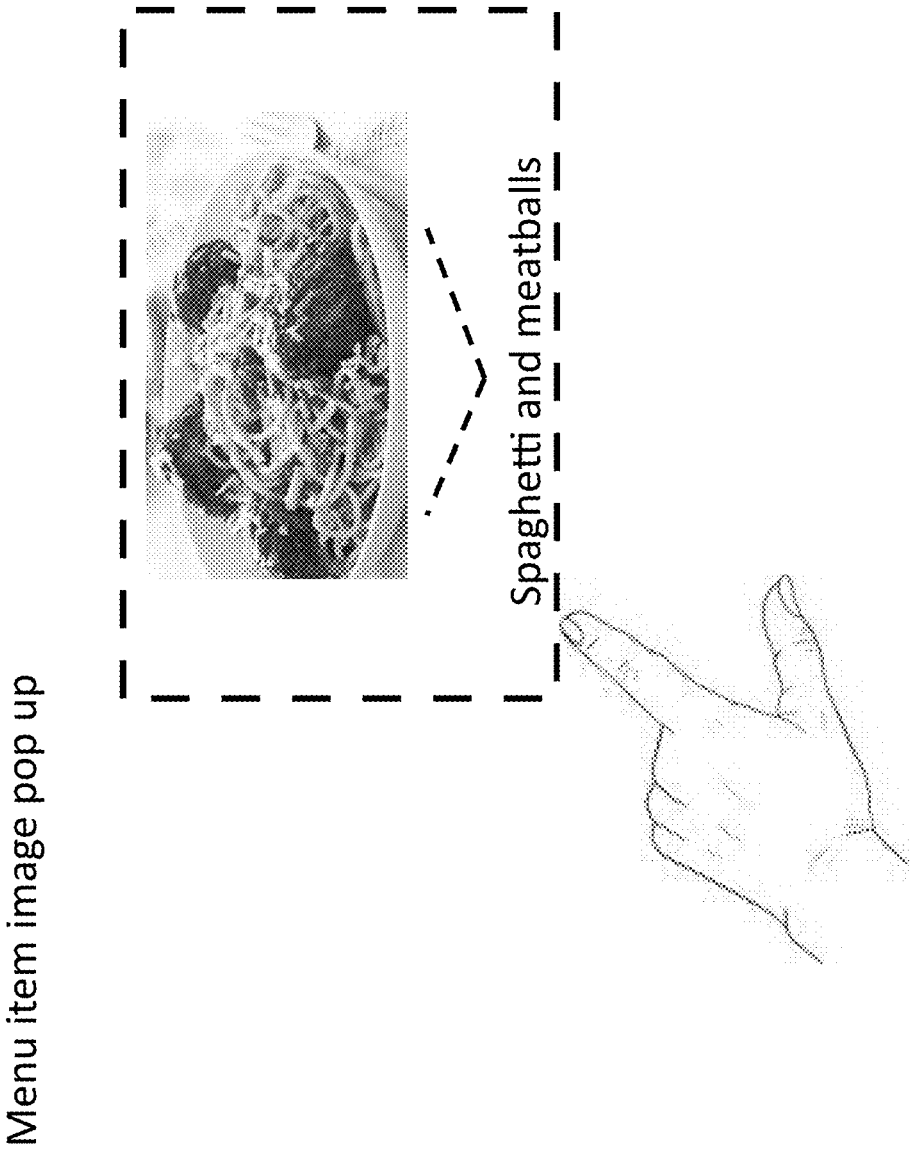


Figure 34

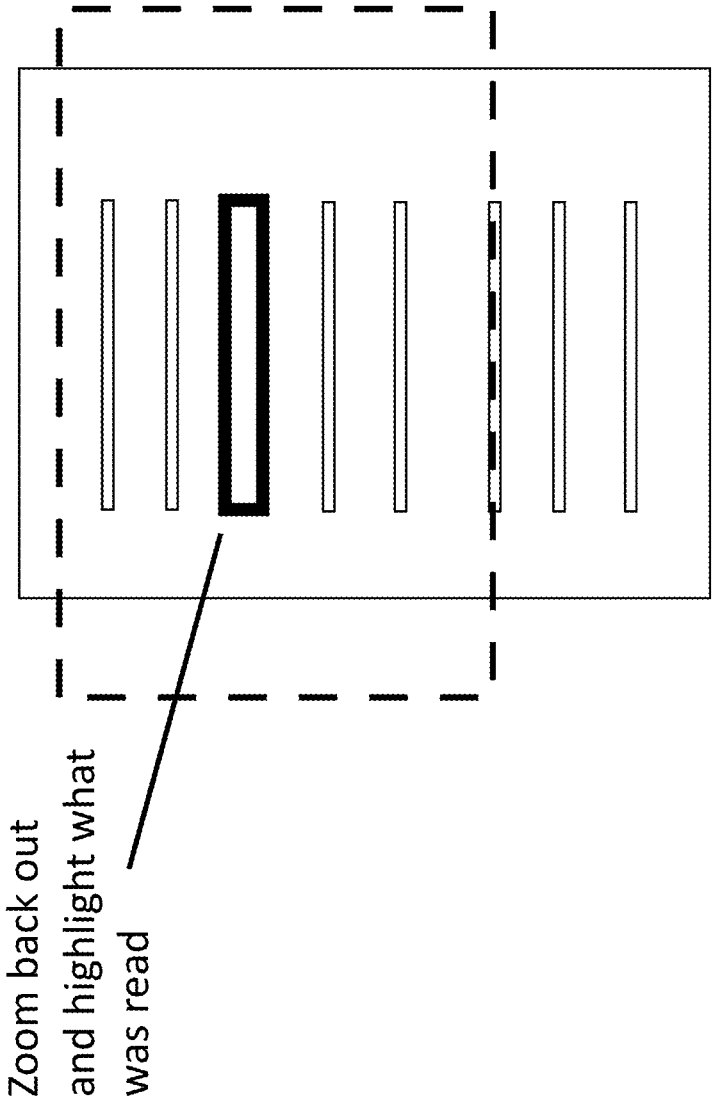


Figure 35

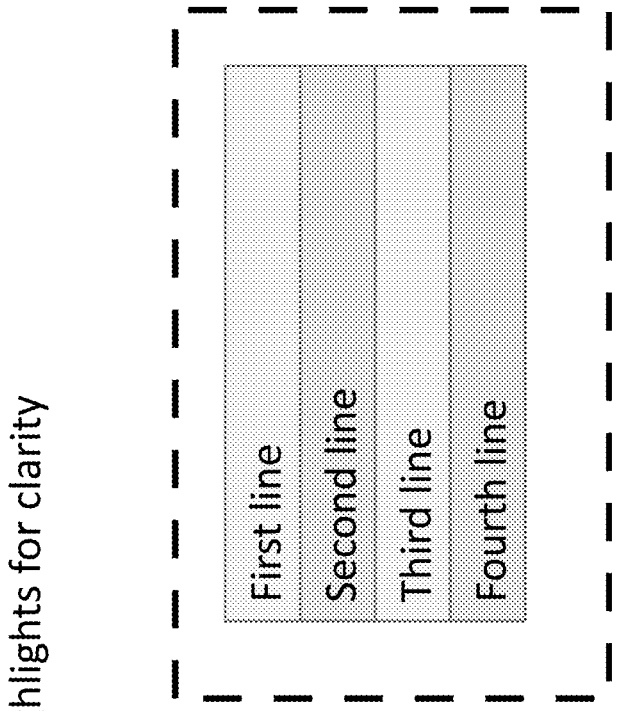

Alternating highlights for clarity
First line
Second line
Third line
Fourth line

Figure 36



Figure 38

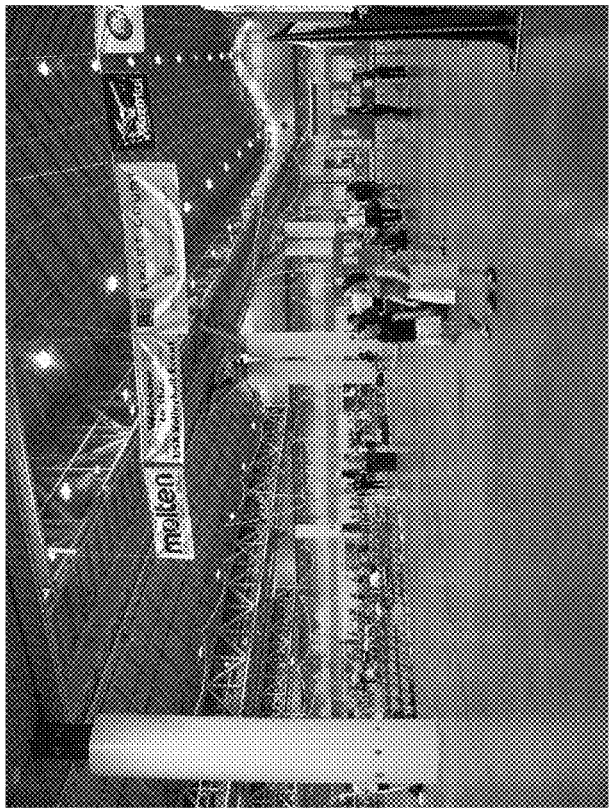


Figure 37

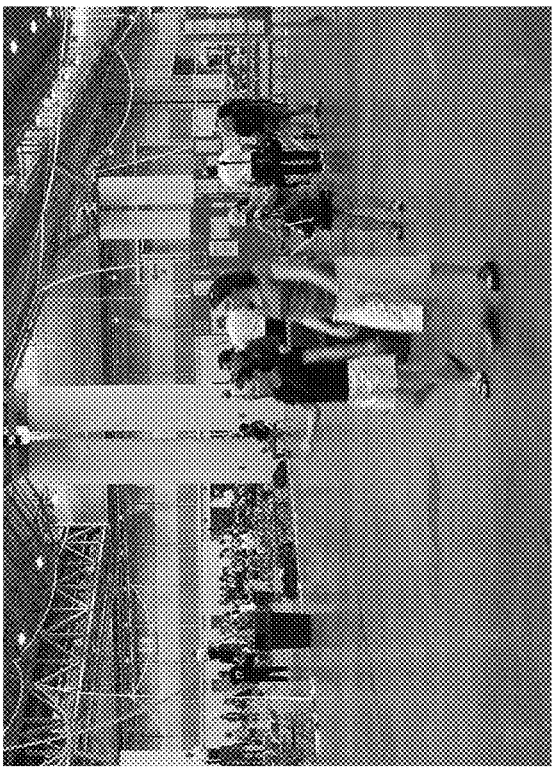


Figure 39

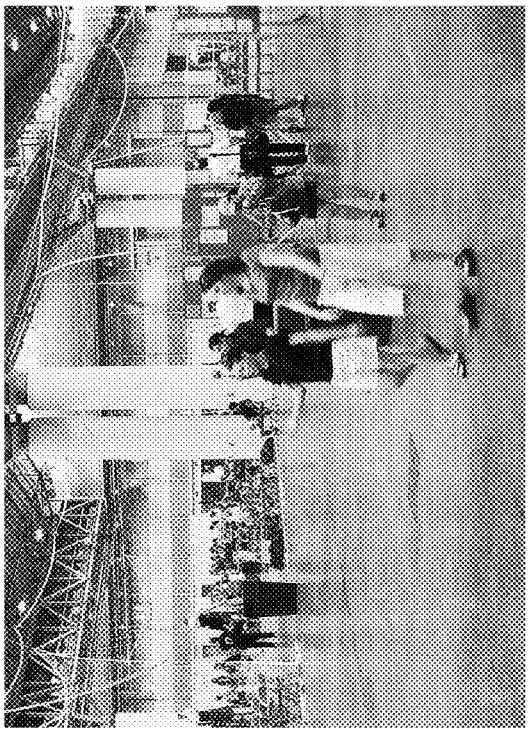


Figure 40



Figure 41

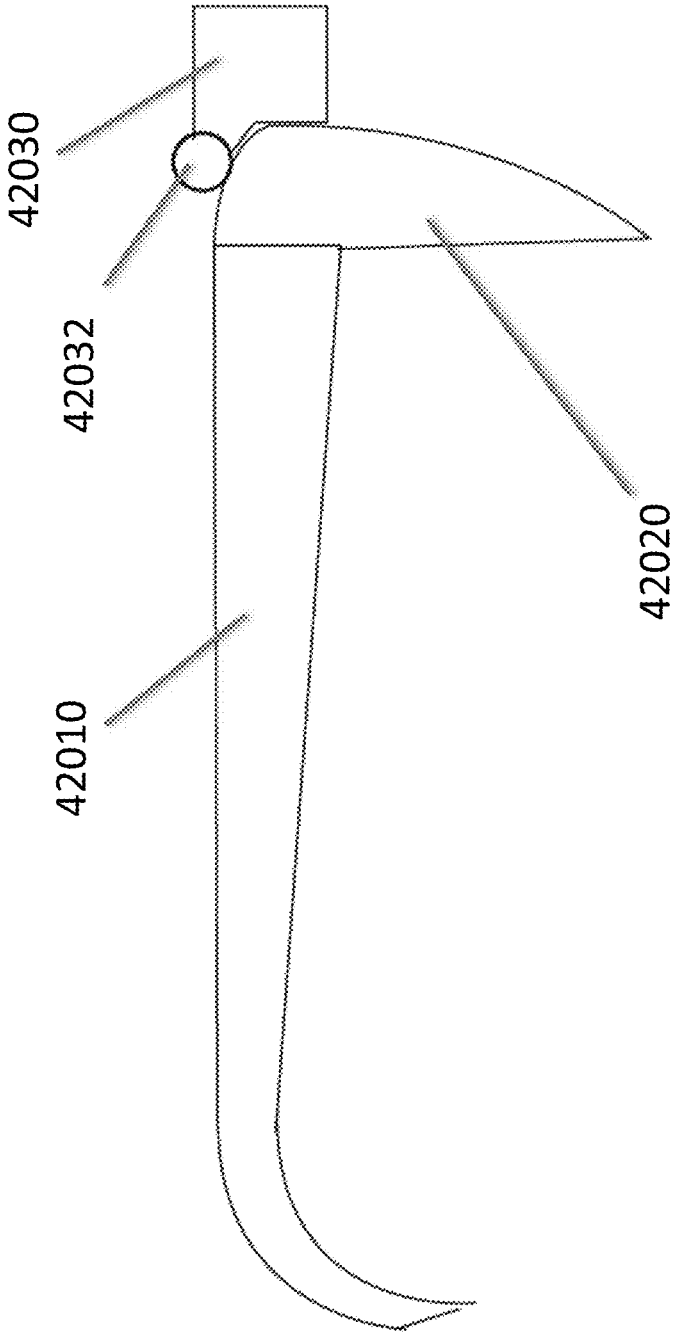


Figure 42

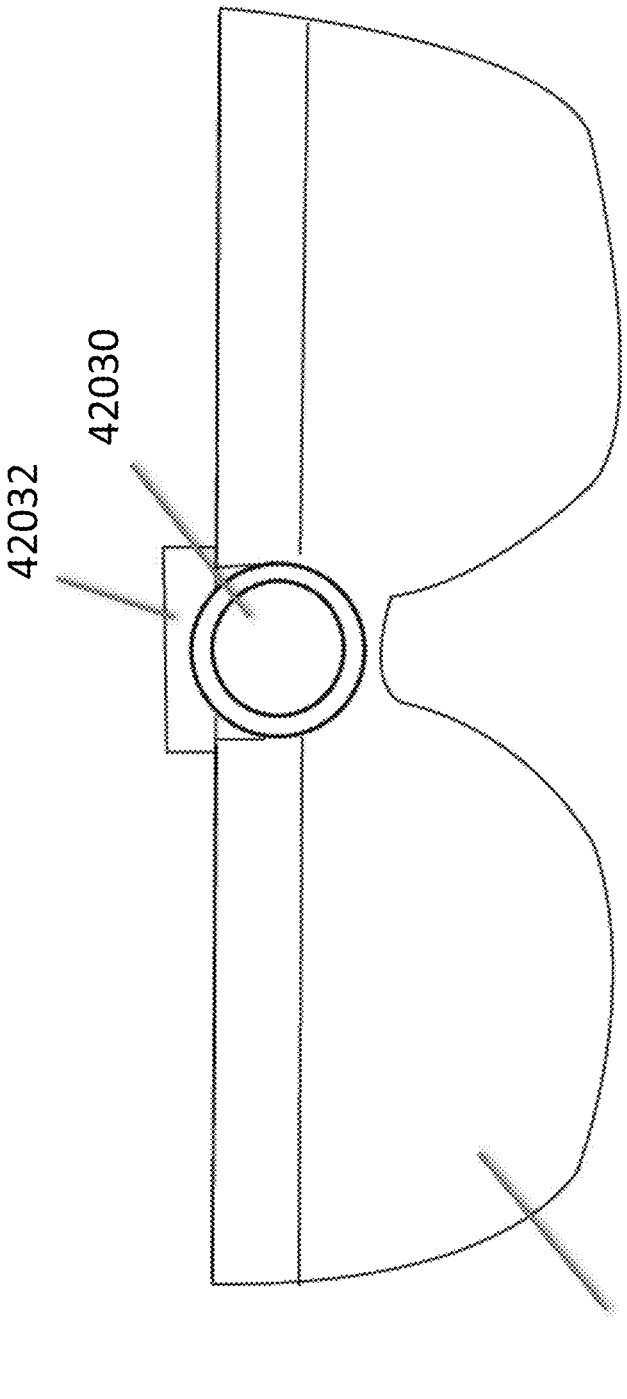


Figure 43

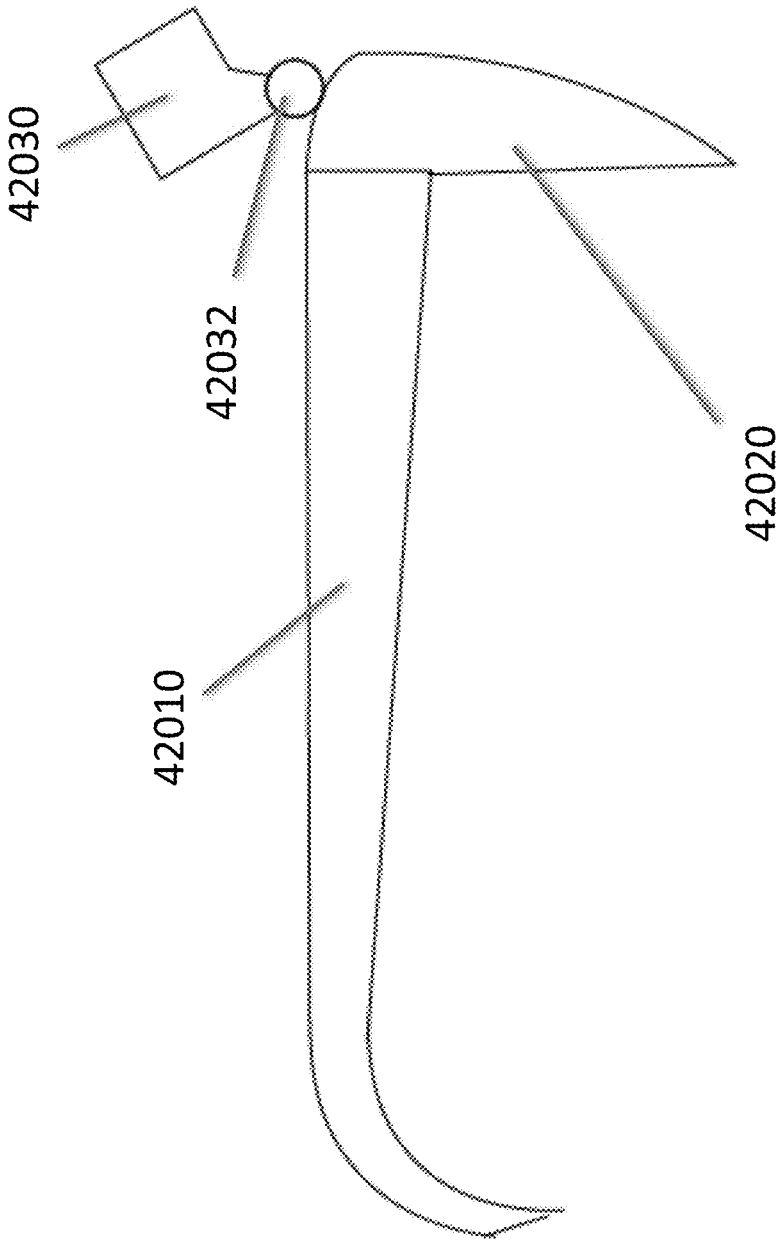


Figure 44

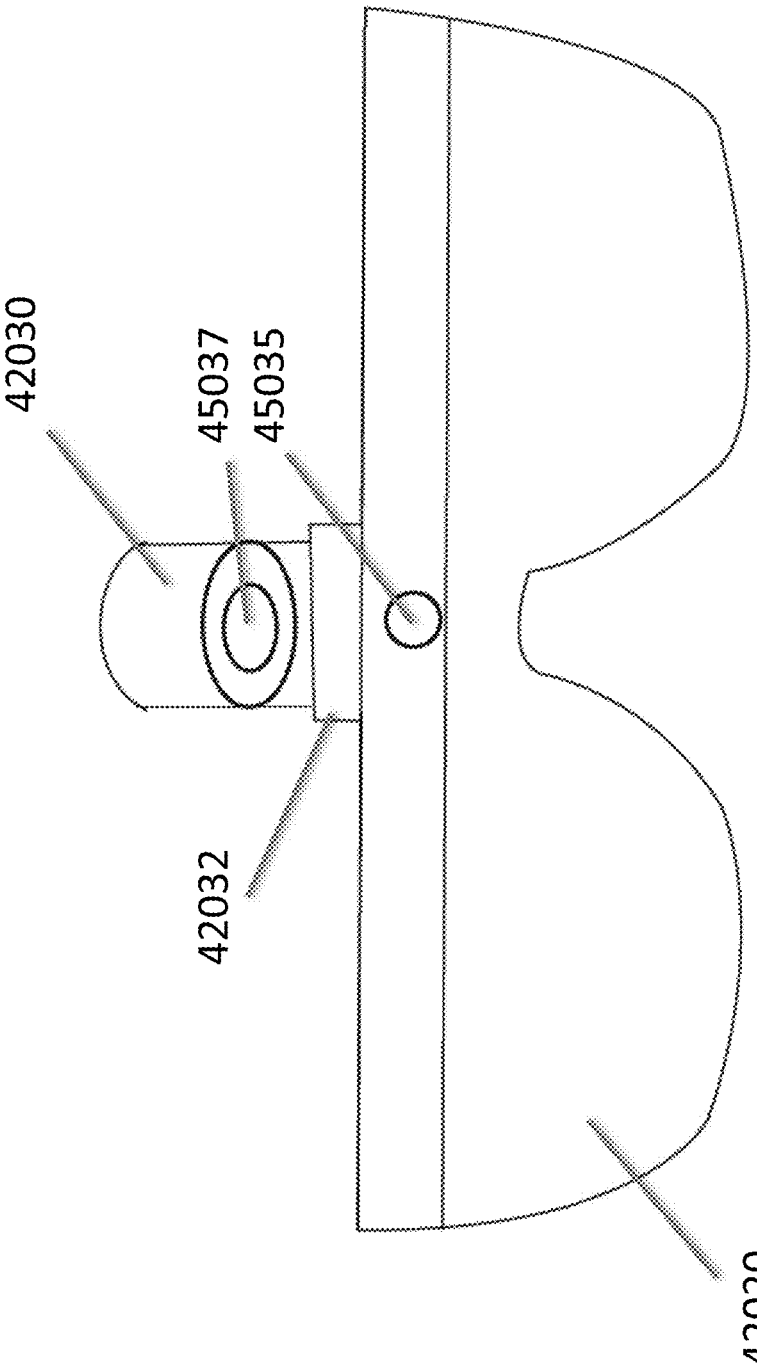


Figure 45

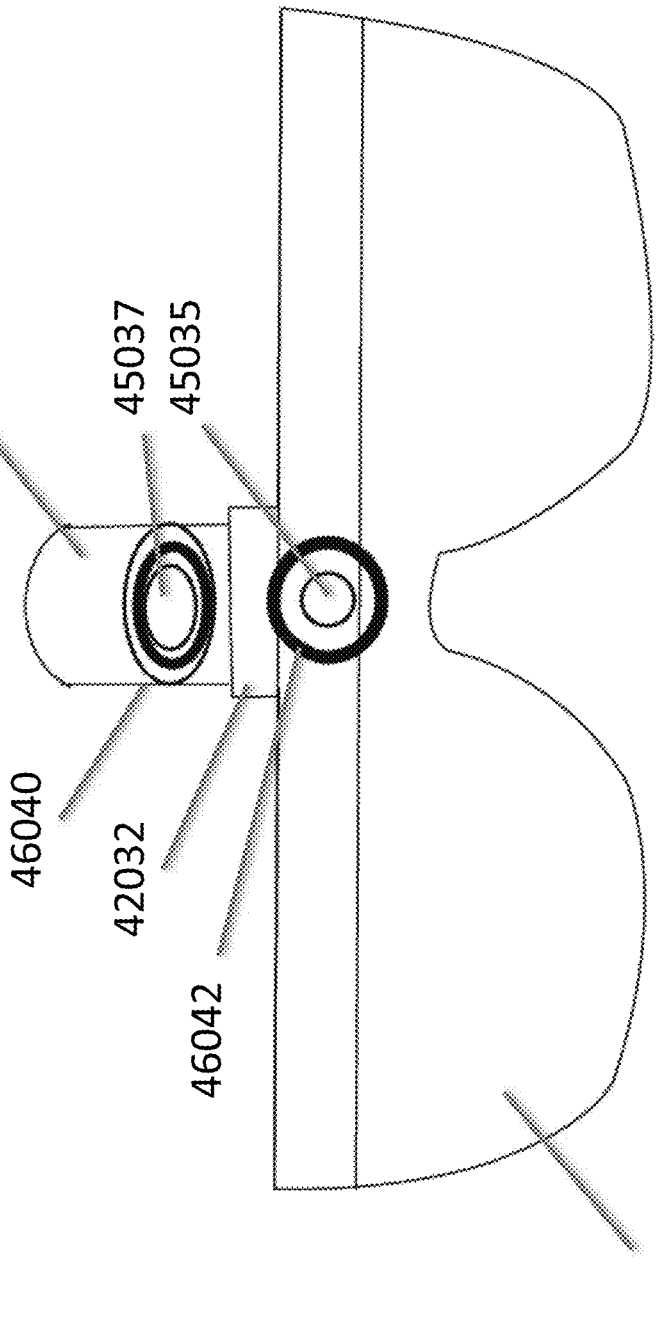


Figure 46

RADAR IMAGERY IN HEAD-WORN COMPUTING

CLAIM TO PRIORITY

[0001] This application is a continuation of the following U.S. patent application, which is incorporated by reference in its entirety: U.S. application Ser. No. 15/056,573, filed Feb. 29, 2016 (ODGP-3019-U01).

BACKGROUND

[0002] Field of the Invention

[0003] This disclosure relates to head-worn computer systems adapted to assist visually impaired people.

[0004] Description of Related Art

[0005] Head mounted displays (HMDs) and particularly HMDs that provide a see-through view of the environment are valuable instruments. The presentation of content in the see-through display can be a complicated operation when attempting to ensure that the user experience is optimized. Improved systems and methods for presenting content in the see-through display are required to improve the user experience.

SUMMARY

[0006] Aspects of the present disclosure relate to methods and systems for providing visual assistance to the visually impaired.

[0007] These and other systems, methods, objects, features, and advantages of the present disclosure will be apparent to those skilled in the art from the following detailed description of the preferred embodiment and the drawings. All documents mentioned herein are hereby incorporated in their entirety by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Embodiments are described with reference to the following Figures. The same numbers may be used throughout to reference like features and components that are shown in the Figures:

[0009] FIG. **1** illustrates a head worn computing system in accordance with the principles of the present disclosure.

[0010] FIG. **2** illustrates a head worn computing system with optical system in accordance with the principles of the present disclosure.

[0011] FIG. **3** illustrates upper and lower optical modules in accordance with the principles of the present disclosure.

[0012] FIG. **4** illustrates angles of combiner elements in accordance with the principles of the present disclosure.

[0013] FIG. **5** illustrates upper and lower optical modules in accordance with the principles of the present disclosure.

[0014] FIG. **6** illustrates upper and lower optical modules in accordance with the principles of the present disclosure.

[0015] FIG. **7** illustrates upper and lower optical modules in accordance with the principles of the present disclosure.

[0016] FIG. **8** illustrates upper and lower optical modules in accordance with the principles of the present disclosure.

[0017] FIGS. **9**, **10***a*, **10***b* and **11** illustrate light sources and filters in accordance with the principles of the present disclosure.

[0018] FIGS. **12***a* to **12***c* illustrate light sources and quantum dot systems in accordance with the principles of the present disclosure.

[0019] FIGS. **13***a* to **13***c* illustrate peripheral lighting systems in accordance with the principles of the present disclosure.

[0020] FIGS. **14***a* to **14***h* illustrate light suppression systems in accordance with the principles of the present disclosure.

[0021] FIG. **15** illustrates an external user interface in accordance with the principles of the present disclosure.

[0022] FIG. **16** illustrates external user interfaces in accordance with the principles of the present disclosure.

[0023] FIGS. **17** and **18** illustrate structured eye lighting systems according to the principles of the present disclosure.

[0024] FIG. **19** illustrates eye glint in the prediction of eye direction analysis in accordance with the principles of the present disclosure.

[0025] FIG. **20***a* illustrates eye characteristics that may be used in personal identification through analysis of a system according to the principles of the present disclosure.

[0026] FIG. **20***b* illustrates a digital content presentation reflection off of the wearer's eye that may be analyzed in accordance with the principles of the present disclosure.

[0027] FIG. **21** illustrates eye imaging along various virtual target lines and various focal planes in accordance with the principles of the present disclosure.

[0028] FIG. **22** illustrates content control with respect to eye movement based on eye imaging in accordance with the principles of the present disclosure.

[0029] FIG. **23** illustrates eye imaging and eye convergence in accordance with the principles of the present disclosure.

[0030] FIG. **24** illustrates light impinging an eye in accordance with the principles of the present disclosure.

[0031] FIG. **25** illustrates a view of an eye in accordance with the principles of the present disclosure.

[0032] FIGS. **26***a* and **26***b* illustrate views of an eye with a structured light pattern in accordance with the principles of the present disclosure.

[0033] FIG. **27** illustrates a user interface in accordance with the principles of the present disclosure.

[0034] FIG. **28** illustrates a user interface in accordance with the principles of the present disclosure.

[0035] FIGS. **29** and **29***a* illustrate haptic systems in accordance with the principles of the present disclosure.

[0036] FIG. **30***a* illustrates an example situation where a user is viewing a document while wearing a head-worn computer and the document has writing on it.

[0037] FIG. **30***b* illustrates a situation where the user points to a section of the document to indicate to the head-worn computer that this is the area or section the user is interested in viewing as a magnified or digitally enhanced displayed image.

[0038] FIGS. **31***a* through **31***c* illustrate several examples of how the head-worn computer system may present information to the visually impaired user after an indication of what the user would like to look at is received.

[0039] FIG. **32** illustrates a system where the words of a line are enhanced as they are read.

[0040] FIG. **33** illustrates a system for the stabilization of enhanced images.

[0041] FIG. **34** illustrates a system where the indication by the user of the menu item causes a pop up of a picture, video or other content.

[0042] FIG. **35** illustrates a system where the user has asked or indicated that they would like to zoom back out to see a larger portion of a page for context.

[0043] FIG. **36** illustrates a system where alternating lines of text are enhanced to help a visually impaired person separate and read the lines.

[0044] FIG. **37** shows an illustration of an environment as seen by a person that is not vision impaired.

[0045] FIG. **38** shows an illustration of the same environment as seen in a blurred condition to illustrate what might be seen by a person with impaired vision.

[0046] FIG. **39** shows an illustration of an image of the environment as captured by the camera in the head-worn computer.

[0047] FIG. **40** shows an illustration of the captured image after being enhanced to increase contrast, sharpness and brightness.

[0048] FIG. **41** shows an illustration of the enhanced version of the captured image of the environment being displayed in the head-worn computer as seen by the impaired vision user as the enhanced image overlaid onto a see-through view of the environment.

[0049] FIGS. **42** through **46** show illustrations of an example of a head-worn computer including a display system.

[0050] While the disclosure has been described in connection with certain preferred embodiments, other embodiments would be understood by one of ordinary skill in the art and are encompassed herein.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0051] Aspects of the present disclosure relate to head-worn computing ("HWC") systems. HWC involves, in some instances, a system that mimics the appearance of head-worn glasses or sunglasses. The glasses may be a fully developed computing platform, such as including computer displays presented in each of the lenses of the glasses to the eyes of the user. In embodiments, the lenses and displays may be configured to allow a person wearing the glasses to see the environment through the lenses while also seeing, simultaneously, digital imagery, which forms an overlaid image that is perceived by the person as a digitally augmented image of the environment, or augmented reality ("AR").

[0052] HWC involves more than just placing a computing system on a person's head. The system may need to be designed as a lightweight, compact and fully functional computer display, such as wherein the computer display includes a high resolution digital display that provides a high level of emersion comprised of the displayed digital content and the see-through view of the environmental surroundings. User interfaces and control systems suited to the HWC device may be required that are unlike those used for a more conventional computer such as a laptop. For the HWC and associated systems to be most effective, the glasses may be equipped with sensors to determine environmental conditions, geographic location, relative positioning to other points of interest, objects identified by imaging and movement by the user or other users in a connected group, compass heading, head tilt, where the user is looking and the like. The HWC may then change the mode of operation to match the conditions, location, positioning, movements, and the like, in a method generally referred to as a contextually aware HWC. The glasses also may need to be connected, wirelessly or otherwise, to other systems either locally or through a network. Controlling the glasses may be achieved through the use of an external device, automatically through contextually gathered information, through user gestures captured by the glasses sensors, and the like. Each technique may be further refined depending on the software application being used in the glasses. The glasses may further be used to control or coordinate with external devices that are associated with the glasses.

[0053] Referring to FIG. **1**, an overview of the HWC system **100** is presented. As shown, the HWC system **100** comprises a HWC **102**, which in this instance is configured as glasses to be worn on the head with sensors such that the HWC **102** is aware of the objects and conditions in the environment **114**. In this instance, the HWC **102** also receives and interprets control inputs such as gestures and movements **116**. The HWC **102** may communicate with external user interfaces **104**. The external user interfaces **104** may provide a physical user interface to take control instructions from a user of the HWC **102** and the external user interfaces **104** and the HWC **102** may communicate bi-directionally to affect the user's command and provide feedback to the external device **108**. The HWC **102** may also communicate bi-directionally with externally controlled or coordinated local devices **108**. For example, an external user interface **104** may be used in connection with the HWC **102** to control an externally controlled or coordinated local device **108**. The externally controlled or coordinated local device **108** may provide feedback to the HWC **102** and a customized GUI may be presented in the HWC **102** based on the type of device or specifically identified device **108**. The HWC **102** may also interact with remote devices and information sources **112** through a network connection **110**. Again, the external user interface **104** may be used in connection with the HWC **102** to control or otherwise interact with any of the remote devices **108** and information sources **112** in a similar way as when the external user interfaces **104** are used to control or otherwise interact with the externally controlled or coordinated local devices **108**. Similarly, HWC **102** may interpret gestures **116** (e.g captured from forward, downward, upward, rearward facing sensors such as camera(s), range finders, IR sensors, etc.) or environmental conditions sensed in the environment **114** to control either local or remote devices **108** or **112**.

[0054] We will now describe each of the main elements depicted on FIG. **1** in more detail; however, these descriptions are intended to provide general guidance and should not be construed as limiting. Additional description of each element may also be further described herein.

[0055] The HWC **102** is a computing platform intended to be worn on a person's head. The HWC **102** may take many different forms to fit many different functional requirements. In some situations, the HWC **102** will be designed in the form of conventional glasses. The glasses may or may not have active computer graphics displays. In situations where the HWC **102** has integrated computer displays the displays may be configured as see-through displays such that the digital imagery can be overlaid with respect to the user's view of the environment **114**. There are a number of see-through optical designs that may be used, including ones that have a reflective display (e.g. LCoS, DLP), emissive displays (e.g. OLED, LED), hologram, TIR waveguides, and the like. In embodiments, lighting systems used in connection with the display optics may be solid state lighting

systems, such as LED, OLED, quantum dot, quantum dot LED, etc. In addition, the optical configuration may be monocular or binocular. It may also include vision corrective optical components. In embodiments, the optics may be packaged as contact lenses. In other embodiments, the HWC **102** may be in the form of a helmet with a see-through shield, sunglasses, safety glasses, goggles, a mask, fire helmet with see-through shield, police helmet with see through shield, military helmet with see-through shield, utility form customized to a certain work task (e.g. inventory control, logistics, repair, maintenance, etc.), and the like.

[0056] The HWC **102** may also have a number of integrated computing facilities, such as an integrated processor, integrated power management, communication structures (e.g. cell net, WiFi, Bluetooth, local area connections, mesh connections, remote connections (e.g. client server, etc.)), and the like. The HWC **102** may also have a number of positional awareness sensors, such as GPS, electronic compass, altimeter, tilt sensor, IMU, and the like. It may also have other sensors such as a camera, rangefinder, hyperspectral camera, Geiger counter, microphone, spectral illumination detector, temperature sensor, chemical sensor, biologic sensor, moisture sensor, ultrasonic sensor, and the like.

[0057] The HWC **102** may also have integrated control technologies. The integrated control technologies may be contextual based control, passive control, active control, user control, and the like. For example, the HWC **102** may have an integrated sensor (e.g. camera) that captures user hand or body gestures **116** such that the integrated processing system can interpret the gestures and generate control commands for the HWC **102**. In another example, the HWC **102** may have sensors that detect movement (e.g. a nod, head shake, and the like) including accelerometers, gyros and other inertial measurements, where the integrated processor may interpret the movement and generate a control command in response. The HWC **102** may also automatically control itself based on measured or perceived environmental conditions. For example, if it is bright in the environment the HWC **102** may increase the brightness or contrast of the displayed image. In embodiments, the integrated control technologies may be mounted on the HWC **102** such that a user can interact with it directly. For example, the HWC **102** may have a button(s), touch capacitive interface, and the like.

[0058] As described herein, the HWC **102** may be in communication with external user interfaces **104**. The external user interfaces may come in many different forms. For example, a cell phone screen may be adapted to take user input for control of an aspect of the HWC **102**. The external user interface may be a dedicated UI (e.g. air mouse, finger mounted mouse), such as a keyboard, touch surface, button (s), joy stick, and the like. In embodiments, the external controller may be integrated into another device such as a ring, watch, bike, car, and the like. In each case, the external user interface **104** may include sensors (e.g. IMU, accelerometers, compass, altimeter, and the like) to provide additional input for controlling the HWD **104**.

[0059] As described herein, the HWC **102** may control or coordinate with other local devices **108**. The external devices **108** may be an audio device, visual device, vehicle, cell phone, computer, and the like. For instance, the local external device **108** may be another HWC **102**, where information may then be exchanged between the separate HWCs **108**.

[0060] Similar to the way the HWC **102** may control or coordinate with local devices **106**, the HWC **102** may control or coordinate with remote devices **112**, such as the HWC **102** communicating with the remote devices **112** through a network **110**. Again, the form of the remote device **112** may have many forms. Included in these forms is another HWC **102**. For example, each HWC **102** may communicate its GPS position such that all the HWCs **102** know where all of HWC **102** are located.

[0061] FIG. **2** illustrates a HWC **102** with an optical system that includes an upper optical module **202** and a lower optical module **204**. While the upper and lower optical modules **202** and **204** will generally be described as separate modules, it should be understood that this is illustrative only and the present disclosure includes other physical configurations, such as that when the two modules are combined into a single module or where the elements making up the two modules are configured into more than two modules. In embodiments, the upper module **202** includes a computer controlled display (e.g. LCoS, FLCoS, DLP, OLED, backlit LCD, etc.) and image light delivery optics. In embodiments, the lower module includes eye delivery optics that are configured to receive the upper module's image light and deliver the image light to the eye of a wearer of the HWC. In FIG. **2**, it should be noted that while the upper and lower optical modules **202** and **204** are illustrated in one side of the HWC such that image light can be delivered to one eye of the wearer, that it is envisioned by the present disclosure that embodiments will contain two image light delivery systems, one for each eye.

[0062] FIG. **3** illustrates a combination of an upper optical module **202** with a lower optical module **204**. In this embodiment, the image light projected from the upper optical module **202** may or may not be polarized. The image light is reflected off a flat combiner element **602** such that it is directed towards the user's eye. Wherein, the combiner element **602** is a partial mirror that reflects image light while transmitting a substantial portion of light from the environment so the user can look through the combiner element and see the environment surrounding the HWC.

[0063] The combiner **602** may include a holographic pattern, to form a holographic mirror. If a monochrome image is desired, there may be a single wavelength reflection design for the holographic pattern on the surface of the combiner **602**. If the intention is to have multiple colors reflected from the surface of the combiner **602**, a multiple wavelength holographic mirror maybe included on the combiner surface. For example, in a three-color embodiment, where red, green and blue pixels are generated in the image light, the holographic mirror may be reflective to wavelengths substantially matching the wavelengths of the red, green and blue light provided in the image light. This configuration can be used as a wavelength specific mirror where pre-determined wavelengths of light from the image light are reflected to the user's eye. This configuration may also be made such that substantially all other wavelengths in the visible pass through the combiner element **602** so the user has a substantially clear view of the environmental surroundings when looking through the combiner element **602**. The transparency between the user's eye and the surrounding may be approximately 80% when using a combiner that is a holographic mirror. Wherein holographic mirrors can be made using lasers to produce interference patterns in the holographic material of the combiner where

the wavelengths of the lasers correspond to the wavelengths of light that are subsequently reflected by the holographic mirror.

[0064] In another embodiment, the combiner element **602** may include a notch mirror comprised of a multilayer coated substrate wherein the coating is designed to substantially reflect the wavelengths of light provided in the image light by the light source and substantially transmit the remaining wavelengths in the visible spectrum. For example, in the case where red, green and blue light is provided by the light source in the upper optics to enable full color images to be provided to the user, the notch mirror is a tristimulus notch mirror wherein the multilayer coating is designed to substantially reflect narrow bands of red, green and blue light that are matched to the what is provided by the light source and the remaining visible wavelengths are substantially transmitted through the coating to enable a view of the environment through the combiner. In another example where monochrome images are provided to the user, the notch mirror is designed to reflect a single narrow band of light that is matched to the wavelength range of the image light provided by the upper optics while transmitting the remaining visible wavelengths to enable a see-thru view of the environment. The combiner **602** with the notch mirror would operate, from the user's perspective, in a manner similar to the combiner that includes a holographic pattern on the combiner element **602**. The combiner, with the tristimulus notch mirror, would reflect image light associated with pixels, to the eye because of the match between the reflective wavelengths of the notch mirror and the wavelengths or color of the image light, and the wearer would simultaneously be able to see with high clarity the environmental surroundings. The transparency between the user's eye and the surrounding may be approximately 80% when using the tristimulus notch mirror. In addition, the image provided with the notch mirror combiner can provide higher contrast images than the holographic mirror combiner because the notch mirror acts in a purely reflective manner compared to the holographic mirror which operates through diffraction, and as such the notch mirror is subject to less scattering of the imaging light by the combiner. In another embodiment, the combiner element **602** may include a simple partial mirror that reflects a portion (e.g. 50%) of all wavelengths of light in the visible.

[0065] Image light can escape through the combiner **602** and may produce face glow from the optics shown in FIG. **3**, as the escaping image light is generally directed downward onto the cheek of the user. When using a holographic mirror combiner or a tristimulus notch mirror combiner, the escaping light can be trapped to avoid face glow. In embodiments, if the image light is polarized before the combiner, a linear polarizer can be laminated, or otherwise associated, to the combiner, with the transmission axis of the polarizer oriented relative to the polarized image light so that any escaping image light is absorbed by the polarizer. In embodiments, the image light would be polarized to provide S polarized light to the combiner for better reflection. As a result, the linear polarizer on the combiner would be oriented to absorb S polarized light and pass P polarized light. This provides the preferred orientation of polarized sunglasses as well.

[0066] If the image light is unpolarized, a microlouvered film such as a privacy filter can be used to absorb the escaping image light while providing the user with a see-thru view of the environment. In this case, the absorbance or transmittance of the microlouvered film is dependent on the angle of the light. Where steep angle light is absorbed and light at less of an angle is transmitted. For this reason, in an embodiment, the combiner with the microlouver film is angled at greater than 45 degrees to the optical axis of the image light (e.g. the combiner can be oriented at 50 degrees so the image light from the file lens is incident on the combiner at an oblique angle.

[0067] FIG. **4** illustrates an embodiment of a combiner element **602** at various angles when the combiner element **602** includes a holographic mirror. Normally, a mirrored surface reflects light at an angle equal to the angle that the light is incident to the mirrored surface. Typically, this necessitates that the combiner element be at 45 degrees, **602***a*, if the light is presented vertically to the combiner so the light can be reflected horizontally towards the wearer's eye. In embodiments, the incident light can be presented at angles other than vertical to enable the mirror surface to be oriented at other than 45 degrees, but in all cases wherein a mirrored surface is employed (including the tristimulus notch mirror described previously), the incident angle equals the reflected angle. As a result, increasing the angle of the combiner **602***a* requires that the incident image light be presented to the combiner **602***a* at a different angle which positions the upper optical module **202** to the left of the combiner as shown in FIG. **4**. In contrast, a holographic mirror combiner, included in embodiments, can be made such that light is reflected at a different angle from the angle that the light is incident onto the holographic mirrored surface. This allows freedom to select the angle of the combiner element **602***b* independent of the angle of the incident image light and the angle of the light reflected into the wearer's eye. In embodiments, the angle of the combiner element **602***b* is greater than 45 degrees (shown in FIG. **4**) as this allows a more laterally compact HWC design. The increased angle of the combiner element **602***b* decreases the front to back width of the lower optical module **204** and may allow for a thinner HWC display (i.e. the furthest element from the wearer's eye can be closer to the wearer's face).

[0068] FIG. **5** illustrates another embodiment of a lower optical module **204**. In this embodiment, polarized or unpolarized image light provided by the upper optical module **202**, is directed into the lower optical module **204**. The image light reflects off a partial mirror **804** (e.g. polarized mirror, notch mirror, holographic mirror, etc.) and is directed toward a curved partially reflective mirror **802**. The curved partial mirror **802** then reflects the image light back towards the user's eye, which passes through the partial mirror **804**. The user can also see through the partial mirror **804** and the curved partial mirror **802** to see the surrounding environment. As a result, the user perceives a combined image comprised of the displayed image light overlaid onto the see-thru view of the environment. In a preferred embodiment, the partial mirror **804** and the curved partial mirror **802** are both non-polarizing so that the transmitted light from the surrounding environment is unpolarized so that rainbow interference patterns are eliminated when looking at polarized light in the environment such as provided by a computer monitor or in the reflected light from a lake.

[0069] While many of the embodiments of the present disclosure have been referred to as upper and lower modules containing certain optical components, it should be understood that the image light production and management

functions described in connection with the upper module may be arranged to direct light in other directions (e.g. upward, sideward, etc.). In embodiments, it may be preferred to mount the upper module **202** above the wearer's eye, in which case the image light would be directed downward. In other embodiments it may be preferred to produce light from the side of the wearer's eye, or from below the wearer's eye. In addition, the lower optical module is generally configured to deliver the image light to the wearer's eye and allow the wearer to see through the lower optical module, which may be accomplished through a variety of optical components.

[0070] FIG. **6** illustrates an embodiment of the present disclosure where the upper optical module **202** is arranged to direct image light into a total internal reflection (TIR) waveguide **810**. In this embodiment, the upper optical module **202** is positioned above the wearer's eye **812** and the light is directed horizontally into the TIR waveguide **810**. The TIR waveguide is designed to internally reflect the image light in a series of downward TIR reflections until it reaches the portion in front of the wearer's eye, where the light passes out of the TIR waveguide **812** in a direction toward the wearer's eye. In this embodiment, an outer shield **814** may be positioned in front of the TIR waveguide **810**.

[0071] FIG. **7** illustrates an embodiment of the present disclosure where the upper optical module **202** is arranged to direct image light into a TIR waveguide **818**. In this embodiment, the upper optical module **202** is arranged on the side of the TIR waveguide **818**. For example, the upper optical module may be positioned in the arm or near the arm of the HWC when configured as a pair of head worn glasses. The TIR waveguide **818** is designed to internally reflect the image light in a series of TIR reflections until it reaches the portion in front of the wearer's eye, where the light passes out of the TIR waveguide **818** in a direction toward the wearer's eye **812**.

[0072] FIG. **8** illustrates yet further embodiments of the present disclosure where an upper optical module **202** directs polarized image light into an optical guide **828** where the image light passes through a polarized reflector **824**, changes polarization state upon reflection of the optical element **822** which includes a ¼ wave film for example and then is reflected by the polarized reflector **824** towards the wearer's eye, due to the change in polarization of the image light. The upper optical module **202** may be positioned behind the optical guide **828** wherein the image light is directed toward a mirror **820** that reflects the image light along the optical guide **828** and towards the polarized reflector **824**. Alternatively, in other embodiments, the upper optical module **202** may direct the image light directly along the optical guide **828** and towards the polarized reflector **824**. It should be understood that the present disclosure comprises other optical arrangements intended to direct image light into the wearer's eye.

[0073] FIG. **9** illustrates a light source **1100** that may be used in association with the upper optics module **202**. In embodiments, the light source **1100** may provide light to a backlighting optical system that is associated with the light source **1100** and which serves to homogenize the light and thereby provide uniform illuminating light to an image source in the upper optics. In embodiments, the light source **1100** includes a tristimulus notch filter **1102**. The tristimulus notch filter **1102** has narrow band pass filters for three wavelengths, as indicated in FIG. **10***b* in a transmission graph **1108**. The graph shown in FIG. **10***a*, as **1104** illustrates an output of three different colored LEDs. One can see that the bandwidths of emission are narrow, but they have long tails. The tristimulus notch filter **1102** can be used in connection with such LEDs to provide a light source **1100** that emits narrow filtered wavelengths of light as shown in FIG. **11** as the transmission graph **1110**. Wherein the clipping effects of the tristimulus notch filter **1102** can be seen to have cut the tails from the LED emission graph **1104** to provide narrower wavelength bands of light to the upper optical module **202**. The light source **1100** can be used in connection with a matched combiner **602** that includes a holographic mirror or tristimulus notch mirror that substantially reflects the narrow bands of image light toward the wearer's eye with a reduced amount of image light that does not get reflected by the combiner, thereby improving efficiency of the head-worn computer (HWC) or head-mounted display (HMD) and reducing escaping light that can cause faceglow.

[0074] FIG. **12***a* illustrates another light source **1200** that may be used in association with the upper optics module **202**. In embodiments, the light source **1200** may provide light to a backlighting optical system that homogenizes the light prior to illuminating the image source in the upper optics as described previously herein. In embodiments, the light source **1200** includes a quantum dot cover glass **1202**. Where the quantum dots absorb light of a shorter wavelength and emit light of a longer wavelength (FIG. **12***b* shows an example wherein a UV spectrum **1202** applied to a quantum dot results in the quantum dot emitting a narrow band shown as a PL spectrum **1204**) that is dependent on the material makeup and size of the quantum dot. As a result, quantum dots in the quantum dot cover glass **1202** can be tailored to provide one or more bands of narrow bandwidth light (e.g. red, green and blue emissions dependent on the different quantum dots included as illustrated in the graph shown in FIG. **12***c* where three different quantum dots are used. In embodiments, the LED driver light emits UV light, deep blue or blue light. For sequential illumination of different colors, multiple light sources **1200** would be used where each light source **1200** would include a quantum dot cover glass **1202** with at least one type of quantum dot selected to emit at one of each of the desired colors. The light source **1100** can be used in connection with a combiner **602** with a holographic mirror or tristimulus notch mirror to provide narrow bands of image light that are reflected toward the wearer's eye with less wasted image light that does not get reflected.

[0075] Another aspect of the present disclosure relates to the generation of peripheral image lighting effects for a person wearing a HWC. In embodiments, a solid state lighting system (e.g. LED, OLED, etc), or other lighting system, may be included inside the optical elements of an lower optical module **204**. The solid state lighting system may be arranged such that lighting effects outside of a field of view (FOV) associated with displayed digital content is presented to create an immersive effect for the person wearing the HWC. To this end, the lighting effects may be presented to any portion of the HWC that is visible to the wearer. The solid state lighting system may be digitally controlled by an integrated processor on the HWC. In embodiments, the integrated processor will control the lighting effects in coordination with digital content that is presented within the FOV of the HWC. For example, a movie,

picture, game, or other content, may be displayed or playing within the FOV of the HWC. The content may show a bomb blast on the right side of the FOV and at the same moment, the solid state lighting system inside of the upper module optics may flash quickly in concert with the FOV image effect. The effect may not be fast, it may be more persistent to indicate, for example, a general glow or color on one side of the user. The solid state lighting system may be color controlled, with red, green and blue LEDs, for example, such that color control can be coordinated with the digitally presented content within the field of view.

[0076] FIG. **13***a* illustrates optical components of a lower optical module **204** together with an outer lens **1302**. FIG. **13***a* also shows an embodiment including effects LED's **1308***a* and **1308***b*. FIG. **13***a* illustrates image light **1312**, as described herein elsewhere, directed into the upper optical module where it will reflect off of the combiner element **1304**, as described herein elsewhere. The combiner element **1304** in this embodiment is angled towards the wearer's eye at the top of the module and away from the wearer's eye at the bottom of the module, as also illustrated and described in connection with FIG. **8** (e.g. at a 45 degree angle). The image light **1312** provided by an upper optical module **202** (not shown in FIG. **13***a*) reflects off of the combiner element **1304** towards the collimating mirror **1310**, away from the wearer's eye, as described herein elsewhere. The image light **1312** then reflects and focuses off of the collimating mirror **1304**, passes back through the combiner element **1304**, and is directed into the wearer's eye. The wearer can also view the surrounding environment through the transparency of the combiner element **1304**, collimating mirror **1310**, and outer lens **1302** (if it is included). As described herein elsewhere, the image light may or may not be polarized and the see-through view of the surrounding environment is preferably non-polarized to provide a view of the surrounding environment that does not include rainbow interference patterns if the light from the surrounding environment is polarized such as from a computer monitor or reflections from a lake. The wearer will generally perceive that the image light forms an image in the FOV **1305**. In embodiments, the outer lens **1302** may be included. The outer lens **1302** is an outer lens that may or may not be corrective and it may be designed to conceal the lower optical module components in an effort to make the HWC appear to be in a form similar to standard glasses or sunglasses.

[0077] In the embodiment illustrated in FIG. **13***a*, the effects LEDs **1308***a* and **1308***b* are positioned at the sides of the combiner element **1304** and the outer lens **1302** and/or the collimating mirror **1310**. In embodiments, the effects LEDs **1308***a* are positioned within the confines defined by the combiner element **1304** and the outer lens **1302** and/or the collimating mirror. The effects LEDs **1308***a* and **1308***b* are also positioned outside of the FOV **1305** associated with the displayed digital content. In this arrangement, the effects LEDs **1308***a* and **1308***b* can provide lighting effects within the lower optical module outside of the FOV **1305**. In embodiments the light emitted from the effects LEDs **1308***a* and **1308***b* may be polarized and the outer lens **1302** may include a polarizer such that the light from the effects LEDs **1308***a* and **1308***b* will pass through the combiner element **1304** toward the wearer's eye and will be absorbed by the outer lens **1302**. This arrangement provides peripheral lighting effects to the wearer in a more private setting by not transmitting the lighting effects through the front of the HWC into the surrounding environment. However, in other embodiments, the effects LEDs **1308***a* and **1308***b* may be non-polarized so the lighting effects provided are made to be purposefully viewable by others in the environment for entertainment such as giving the effect of the wearer's eye glowing in correspondence to the image content being viewed by the wearer.

[0078] FIG. **13***b* illustrates a cross section of the embodiment described in connection with FIG. **13***a*. As illustrated, the effects LED **1308***a* is located in the upper-front area inside of the optical components of the lower optical module. It should be understood that the effects LED **1308***a* position in the described embodiments is only illustrative and alternate placements are encompassed by the present disclosure. Additionally, in embodiments, there may be one or more effects LEDs **1308***a* in each of the two sides of HWC to provide peripheral lighting effects near one or both eyes of the wearer.

[0079] FIG. **13***c* illustrates an embodiment where the combiner element **1304** is angled away from the eye at the top and towards the eye at the bottom (e.g. in accordance with the holographic or notch filter embodiments described herein). In this embodiment, the effects LED **1308***a* may be located on the outer lens **1302** side of the combiner element **1304** to provide a concealed appearance of the lighting effects. As with other embodiments, the effects LED **1308***a* of FIG. **13***c* may include a polarizer such that the emitted light can pass through a polarized element associated with the combiner element **1304** and be blocked by a polarized element associated with the outer lens **1302**. Alternatively the effects LED **13087***a* can be configured such that at least a portion of the light is reflected away from the wearer's eye so that it is visible to people in the surrounding environment. This can be accomplished for example by using a combiner **1304** that is a simple partial mirror so that a portion of the image light **1312** is reflected toward the wearer's eye and a first portion of the light from the effects LED **13087***a* is transmitted toward the wearer's eye and a second portion of the light from the effects LED **1308***a* is reflected outward toward the surrounding environment.

[0080] FIGS. **14***a*, **14***b*, **14***c* and **14***d* show illustrations of a HWC that includes eye covers **1402** to restrict loss of image light to the surrounding environment and to restrict the ingress of stray light from the environment. Where the eye covers **1402** can be removably attached to the HWC with magnets **1404**. Another aspect of the present disclosure relates to automatically configuring the lighting system(s) used in the HWC **102**. In embodiments, the display lighting and/or effects lighting, as described herein, may be controlled in a manner suitable for when an eye cover **1402** is attached or removed from the HWC **102**. For example, at night, when the light in the environment is low, the lighting system(s) in the HWC may go into a low light mode to further control any amounts of stray light escaping from the HWC and the areas around the HWC. Covert operations at night, while using night vision or standard vision, may require a solution which prevents as much escaping light as possible so a user may clip on the eye cover(s) **1402** and then the HWC may go into a low light mode. The low light mode may, in some embodiments, only go into a low light mode when the eye cover **1402** is attached if the HWC identifies that the environment is in low light conditions (e.g. through environment light level sensor detection). In embodiments,

the low light level may be determined to be at an intermediate point between full and low light dependent on environmental conditions.

[0081] Another aspect of the present disclosure relates to automatically controlling the type of content displayed in the HWC when eye covers **1402** are attached or removed from the HWC. In embodiments, when the eye cover(s) **1402** is attached to the HWC, the displayed content may be restricted in amount or in color amounts. For example, the display(s) may go into a simple content delivery mode to restrict the amount of information displayed. This may be done to reduce the amount of light produced by the display (s). In an embodiment, the display(s) may change from color displays to monochrome displays to reduce the amount of light produced. In an embodiment, the monochrome lighting may be red to limit the impact on the wearer's eyes to maintain an ability to see better in the dark.

[0082] Another aspect of the present disclosure relates to a system adapted to quickly convert from a see-through system to a non-see-through or very low transmission see-through system for a more immersive user experience. The conversion system may include replaceable lenses, an eye cover, and optics adapted to provide user experiences in both modes. The outer lenses, for example, may be 'blacked-out' with an opaque cover **1412** to provide an experience where all of the user's attention is dedicated to the digital content and then the outer lenses may be switched out for high see-through lenses so the digital content is augmenting the user's view of the surrounding environment. Another aspect of the disclosure relates to low transmission outer lenses that permit the user to see through the outer lenses but remain dark enough to maintain most of the user's attention on the digital content. The slight see-through can provide the user with a visual connection to the surrounding environment and this can reduce or eliminate nausea and other problems associated with total removal of the surrounding view when viewing digital content.

[0083] FIG. **14***d* illustrates a head-worn computer system **102** with a see-through digital content display **204** adapted to include a removable outer lens **1414** and a removable eye cover **1402**. The eye cover **1402** may be attached to the head-worn computer **102** with magnets **1404** or other attachment systems (e.g. mechanical attachments, a snug friction fit between the arms of the head-worn computer **102**, etc.). The eye cover **1402** may be attached when the user wants to cut stray light from escaping the confines of the head-worn computer, create a more immersive experience by removing the otherwise viewable peripheral view of the surrounding environment, etc. The removable outer lens **1414** may be of several varieties for various experiences. It may have no transmission or a very low transmission to create a dark background for the digital content, creating an immersive experience for the digital content. It may have a high transmission so the user can see through the see-through display and the outer lens **1414** to view the surrounding environment, creating a system for a heads-up display, augmented reality display, assisted reality display, etc. The outer lens **1414** may be dark in a middle portion to provide a dark background for the digital content (i.e. dark backdrop behind the see-through field of view from the user's perspective) and a higher transmission area elsewhere. The outer lenses **1414** may have a transmission in the range of 2 to 5%, 5 to 10%, 10 to 20% for the immersion effect and above 10% or 20% for the augmented reality effect, for example. The outer lenses **1414** may also have an adjustable transmission to facilitate the change in system effect. For example, the outer lenses **1414** may be electronically adjustable tint lenses (e.g. liquid crystal or have crossed polarizers with an adjustment for the level of cross).

[0084] In embodiments, the eye cover **1402** may have areas of transparency or partial transparency to provide some visual connection with the user's surrounding environment. This may also reduce or eliminate nausea or other feelings associated with the complete removal of the view of the surrounding environment.

[0085] FIG. **14***e* illustrates a HWC **102** assembled with an eye cover **1402** without outer lenses in place. The outer lenses, in embodiments, may be held in place with magnets **1418** for ease of removal and replacement. In embodiments, the outer lenses may be held in place with other systems, such as mechanical systems.

[0086] Another aspect of the present disclosure relates to an effects system that generates effects outside of the field of view in the see-through display of the head-worn computer. The effects may be, for example, lighting effects, sound effects, tactile effects (e.g. through vibration), air movement effects, etc. In embodiments, the effect generation system is mounted on the eye cover **1402**. For example, a lighting system (e.g. LED(s), OLEDs, etc.) may be mounted on an inside surface **1420**, or exposed through the inside surface **1420**, as illustrated in FIG. **14***f*, such that they can create a lighting effect (e.g. a bright light, colored light, subtle color effect) in coordination with content being displayed in the field of view of the see-through display. The content may be a movie or a game, for example, and an explosion may happen on the right side of the content, as scripted, and matching the content, a bright flash may be generated by the effects lighting system to create a stronger effect. As another example, the effects system may include a vibratory system mounted near the sides or temples, or otherwise, and when the same explosion occurs, the vibratory system may generate a vibration on the right side to increase the user experience indicating that the explosion had a real sound wave creating the vibration. As yet a further example, the effects system may have an air system where the effect is a puff of air blown onto the user's face. This may create a feeling of closeness with some fast moving object in the content. The effects system may also have speakers directed towards the user's ears or an attachment for ear buds, etc.

[0087] In embodiments, the effects generated by the effects system may be scripted by an author to coordinate with the content. In embodiments, sensors may be placed inside of the eye cover to monitor content effects (e.g. a light sensor to measure strong lighting effects or peripheral lighting effects) that would than cause an effect(s) to be generated.

[0088] The effects system in the eye cover may be powered by an internal battery and the battery, in embodiments, may also provide additional power to the head-worn computer **102** as a back-up system. In embodiments, the effects system is powered by the batteries in the head-worn computer. Power may be delivered through the attachment system (e.g. magnets, mechanical system) or a dedicated power system.

[0089] The effects system may receive data and/or commands from the head-worn computer through a data connection that is wired or wireless. The data may come through

the attachment system, a separate line, or through Bluetooth or other short range communication protocol, for example.

[0090] In embodiments, the eye cover **1402** is made of reticulated foam, which is very light and can contour to the user's face. The reticulated foam also allows air to circulate because of the open-celled nature of the material, which can reduce user fatigue and increase user comfort. The eye cover **1402** may be made of other materials, soft, stiff, priable, etc. and may have another material on the periphery that contacts the face for comfort. In embodiments, the eye cover **1402** may include a fan to exchange air between an external environment and an internal space, where the internal space is defined in part by the face of the user. The fan may operate very slowly and at low power to exchange the air to keep the face of the user cool. In embodiments the fan may have a variable speed controller and/or a temperature sensor may be positioned to measure temperature in the internal space to control the temperature in the internal space to a specified range, temperature, etc. The internal space is generally characterized by the space confined space in front of the user's eyes and upper cheeks where the eye cover encloses the area.

[0091] Another aspect of the present disclosure relates to flexibly mounting an audio headset on the head-worn computer **102** and/or the eye cover **1402**. In embodiments, the audio headset is mounted with a relatively rigid system that has flexible joint(s) (e.g. a rotational joint at the connection with the eye cover, a rotational joint in the middle of a rigid arm, etc.) and extension(s) (e.g. a telescopic arm) to provide the user with adjustability to allow for a comfortable fit over, in or around the user's ear. In embodiments, the audio headset is mounted with a flexible system that is more flexible throughout, such as with a wire-based connection.

[0092] FIG. **14***g* illustrates a head-worn computer **102** with removable lenses **1414** along with a mounted eye cover **1402**. The head-worn computer, in embodiments, includes a see-through display (as disclosed herein). The eye cover **1402** also includes a mounted audio headset **1422**. The mounted audio headset **1422** in this embodiment is mounted to the eye cover **1402** and has audio wire connections (not shown). In embodiments, the audio wires' connections may connect to an internal wireless communication system (e.g. Bluetooth, NFC, WiFi) to make connection to the processor in the head-worn computer. In embodiments, the audio wires may connect to a magnetic connector, mechanical connector or the like to make the connection.

[0093] FIG. **14***h* illustrates an unmounted eye cover **1402** with a mounted audio headset **1422**. As illustrated, the mechanical design of the eye cover is adapted to fit onto the head-worn computer to provide visual isolation or partial isolation and the audio headset.

[0094] In embodiments, the eye cover **1402** may be adapted to be removably mounted on a head-worn computer **102** with a see-through computer display. An audio headset **1422** with an adjustable mount may be connected to the eye cover, wherein the adjustable mount may provide extension and rotation to provide a user of the head-worn computer with a mechanism to align the audio headset with an ear of the user. In embodiments, the audio headset includes an audio wire connected to a connector on the eye cover and the eye cover connector may be adapted to removably mate with a connector on the head-worn computer. In embodiments, the audio headset may be adapted to receive audio signals from the head-worn computer **102** through a wireless connection (e.g. Bluetooth, WiFi). As described elsewhere herein, the head-worn computer **102** may have a removable and replaceable front lens **1414**. The eye cover **1402** may include a battery to power systems internal to the eye cover **1402**. The eye cover **1402** may have a battery to power systems internal to the head-worn computer **102**.

[0095] In embodiments, the eye cover **1402** may include a fan adapted to exchange air between an internal space, defined in part by the user's face, and an external environment to cool the air in the internal space and the user's face. In embodiments, the audio headset **1422** may include a vibratory system (e.g. a vibration motor, piezo motor, etc. in the armature and/or in the section over the ear) adapted to provide the user with a haptic feedback coordinated with digital content presented in the see-through computer display. In embodiments, the head-worn computer **102** includes a vibratory system adapted to provide the user with a haptic feedback coordinated with digital content presented in the see-through computer display.

[0096] In embodiments, the eye cover **1402** is adapted to be removably mounted on a head-worn computer with a see-through computer display. The eye cover **1402** may also include a flexible audio headset mounted to the eye cover **1402**, wherein the flexibility provides the user of the head-worn computer **102** with a mechanism to align the audio headset with an ear of the user. In embodiments, the flexible audio headset is mounted to the eye cover **1402** with a magnetic connection. In embodiments, the flexible audio headset may be mounted to the eye cover **1402** with a mechanical connection.

[0097] In embodiments, the audio headset **1422** may be spring or otherwise loaded such that the head set presses inward towards the user's ears for a more secure fit.

[0098] Referring to FIG. **15**, we now turn to describe a particular external user interface **104**, referred to generally as a pen **1500**. The pen **1500** is a specially designed external user interface **104** and can operate as a user interface, to many different styles of HWC **102**. The pen **1500** generally follows the form of a conventional pen, which is a familiar user handled device and creates an intuitive physical interface for many of the operations to be carried out in the HWC system **100**. The pen **1500** may be one of several user interfaces **104** used in connection with controlling operations within the HWC system **100**. For example, the HWC **102** may watch for and interpret hand gestures **116** as control signals, where the pen **1500** may also be used as a user interface with the same HWC **102**. Similarly, a remote keyboard may be used as an external user interface **104** in concert with the pen **1500**. The combination of user interfaces or the use of just one control system generally depends on the operation(s) being executed in the HWC's system **100**.

[0099] While the pen **1500** may follow the general form of a conventional pen, it contains numerous technologies that enable it to function as an external user interface **104**. FIG. **15** illustrates technologies comprised in the pen **1500**. As can be seen, the pen **1500** may include a camera **1508**, which is arranged to view through lens **1502**. The camera may then be focused, such as through lens **1502**, to image a surface upon which a user is writing or making other movements to interact with the HWC **102**. There are situations where the pen **1500** will also have an ink, graphite, or other system such that what is being written can be seen on the writing surface. There are other situations where the pen **1500** does

not have such a physical writing system so there is no deposit on the writing surface, where the pen would only be communicating data or commands to the HWC **102**. The lens **1502** configuration is described in greater detail herein. The function of the camera **1508** is to capture information from an unstructured writing surface such that pen strokes can be interpreted as intended by the user. To assist in the predication of the intended stroke path, the pen **1500** may include a sensor, such as an IMU **1512**. Of course, the IMU could be included in the pen **1500** in its separate parts (e.g. gyro, accelerometer, etc.) or an IMU could be included as a single unit. In this instance, the IMU **1512** is used to measure and predict the motion of the pen **1500**. In turn, the integrated microprocessor **1510** would take the IMU information and camera information as inputs and process the information to form a prediction of the pen tip movement.

[0100] The pen **1500** may also include a pressure monitoring system **1504**, such as to measure the pressure exerted on the lens **1502**. As will be described in greater detail herein, the pressure measurement can be used to predict the user's intention for changing the weight of a line, type of a line, type of brush, click, double click, and the like. In embodiments, the pressure sensor may be constructed using any force or pressure measurement sensor located behind the lens **1502**, including for example, a resistive sensor, a current sensor, a capacitive sensor, a voltage sensor such as a piezoelectric sensor, and the like.

[0101] The pen **1500** may also include a communications module **1518**, such as for bi-directional communication with the HWC **102**. In embodiments, the communications module **1518** may be a short distance communication module (e.g. Bluetooth). The communications module **1518** may be security matched to the HWC **102**. The communications module **1518** may be arranged to communicate data and commands to and from the microprocessor **1510** of the pen **1500**. The microprocessor **1510** may be programmed to interpret data generated from the camera **1508**, IMU **1512**, and pressure sensor **1504**, and the like, and then pass a command onto the HWC **102** through the communications module **1518**, for example. In another embodiment, the data collected from any of the input sources (e.g. camera **1508**, IMU **1512**, pressure sensor **1504**) by the microprocessor may be communicated by the communication module **1518** to the HWC **102**, and the HWC **102** may perform data processing and prediction of the user's intention when using the pen **1500**. In yet another embodiment, the data may be further passed on through a network **110** to a remote device **112**, such as a server, for the data processing and prediction. The commands may then be communicated back to the HWC **102** for execution (e.g. display writing in the glasses display, make a selection within the UI of the glasses display, control a remote external device **112**, control a local external device **108**), and the like. The pen may also include memory **1514** for long or short term uses.

[0102] The pen **1500** may also include a number of physical user interfaces, such as quick launch buttons **1522**, a touch sensor **1520**, and the like. The quick launch buttons **1522** may be adapted to provide the user with a fast way of jumping to a software application in the HWC system **100**. For example, the user may be a frequent user of communication software packages (e.g. email, text, Twitter, Instagram, Facebook, Google+, and the like), and the user may program a quick launch button **1522** to command the HWC **102** to launch an application. The pen **1500** may be provided with several quick launch buttons **1522**, which may be user programmable or factory programmable. The quick launch button **1522** may be programmed to perform an operation. For example, one of the buttons may be programmed to clear the digital display of the HWC **102**. This would create a fast way for the user to clear the screens on the HWC **102** for any reason, such as for example to better view the environment. The quick launch button functionality will be discussed in further detail below. The touch sensor **1520** may be used to take gesture style input from the user. For example, the user may be able to take a single finger and run it across the touch sensor **1520** to affect a page scroll.

[0103] The pen **1500** may also include a laser pointer **1524**. The laser pointer **1524** may be coordinated with the IMU **1512** to coordinate gestures and laser pointing. For example, a user may use the laser **1524** in a presentation to help with guiding the audience with the interpretation of graphics and the IMU **1512** may, either simultaneously or when the laser **1524** is off, interpret the user's gestures as commands or data input.

[0104] FIG. **16** illustrates yet another embodiment of the present disclosure. FIG. **16** illustrates a watchband clip-on controller **2000**. The watchband clip-on controller may be a controller used to control the HWC **102** or devices in the HWC system **100**. The watchband clip-on controller **2000** has a fastener **2018** (e.g. rotatable clip) that is mechanically adapted to attach to a watchband, as illustrated at **2004**.

[0105] The watchband controller **2000** may have quick launch interfaces **2008** (e.g. to launch applications and choosers as described herein), a touch pad **2014** (e.g. to be used as a touch style mouse for GUI control in a HWC **102** display) and a display **2012**. The clip **2018** may be adapted to fit a wide range of watchbands so it can be used in connection with a watch that is independently selected for its function. The clip, in embodiments, is rotatable such that a user can position it in a desirable manner. In embodiments the clip may be a flexible strap. In embodiments, the flexible strap may be adapted to be stretched to attach to a hand, wrist, finger, device, weapon, and the like.

[0106] In embodiments, the watchband controller may be configured as a removable and replacable watchband. For example, the controller may be incorporated into a band with a certain width, segment spacing's, etc. such that the watchband, with its incorporated controller, can be attached to a watch body. The attachment, in embodiments, may be mechanically adapted to attach with a pin upon which the watchband rotates. In embodiments, the watchband controller may be electrically connected to the watch and/or watch body such that the watch, watch body and/or the watchband controller can communicate data between them.

[0107] The watchband controller **2000** may have 3-axis motion monitoring (e.g. through an IMU, accelerometers, magnetometers, gyroscopes, etc.) to capture user motion. The user motion may then be interpreted for gesture control.

[0108] In embodiments, the watchband controller **2000** may comprise fitness sensors and a fitness computer. The sensors may track heart rate, calories burned, strides, distance covered, and the like. The data may then be compared against performance goals and/or standards for user feedback.

[0109] In embodiments directed to capturing images of the wearer's eye, light to illuminate the wearer's eye can be provided by several different sources including: light from the displayed image (i.e. image light); light from the envi-

ronment that passes through the combiner or other optics; light provided by a dedicated eye light, etc. FIGS. **17** and **18** show illustrations of dedicated eye illumination lights **3420**. FIG. **17** shows an illustration from a side view in which the dedicated illumination eye light **3420** is positioned at a corner of the combiner **3410** so that it doesn't interfere with the image light **3415**. The dedicated eye illumination light **3420** is pointed so that the eye illumination light **3425** illuminates the eyebox **3427** where the eye **3430** is located when the wearer is viewing displayed images provided by the image light **3415**. FIG. **18** shows an illustration from the perspective of the eye of the wearer to show how the dedicated eye illumination light **3420** is positioned at the corner of the combiner **3410**. While the dedicated eye illumination light **3420** is shown at the upper left corner of the combiner **3410**, other positions along one of the edges of the combiner **3410**, or other optical or mechanical components, are possible as well. In other embodiments, more than one dedicated eye light **3420** with different positions can be used. In an embodiment, the dedicated eye light **3420** is an infrared light that is not visible by the wearer (e.g. 800 nm) so that the eye illumination light **3425** doesn't interfere with the displayed image perceived by the wearer.

[0110] In embodiments, the eye imaging camera is inline with the image light optical path, or part of the image light optical path. For example, the eye camera may be positioned in the upper module to capture eye image light that reflects back through the optical system towards the image display. The eye image light may be captured after reflecting off of the image source (e.g. in a DLP configuration where the mirrors can be positioned to reflect the light towards the eye image light camera), a partially reflective surface may be placed along the image light optical path such that when the eye image light reflects back into the upper or lower module that it is reflected in a direction that the eye imaging camera can capture light eye image light. In other embodiments, the eye image light camera is positioned outside of the image light optical path. For example, the camera(s) may be positioned near the outer lens of the platform.

[0111] FIG. **19** shows a series of illustrations of captured eye images that show the eye glint (i.e. light that reflects off the front of the eye) produced by a dedicated eye light mounted adjacent to the combiner as previously described herein. In this embodiment of the disclosure, captured images of the wearer's eye are analyzed to determine the relative positions of the iris **3550**, pupil, or other portion of the eye, and the eye glint **3560**. The eye glint is a reflected image of the dedicated eye light **3420** when the dedicated light is used. FIG. **19** illustrates the relative positions of the iris **3550** and the eye glint **3560** for a variety of eye positions. By providing a dedicated eye light **3420** in a fixed position, combined with the fact that the human eye is essentially spherical, or at least a reliably repeatable shape, the eye glint provides a fixed reference point against which the determined position of the iris can be compared to determine where the wearer is looking, either within the displayed image or within the see-through view of the surrounding environment. By positioning the dedicated eye light **3420** at a corner of the combiner **3410**, the eye glint **3560** is formed away from the iris **3550** in the captured images. As a result, the positions of the iris and the eye glint can be determined more easily and more accurately during the analysis of the captured images, since they do not interfere with one another. In a further embodiment, the combiner includes an associated cut filter that prevents infrared light from the environment from entering the HWC and the eye camera is an infrared camera, so that the eye glint **3560** is only provided by light from the dedicated eye light. For example, the combiner can include a low pass filter that passes visible light while reflecting infrared light from the environment away from the eye camera, reflecting infrared light from the dedicated eye light toward the user's eye and the eye camera can include a high pass filter that absorbs visible light associated with the displayed image while passing infrared light associated with the eye image.

[0112] In an embodiment of the eye imaging system, the lens for the eye camera is designed to take into account the optics associated with the upper module **202** and the lower module **204**. This is accomplished by designing the eye camera to include the optics in the upper module **202** and optics in the lower module **204**, so that a high MTF image is produced, at the image sensor in the eye camera, of the wearer's eye. In yet a further embodiment, the eye camera lens is provided with a large depth of field to eliminate the need for focusing the eye camera to enable sharp images of the eye to be captured. Where a large depth of field is typically provided by a high f/# lens (e.g. f/#>5). In this case, the reduced light gathering associated with high f/# lenses is compensated by the inclusion of a dedicated eye light to enable a bright image of the eye to be captured. Further, the brightness of the dedicated eye light can be modulated and synchronized with the capture of eye images so that the dedicated eye light has a reduced duty cycle and the brightness of infrared light on the wearer's eye is reduced.

[0113] In a further embodiment, FIG. **20***a* shows an illustration of an eye image that is used to identify the wearer of the HWC. In this case, an image of the wearer's eye **3611** is captured and analyzed for patterns of identifiable features **3612**. The patterns are then compared to a database of eye images to determine the identity of the wearer. After the identity of the wearer has been verified, the operating mode of the HWC and the types of images, applications, and information to be displayed can be adjusted and controlled in correspondence to the determined identity of the wearer. Examples of adjustments to the operating mode depending on who the wearer is determined to be or not be include: making different operating modes or feature sets available, shutting down or sending a message to an external network, allowing guest features and applications to run, etc.

[0114] FIG. **20***b* is an illustration of another embodiment using eye imaging, in which the sharpness of the displayed image is determined based on the eye glint produced by the reflection of the displayed image from the wearer's eye surface. By capturing images of the wearer's eye **3611**, an eye glint **3622**, which is a small version of the displayed image can be captured and analyzed for sharpness. If the displayed image is determined to not be sharp, then an automated adjustment to the focus of the HWC optics can be performed to improve the sharpness. This ability to perform a measurement of the sharpness of a displayed image at the surface of the wearer's eye can provide a very accurate measurement of image quality. Having the ability to measure and automatically adjust the focus of displayed images can be very useful in augmented reality imaging where the focus distance of the displayed image can be varied in response to changes in the environment or changes in the method of use by the wearer.

[0115] An aspect of the present disclosure relates to controlling the HWC **102** through interpretations of eye imagery. In embodiments, eye-imaging technologies, such as those described herein, are used to capture an eye image or a series of eye images for processing. The image(s) may be processed to determine a user intended action, an HWC predetermined reaction, or other action. For example, the imagery may be interpreted as an affirmative user control action for an application on the HWC **102**. Or, the imagery may cause, for example, the HWC **102** to react in a predetermined way such that the HWC **102** is operating safely, intuitively, etc.

[0116] FIG. **21** illustrates an eye imagery process that involves imaging the HWC **102** wearer's eye(s) and processing the images (e.g. through eye imaging technologies described herein) to determine in what position **3702** the eye is relative to it's neutral or forward looking position and/or the FOV **3708**. The process may involve a calibration step where the user is instructed, through guidance provided in the FOV of the HWC **102**, to look in certain directions such that a more accurate prediction of the eye position relative to areas of the FOV can be made. In the event the wearer's eye is determined to be looking towards the right side of the FOV **3708** (as illustrated in FIG. **21**, the eye is looking out of the page) a virtual target line may be established to project what in the environment the wearer may be looking towards or at. The virtual target line may be used in connection with an image captured by camera on the HWC **102** that images the surrounding environment in front of the wearer. In embodiments, the field of view of the camera capturing the surrounding environment matches, or can be matched (e.g. digitally), to the FOV **3708** such that making the comparison is made more clear. For example, with the camera capturing the image of the surroundings in an angle that matches the FOV **3708** the virtual line can be processed (e.g. in **2***d* or **3***d*, depending on the camera images capabilities and/or the processing of the images) by projecting what surrounding environment objects align with the virtual target line. In the event there are multiple objects along the virtual target line, focal planes may be established corresponding to each of the objects such that digital content may be placed in an area in the FOV **3708** that aligns with the virtual target line and falls at a focal plane of an intersecting object. The user then may see the digital content when he focuses on the object in the environment, which is at the same focal plane. In embodiments, objects in line with the virtual target line may be established by comparison to mapped information of the surroundings.

[0117] In embodiments, the digital content that is in line with the virtual target line may not be displayed in the FOV until the eye position is in the right position. This may be a predetermined process. For example, the system may be set up such that a particular piece of digital content (e.g. an advertisement, guidance information, object information, etc.) will appear in the event that the wearer looks at a certain object(s) in the environment. A virtual target line(s) may be developed that virtually connects the wearer's eye with an object(s) in the environment (e.g. a building, portion of a building, mark on a building, gps location, etc.) and the virtual target line may be continually updated depending on the position and viewing direction of the wearer (e.g. as determined through GPS, e-compass, IMU, etc.) and the position of the object. When the virtual target line suggests that the wearer's pupil is substantially aligned with the virtual target line or about to be aligned with the virtual target line, the digital content may be displayed in the FOV **3704**.

[0118] In embodiments, the time spent looking along the virtual target line and/or a particular portion of the FOV **3708** may indicate that the wearer is interested in an object in the environment and/or digital content being displayed. In the event there is no digital content being displayed at the time a predetermined period of time is spent looking at a direction, digital content may be presented in the area of the FOV **3708**. The time spent looking at an object may be interpreted as a command to display information about the object, for example. In other embodiments, the content may not relate to the object and may be presented because of the indication that the person is relatively inactive. In embodiments, the digital content may be positioned in proximity to the virtual target line, but not inline with it such that the wearer's view of the surroundings are not obstructed but information can augment the wearer's view of the surroundings. In embodiments, the time spent looking along a target line in the direction of displayed digital content may be an indication of interest in the digital content. This may be used as a conversion event in advertising. For example, an advertiser may pay more for an add placement if the wearer of the HWC **102** looks at a displayed advertisement for a certain period of time. As such, in embodiments, the time spent looking at the advertisement, as assessed by comparing eye position with the content placement, target line or other appropriate position may be used to determine a rate of conversion or other compensation amount due for the presentation.

[0119] An aspect of the disclosure relates to removing content from the FOV of the HWC **102** when the wearer of the HWC **102** apparently wants to view the surrounding environments clearly. FIG. **22** illustrates a situation where eye imagery suggests that the eye has or is moving quickly so the digital content **3804** in the FOV **3808** is removed from the FOV **3808**. In this example, the wearer may be looking quickly to the side indicating that there is something on the side in the environment that has grabbed the wearer's attention. This eye movement **3802** may be captured through eye imaging techniques (e.g. as described herein) and if the movement matches a predetermined movement (e.g. speed, rate, pattern, etc.) the content may be removed from view. In embodiments, the eye movement is used as one input and HWC movements indicated by other sensors (e.g. IMU in the HWC) may be used as another indication. These various sensor movements may be used together to project an event that should cause a change in the content being displayed in the FOV.

[0120] Another aspect of the present disclosure relates to determining a focal plane based on the wearer's eye convergence. Eyes are generally converged slightly and converge more when the person focuses on something very close. This is generally referred to as convergence. In embodiments, convergence is calibrated for the wearer. That is, the wearer may be guided through certain focal plane exercises to determine how much the wearer's eyes converge at various focal planes and at various viewing angles. The convergence information may then be stored in a database for later reference. In embodiments, a general table may be used in the event there is no calibration step or the person skips the calibration step. The two eyes may then be imaged periodically to determine the convergence in an

attempt to understand what focal plane the wearer is focused on. In embodiments, the eyes may be imaged to determine a virtual target line and then the eye's convergence may be determined to establish the wearer's focus, and the digital content may be displayed or altered based thereon.

[0121] FIG. **23** illustrates a situation where digital content is moved **3902** within one or both of the FOVs **3908** and **3910** to align with the convergence of the eyes as determined by the pupil movement **3904**. By moving the digital content to maintain alignment, in embodiments, the overlapping nature of the content is maintained so the object appears properly to the wearer. This can be important in situations where **3**D content is displayed.

[0122] An aspect of the present disclosure relates to controlling the HWC **102** based on events detected through eye imaging. A wearer winking, blinking, moving his eyes in a certain pattern, etc. may, for example, control an application of the HWC **102**. Eye imaging (e.g. as described herein) may be used to monitor the eye(s) of the wearer and once a pre-determined pattern is detected an application control command may be initiated.

[0123] An aspect of the disclosure relates to monitoring the health of a person wearing a HWC **102** by monitoring the wearer's eye(s). Calibrations may be made such that the normal performance, under various conditions (e.g. lighting conditions, image light conditions, etc.) of a wearer's eyes may be documented. The wearer's eyes may then be monitored through eye imaging (e.g. as described herein) for changes in their performance. Changes in performance may be indicative of a health concern (e.g. concussion, brain injury, stroke, loss of blood, etc.). If detected the data indicative of the change or event may be communicated from the HWC **102**.

[0124] Aspects of the present disclosure relate to security and access of computer assets (e.g. the HWC itself and related computer systems) as determined through eye image verification. As discussed herein elsewhere, eye imagery may be compared to known person eye imagery to confirm a person's identity. Eye imagery may also be used to confirm the identity of people wearing the HWCs **102** before allowing them to link together or share files, streams, information, etc.

[0125] A variety of use cases for eye imaging are possible based on technologies described herein. An aspect of the present disclosure relates to the timing of eye image capture. The timing of the capture of the eye image and the frequency of the capture of multiple images of the eye can vary dependent on the use case for the information gathered from the eye image. For example, capturing an eye image to identify the user of the HWC may be required only when the HWC has been turned ON or when the HWC determines that the HWC has been put onto a wearer's head to control the security of the HWC and the associated information that is displayed to the user, wherein the orientation, movement pattern, stress or position of the earhorns (or other portions of the HWC) of the HWC can be used to determine that a person has put the HWC onto their head with the intention to use the HWC. Those same parameters may be monitored in an effort to understand when the HWC is dismounted from the user's head. This may enable a situation where the capture of an eye image for identifying the wearer may be completed only when a change in the wearing status is identified. In a contrasting example, capturing eye images to monitor the health of the wearer may require images to be captured periodically (e.g. every few seconds, minutes, hours, days, etc.). For example, the eye images may be taken in minute intervals when the images are being used to monitor the health of the wearer when detected movements indicate that the wearer is exercising. In a further contrasting example, capturing eye images to monitor the health of the wearer for long-term effects may only require that eye images be captured monthly. Embodiments of the disclosure relate to selection of the timing and rate of capture of eye images to be in correspondence with the selected use scenario associated with the eye images. These selections may be done automatically, as with the exercise example above where movements indicate exercise, or these selections may be set manually. In a further embodiment, the selection of the timing and rate of eye image capture is adjusted automatically depending on the mode of operation of the HWC. The selection of the timing and rate of eye image capture can further be selected in correspondence with input characteristics associated with the wearer including age and health status, or sensed physical conditions of the wearer including heart rate, chemical makeup of the blood and eye blink rate.

[0126] FIG. **24** illustrates a cross section of an eyeball of a wearer of an HWC with focus points that can be associated with the eye imaging system of the disclosure. The eyeball **5010** includes an iris **5012** and a retina **5014**. Because the eye imaging system of the disclosure provides coaxial eye imaging with a display system, images of the eye can be captured from a perspective directly in front of the eye and inline with where the wearer is looking. In embodiments of the disclosure, the eye imaging system can be focused at the iris **5012** and/or the retina **5014** of the wearer, to capture images of the external surface of the iris **5012** or the internal portions of the eye, which includes the retina **5014**. FIG. **24** shows light rays **5020** and **5025** that are respectively associated with capturing images of the iris **5012** or the retina **5014** wherein the optics associated with the eye imaging system are respectively focused at the iris **5012** or the retina **5014**. Illuminating light can also be provided in the eye imaging system to illuminate the iris **5012** or the retina **5014**. FIG. **25** shows an illustration of an eye including an iris **5130** and a sclera **5125**. In embodiments, the eye imaging system can be used to capture images that include the iris **5130** and portions of the sclera **5125**. The images can then be analyzed to determine color, shapes and patterns that are associated with the user. In further embodiments, the focus of the eye imaging system is adjusted to enable images to be captured of the iris **5012** or the retina **5014**. Illuminating light can also be adjusted to illuminate the iris **5012** or to pass through the pupil of the eye to illuminate the retina **5014**. The illuminating light can be visible light to enable capture of colors of the iris **5012** or the retina **5014**, or the illuminating light can be ultraviolet (e.g. 340 nm), near infrared (e.g. 850 nm) or mid-wave infrared (e.g. 5000 nm) light to enable capture of hyperspectral characteristics of the eye.

[0127] FIGS. **26***a* and **26***b* illustrate captured images of eyes where the eyes are illuminated with structured light patterns. In FIG. **26***a*, an eye **5220** is shown with a projected structured light pattern **5230**, where the light pattern is a grid of lines. A light pattern of such as **5230** can be provided by the light source **5355** by including a diffractive or a refractive device to modify the light **5357** as are known by those skilled in the art. A visible light source can also be included for the second camera, which can include a diffractive or refractive to modify the light **5467** to provide a light pattern.

FIG. **26***b* illustrates how the structured light pattern of **5230** becomes distorted to **5235** when the user's eye **5225** looks to the side. This distortion comes from the fact that the human eye is not completely spherical in shape, instead the iris sticks out slightly from the eyeball to form a bump in the area of the iris. As a result, the shape of the eye and the associated shape of the reflected structured light pattern is different depending on which direction the eye is pointed, when images of the eye are captured from a fixed position. Changes in the structured light pattern can subsequently be analyzed in captured eye images to determine the direction that the eye is looking.

[0128] The eye imaging system can also be used for the assessment of aspects of health of the user. In this case, information gained from analyzing captured images of the iris **5130** or sclera **5125** are different from information gained from analyzing captured images of the retina **5014**. Where images of the retina **5014** are captured using light that illuminates the inner portions of the eye including the retina **5014**. The light can be visible light, but in an embodiment, the light is infrared light (e.g. wavelength 1 to 5 microns) and the eye camera is an infrared light sensor (e.g. an InGaAs sensor) or a low resolution infrared image sensor that is used to determine the relative amount of light that is absorbed, reflected or scattered by the inner portions of the eye. Wherein the majority of the light that is absorbed, reflected or scattered can be attributed to materials in the inner portion of the eye including the retina where there are densely packed blood vessels with thin walls so that the absorption, reflection and scattering are caused by the material makeup of the blood. These measurements can be conducted automatically when the user is wearing the HWC, either at regular intervals, after identified events or when prompted by an external communication. In a preferred embodiment, the illuminating light is near infrared or mid infrared (e.g. 0.7 to 5 microns wavelength) to reduce the chance for thermal damage to the wearer's eye. In a further embodiment, the light source and the camera together comprise a spectrometer wherein the relative intensity of the light reflected by the eye is analyzed over a series of narrow wavelengths within the range of wavelengths provided by the light source to determine a characteristic spectrum of the light that is absorbed, reflected or scattered by the eye. For example, the light source can provide a broad range of infrared light to illuminate the eye and the camera can include: a grating to laterally disperse the reflected light from the eye into a series of narrow wavelength bands that are captured by a linear photodetector so that the relative intensity by wavelength can be measured and a characteristic absorbance spectrum for the eye can be determined over the broad range of infrared. In a further example, the light source can provide a series of narrow wavelengths of light (ultraviolet, visible or infrared) to sequentially illuminate the eye and camera includes a photodetector that is selected to measure the relative intensity of the series of narrow wavelengths in a series of sequential measurements that together can be used to determine a characteristic spectrum of the eye. The determined characteristic spectrum is then compared to known characteristic spectra for different materials to determine the material makeup of the eye. In yet another embodiment, the illuminating light is focused on the retina and a characteristic spectrum of the retina is determined and the spectrum is compared to known spectra for materials that may be present in the user's blood. For example, in the visible wavelengths 540 nm is useful for detecting hemoglobin and 660 nm is useful for differentiating oxygenated hemoglobin. In a further example, in the infrared, a wide variety of materials can be identified as is known by those skilled in the art, including: glucose, urea, alcohol and controlled substances.

[0129] Another aspect of the present disclosure relates to an intuitive user interface mounted on the HWC **102** where the user interface includes tactile feedback (otherwise referred to as haptic feedback) to the user to provide the user an indication of engagement and change. In embodiments, the user interface is a rotating element on a temple section of a glasses form factor of the HWC **102**. The rotating element may include segments such that it positively engages at certain predetermined angles. This facilitates a tactile feedback to the user. As the user turns the rotating element it 'clicks' through it's predetermined steps or angles and each step causes a displayed user interface content to be changed. For example, the user may cycle through a set of menu items or selectable applications. In embodiments, the rotating element also includes a selection element, such as a pressure-induced section where the user can push to make a selection.

[0130] FIG. **27** illustrates a human head wearing a head-worn computer in a glasses form factor. The glasses have a temple section **11702** and a rotating user interface element **11704**. The user can rotate the rotating element **11704** to cycle through options presented as content in the see-through display of the glasses. FIG. **28** illustrates several examples of different rotating user interface elements **11704***a*, **11704***b* and **11704***c*. Rotating element **11704***a* is mounted at the front end of the temple and has significant side and top exposure for user interaction. Rotating element **11704***b* is mounted further back and also has significant exposure (e.g. 270 degrees of touch). Rotating element **11704***c* has less exposure and is exposed for interaction on the top of the temple. Other embodiments may have a side or bottom exposure.

[0131] Another aspect of the present disclosure relates to a haptic system in a head-worn computer. Creating visual, audio, and haptic sensations in coordination can increase the enjoyment or effectiveness of awareness in a number of situations. For example, when viewing a movie or playing a game while digital content is presented in a computer display of a head-worn computer, it is more immersive to include coordinated sound and haptic effects. When presenting information in the head-worn computer, it may be advantageous to present a haptic effect to enhance or be the information. For example, the haptic sensation may gently cause the user of the head-worn computer believe that there is some presence on the user's right side, but out of sight. It may be a very light haptic effect to cause the 'tingling' sensation of a presence of unknown origin. It may be a high intensity haptic sensation to coordinate with an apparent explosion, either out of sight or in-sight in the computer display. Haptic sensations can be used to generate a perception in the user that objects and events are close by. As another example, digital content may be presented to the user in the computer displays and the digital content may appear to be within reach of the user. If the user reaches out his hand in an attempt to touch the digital object, which is not a real object, the haptic system may cause a sensation and the user may interpret the sensation as a touching sensation. The haptic system may generate slight vibrations

near one or both temples for example and the user may infer from those vibrations that he has touched the digital object. This additional dimension in sensory feedback can be very useful and create a more intuitive and immersive user experience.

[0132] Another aspect of the present disclosure relates to controlling and modulating the intensity of a haptic system in a head-worn computer. In embodiments, the haptic system includes separate piezo strips such that each of the separate strips can be controlled separately. Each strip may be controlled over a range of vibration levels and some of the separate strips may have a greater vibration capacity than others. For example, a set of strips may be mounted in the arm of the head-worn computer (e.g. near the user's temple, ear, rear of the head, substantially along the length of the arm, etc.) and the further forward the strip the higher capacity the strip may have. The strips of varying capacity could be arranged in any number of ways, including linear, curved, compound shape, two dimensional array, one dimensional array, three dimensional array, etc.). A processor in the head-worn computer may regulate the power applied to the strips individually, in sub-groups, as a whole, etc. In embodiments, separate strips or segments of varying capacity are individually controlled to generate a finely controlled multi-level vibration system. Patterns based on frequency, duration, intensity, segment type, and/or other control parameters can be used to generate signature haptic feedback. For example, to simulate the haptic feedback of an explosion close to the user, a high intensity, low frequency, and moderate duration may be a pattern to use. A bullet whipping by the user may be simulated with a higher frequency and shorter duration. Following this disclosure, one can imagine various patterns for various simulation scenarios.

[0133] Another aspect of the present disclosure relates to making a physical connection between the haptic system and the user's head. Typically, with a glasses format, the glasses touch the user's head in several places (e.g. ears, nose, forehead, etc.) and these areas may be satisfactory to generate the necessary haptic feedback. In embodiments, an additional mechanical element may be added to better translate the vibration from the haptic system to a desired location on the user's head. For example, a vibration or signal conduit may be added to the head-worn computer such that there is a vibration translation medium between the head-worn computers internal haptic system and the user's temple area.

[0134] FIG. **29** illustrates a head-worn computer **102** with a haptic system comprised of piezo strips **29002**. In this embodiment, the piezo strips **29002** are arranged linearly with strips of increasing vibration capacity from back to front of the arm **29004**. The increasing capacity may be provided by different sized strips, for example. This arrangement can cause a progressively increased vibration power **29003** from back to front. This arrangement is provided for ease of explanation; other arrangements are contemplated by the inventors of the present application and these examples should not be construed as limiting. The head-worn computer **102** may also have a vibration or signal conduit **29001** that facilitates the physical vibrations from the haptic system to the head of the user **29005**. The vibration conduit may be malleable to form to the head of the user for a tighter or more appropriate fit.

[0135] An aspect of the present invention relates to a head-worn computer, comprising: a frame adapted to hold a computer display in front of a user's eye; a processor adapted to present digital content in the computer display and to produce a haptic signal in coordination with the digital content display; and a haptic system comprised of a plurality of haptic segments, wherein each of the haptic segments is individually controlled in coordination with the haptic signal. In embodiments, the haptic segments comprise a piezo strip activated by the haptic signal to generate a vibration in the frame. The intensity of the haptic system may be increased by activating more than one of the plurality of haptic segments. The intensity may be further increased by activating more than 2 of the plurality of haptic segments. In embodiments, each of the plurality of haptic segments comprises a different vibration capacity. In embodiments, the intensity of the haptic system may be regulated depending on which of the plurality of haptic segments is activated. In embodiments, each of the plurality of haptic segments are mounted in a linear arrangement and the segments are arranged such that the higher capacity segments are at one end of the linear arrangement. In embodiments, the linear arrangement is from back to front on an arm of the head-worn computer. In embodiments, the linear arrangement is proximate a temple of the user. In embodiments, the linear arrangement is proximate an ear of the user. In embodiments, the linear arrangement is proximate a rear portion of the user's head. In embodiments, the linear arrangement is from front to back on an arm of the head-worn computer, or otherwise arranged.

[0136] An aspect of the present disclosure provides a head-worn computer with a vibration conduit, wherein the vibration conduit is mounted proximate the haptic system and adapted to touch the skin of the user's head to facilitate vibration sensations from the haptic system to the user's head. In embodiments, the vibration conduit is mounted on an arm of the head-worn computer. In embodiments, the vibration conduit touches the user's head proximate a temple of the user's head. In embodiments, the vibration conduit is made of a soft material that deforms to increase contact area with the user's head.

[0137] An aspect of the present disclosure relates to a haptic array system in a head-worn computer. The haptic array(s) that can correlate vibratory sensations to indicate events, scenarios, etc. to the wearer. The vibrations may correlate or respond to auditory, visual, proximity to elements, etc. of a video game, movie, or relationships to elements in the real world as a means of augmenting the wearer's reality. As an example, physical proximity to objects in a wearer's environment, sudden changes in elevation in the path of the wearer (e.g. about to step off a curb), the explosions in a game or bullets passing by a wearer. Haptic effects from a piezo array(s) that make contact the side of the wearer's head may be adapted to effect sensations that correlate to other events experienced by the wearer.

[0138] FIG. **29***a* illustrates a haptic system according to the principles of the present disclosure. In embodiments the piezo strips are mounted or deposited with varying width and thus varying force Piezo Elements on a rigid or flexible, non-conductive substrate attached, to or part of the temples of glasses, goggles, bands or other form factor. The non-conductive substrate may conform to the curvature of a head by being curved and it may be able to pivot (e.g. in and out, side to side, up and down, etc.) from a person's head. This

arrangement may be mounted to the inside of the temples of a pair of glasses. Similarly, the vibration conduit, described herein elsewhere, may be mounted with a pivot. As can be seen in FIG. **29***a*, the piezo strips **29002** may be mounted on a substrate and the substrate may be mounted to the inside of a glasses arm, strap, etc. The piezo strips in this embodiment increase in vibration capacity as they move forward.

[0139] An aspect of the present invention relates to providing vision aids to people with vision impairments. In embodiments, the vision aids take the form of a head-worn computer with an augmented reality display system (e.g. as described herein). The head-worn computer may have a camera with magnification adjustment (e.g. either optical or digital zoom). A visually impaired person may wear the head-worn computer to image portions of the person's environment and have the images magnified or digitally manipulated such that they can be presented in the augmented reality computer display to help the person better see things in the environment. In embodiments, the head-worn computer may recognize gestures or other indications such that the user can select items (e.g. words on a page, paragraph on a page, page in a book, content) to have the items magnified or digitally manipulated and presented as digital content in the augmented reality display. The selection and presentation system may be intuitive to provide the person with a system that operates seamlessly in multiple environments.

[0140] The inventors have discovered that visual aid solutions for the visually impaired have significant limitations, are not portable, and are not intuitive to use. The inventors have discovered that using augmented reality head-worn computer display systems drastically improves the way the visually impaired interact with the physical world. By allowing a user to use a camera system in the head-worn system to image a portion of the surrounding environment in front of the user and then magnify or digitally enhance the image for presentation in the head-worn augmented reality system makes it possible for the visually impaired to better interact with objects in the surrounding environment. Magnification and digital enhancement change the view of the world for the visually impaired, and the inventors have also discovered intuitive interaction systems that make the experience even more useful and easy to use. Use of a head-worn computer that provides a displayed image overlaid onto a view of the surrounding environment enables a magnified or enhanced image of the surrounding environment to be provided in a portion of the user's field of view while still providing a view of the surrounding environment in peripheral areas of the user's field of view where high resolution is not needed to maintain an awareness of the environment.

[0141] FIG. **30***a* illustrates an example situation where a user is viewing a document while wearing a head-worn computer and the document has writing on it. The head-worn computer provides an augmented reality view of the document that is unmodified. Because the user cannot read the writing clearly either due to the user being visually impaired or the lighting or other conditions being challenging, the user desires to gain an improved view of the writing such as providing by having a magnified view of a portion of the document. As shown in FIG. **30***a*, the head-worn computer then provides the user with a magnified view of a portion of the document. The user is then viewing the document in two ways: the outer portion of the document is viewed in an unmodified state of the document, and a smaller portion is displayed to the user as a magnified displayed area, shown as the area in the solid line circle. The non-modified view can provide the person with context and orientation while viewing the magnified portion. The magnified displayed area is provided by the head-worn computer by first capturing an image of the document using a camera in the head-worn computer and then the head-worn computer digitally magnifies the portion of the captured image which is then displayed to the user. Where the camera may include a telephoto lens or a zoom lens to provide optical magnification to the captured image of the document. In addition, the camera or head-worn computer may include a capability to digitally magnify an area or portion of the captured image by using digital zoom techniques as is known to those skilled in the art. Once an area of the image is magnified, it is displayed to the user in the head-worn augmented reality display such that the user can see the magnified area of the image of the document overlaying the un-modified (e.g. see-through) view of the document. The magnified area of the image may also be displayed to the user with either a higher brightness than the see-through view or at a different focus distance than the surrounding environment so the user can focus onto the magnified area without being distracted by the unmodified see-through view. As shown in FIG. **30***a*, the selection of the area to be magnified and displayed to the user is determined by the head position of the user corresponding to where the user is looking. This method of using head position to determine the area to be magnified is well suited to the case wherein the camera includes a telephoto lens or a zoom lens as the user can simply move his head as needed and the area he is looking at will be captured as a magnified image of that area. A portion of the captured magnified image (e.g. the center 20% of the captured image) is then displayed to the user in the head-worn computer as a magnified view of the area. This approach based on head position also works well when an unmagnified image of the area is captured and the image is either digitally magnified or digitally enhanced in other ways to provide an improved view of the area to the user. However, as illustrated by the multiple sets of dashed line circles shown in FIG. **30***a*, using head position to determine the area to be magnified or digitally enhanced can have limitations because the user's head can move somewhat erratically and these movements of the head cause changes in what the imaging system is imaging and then magnifying or digitally enhancing. Depending on the size of the magnified or digitally enhanced image presented to the user and the level of magnification in the enhanced image, the desired content can move in and out of the area of enhanced content in the displayed image leading to a frustrating user experience at times. Optical stabilization of the camera lens during capture or digital image stabilization of the image after capture can be used to stabilize the magnified or digitally enhanced image that is presented to the user. The area of magnified or digitally enhanced image is preferably positioned approximately in the center of the display field of view or at least 5% of the display field of view away from the edge of the display field of view to provide substantial room within the display field of view for digital image stabilization. As such, the magnified or digitally enhanced image should comprise less than 81% (90%×90%) of the display field of view.

[0142] In embodiments, and as will be further explained below, the head-worn system may be adapted to identify

content based on a user gesture or external user interface and then manage the content's presentation based on an understanding of what the user wants to view, as opposed to what the user's head is pointing at. FIG. **30***b* illustrates a situation where the user points to a section of the document to indicate to the head-worn computer that this is the area or section the user is interested in viewing as a magnified or digitally enhanced displayed image. The augmented reality head-worn system may then capture an image of that area and magnify or otherwise digitally enhance the image of the area and then display the magnified or digitally enhanced image in the augmented reality head-worn computer for viewing as an overlaid image onto a see-through view of the document. In embodiments, once the portion is captured, manipulated and presented it is stabilized to avoid the desired portion from floating in and out of the field of view of the augmented reality head-worn computer. For example, the portion may be maintained in the center, or other portion, of the field of view while there is an indication (e.g. persistent gesture) that the desired portion is still desirable. In embodiments, the enhanced portion may be world locked (e.g. locked to a mark, marker, word, etc.) such that it does not move as the user's head moves during the desired viewing period. In embodiments, more than one enhancement technique is used in portions of the displayed image so that the center portion of the displayed image may be enhanced using one technique such as for example magnification and the peripheral portions of the image may be contrast enhanced. In addition, an unmodifiedview (e.g. see-through view) may be provided that has a larger field of view than the displayed image, so that user may see a peripheral portion of the document that is unmodified, with an outer portion of the document that is enhanced using one technique such as contrast enhancement or increased brightness and a center portion of the document that is enhanced using a second technique such as magnification.

[0143] FIGS. **31***a* through **31***c* illustrate several examples of how the head-worn computer system may present information to the visually impaired user after an indication of what the user would like to look at is received. Each of these examples may be thought of as dinner menu examples, although they are not limited to menus, where the visually impaired user would like to read a portion of a menu that the user cannot readily see without aid. These dimmer menu examples are provided for ease of illustration and teaching point and should not be considered limiting use scenarios. Such systems may be used to enhance and present content of all types.

[0144] FIG. **31***a* illustrates a system where the user points at words on the menu and the words are magnified through the imaging system and then presented as digital content in the see-through head-worn display. As the user runs his finger under or near the words in the line, the camera in the head-worn computer captures an image of the menu and the user's finger. The processor in the head-worn computer than analyzes the captured image to identify that a pointing finger is present and the portion of the captured image that is adjacent to the finger is identified for enhancement. If the camera has captured a magnified image, the portion adjacent to the pointing finger may then be cropped for presentation as a displayed image to the user, where the displayed image is positioned within the display field of view such that it appears to be adjacent to the pointing finger as seen by the user. If the camera has captured an image that is not magnified, the portion adjacent to the pointing finger may be analyzed for word content, the word content may then be digitally magnified or digitally enhanced and the magnified or enhanced word content is displayed to the user such that the magnified or enhanced word content is positioned in the display field of view so that it appears to be adjacent to the pointing finger as seen in the augmented reality system view. This allows the user to read the line for himself by pointing and moving the finger along the line of text in the menu, which can be a significant benefit for the visually impaired. In embodiments, the indicated words may be highlighted, changed in color, underlined, bolded, or otherwise presented in an enhanced way to accomplish the task of presenting a word that the user can more easily read. In embodiments, when the portion adjacent to the pointing finger is analyzed for word content, words can be identified by the head-worn computer and the identified words can then be converted to computer generated speech which is read to the person. In embodiments, the user simply moves their finger along the line of text and the head-worn computer identifies the words and reads the words to the user as the finger moves.

[0145] In embodiments, the user uses two fingers in a gesture. Wherein one finger indicates the portion to be enhanced and the distance between the two fingers indicates the relative amount of digital zoom to be applied. The camera is then used to capture images of the menu, or other portion of the environment in front of the user, along with the gesture. The processor in the head-worn computer then analyzes the captured image to identify the gesture and then form the enhanced image for display in correspondence to the position and degree of zoom indicated by the gesture.

[0146] FIG. **31***b* illustrates a system where the user points to a line of text, an image is captured by the camera of the pointing finger and the adjacent text. The image is then analyzed by the head-worn computer and the word content of the line of text is determined. A digitally enhanced image of the line of text is then generated for display to the user or provided to the user as computer generated speech. The whole line of text may be enhanced and/or tracked such that the line of text is presented for the user in the see-through display in such a way that they can see and read the line of text and/or the line of text may be read to them. Because the pointing finger identifies the line of text of interest, the user may scan their head while reading the enhanced words in the line without interrupting the process of identifying the word content. In embodiments, the line may not be enhanced, but rather simply tracked through the finger pointing, translated by optical character recognition (OCR) and read to the user. In the reading modes described herein, the system may also be useful as a reading aid for non-visually impaired people, such as children or people with learning disabilities. Further, following the OCR, the identified words may be translated to a different language as desired by the user and then displayed as the translated words or read to the user as translated words. In embodiments, the word content from the line of text may be presented in different formats to better fit the word content within the display field of view (e.g. the text may be shown as multiple short lines of text).

[0147] FIG. **31***c* illustrates a system where the user points to a paragraph of text and then the paragraph is enhanced, similar to the word and sentence tracking illustrated in FIGS. **31***a* and **31***b*.

[0148] FIG. **32** illustrates a system where the words of a line are enhanced as they are read. For example, when a

sentence or paragraph is selected, the words that are being read may be enhanced so the user can follow along. Again, this system may be useful for the visually impaired or as a reading learning tool.

[0149] FIG. **33** illustrates a system for the stabilization of enhanced images. In step A, the user identifies what they would like to select (e.g. by pointing to a word, sentence, paragraph, object, content, etc.). In this case, the user has pointed to a sentence. The head-worn computer than captures and enhances, not necessarily in that order, the sentence in Step B. Then the sentence, or sections of the sentence are presented in a field of view of the see-through computer display(s) in a fixed position within the field of view. This locks the content into position such that the user will be able to continue to see the enhanced words even as the user's head moves around. This helps stabilize the view of the content. The user then does not have to maintain a steady head to maintain a visual connection with the enhanced content. The sentence may be displayed in the same location within the display field of view as long as the gesture can be identified thereby indicating that the user is still interested in seeing an enhanced version of that sentence.

[0150] FIG. **34** illustrates a system where the indication by the user of the menu item causes a pop up of a picture, video or other content to illustrate the menu item based on the OCR determined word or image content, but in a visual form familiar to the user. The visually impaired could then see pictures of menu items instead of having to read the menu. This technique may also be useful when reviewing magazine content, news content, blogs, websites, etc. For example, the user may look at a tablet computer with news content and the head-worn computer could enhance the content as described herein, including presenting a video in the head-worn glasses. This avoids the problem of the visually impaired with having to manipulate the tablet itself. In other embodiments, the content is provided in physical form. The user may pick up a magazine and the head-worn computer may recognize the magazine edition so the system begins to work seamlessly when the user starts looking through the magazine. The user may have whole pages magnified so he can generally review the material and then the user may select a section. The section may include text, images, or other forms of content. If the content is text, the system may present enhanced text such that the user can read or have the text read. The system may also pop up a video when text or other forms of content are selected. The selection of the video may be made by the head-worn computer identifying, either locally or remotely, the content and then presenting an appropriate image or video.

[0151] FIG. **35** illustrates a system where the user has asked or indicated (e.g. through a gesture) that they would like to zoom back out to see a larger portion of a page for context. In this embodiment, a larger portion of the captured image is displayed to the user in the head-worn computer and the portion of the text, or other content, that was previously enhanced is highlighted such that the used can see what he's already zoomed in on, even if in this zoomed out mode, the user cannot read the highlighted content. In embodiments, several areas may be highlighted with different highlighting effects, numbers, text, content, etc. to help remind the user what each previously reviewed section related to.

[0152] FIG. **36** illustrates a system where alternating lines of text are enhanced to help a visually impaired person separate and read the lines. In this example, the lines alternate background colors. In other embodiments, the text of each line may be enhanced differently.

[0153] In embodiments, the entire image of the surrounding environment as captured by the camera in the head-worn computer, is enhanced without magnifying the image and the enhanced image is displayed to the user in the augmented reality head-worn computer. The enhanced image can be cropped and positioned within the display field of view, such that the angular size and position of the enhanced image when displayed in the head-worn computer matches the angular size and position of the portion of the surrounding environment included in the enhanced image as seen in the augmented reality display view of the surrounding environment. The user is therefore provided with an enhanced view of the surrounding environment so the user can better understand ongoing activities in the surrounding environment and the user can then navigate the surrounding environment better. By matching the displayed size of the enhanced image to the size of the see-through view of the surrounding environment, the user is provided with an undistorted enhanced image of the surrounding environment. FIGS. **37** thru **41** illustrate how the captured image of the environment can be enhanced and displayed to the user for improved navigation in an environment. FIG. **37** shows an illustration of an environment as seen by a person that is not vision impaired. FIG. **38** shows an illustration of the same environment as seen in a blurred condition to illustrate what might be seen by a person with impaired vision. There are many vision impairment types and this is provided for simplification of illustration only. FIG. **39** shows an illustration of an image of the environment as captured by the camera in the head-worn computer wherein the camera captures a smaller field of view than is seen by the user in a see-through view as shown in FIGS. **37** and **38**. FIG. **40** shows an illustration of the captured image after being enhanced to increase contrast, sharpness and brightness. FIG. **41** shows an illustration of the enhanced version of the captured image of the environment being displayed in the head-worn computer as seen by the impaired vision user as the enhanced image overlaid onto a see-through view of the environment. Where the displayed image can be presented to the impaired vision user with a focus distance that is determined in correspondence to the user's ophthalmic prescription or other characteristics of the user's eyes, such as with a shorter focus distance for a user that is near sighted. As a result, the benefit provided to the user comes from both the enhanced image and from the ability to select the focus distance to better suit the user. To better illustrate the experience for the vision impaired user, the enhanced displayed image is shown in FIG. **41** with some blur of the displayed image, but much less than the background which is not recognizable. The benefit provided by the system to a user with impaired vision is easily recognizable in FIG. **41** for navigating an environment such as walking through the gymnasium shown in FIGS. **37** to **41**.

[0154] In embodiments, portions of images captured by the camera in the head-worn computer are enhanced to suit the user's eyes capabilities by increasing the contrast, brightness, sharpness or by increasing the saturation as appropriate. The various enhancements can be adjusted to provide an improved view of the environment. Where contrast can be

enhanced by increasing the luma (where luma is defined as the brightness of the pixel) of portions of the enhanced image where the luma is above a threshold and decreasing the luma of portions of the enhanced image where luma is below the threshold. Where luma can be increased or decreased for example by applying a factor (e.g. a % increase or % decrease) to the code values associated with the pixel. In this way, dark areas of the enhanced image may be made to be darker and bright areas of the enhanced image may be made to be brighter. Color saturation can also be enhanced in the enhanced image by increasing the red, green and blue digital code values associated with pixels in the enhanced image. Color contrast can be enhanced in the enhanced image by increasing the red, green and/or blue digital code values associated with pixels that have code values above a threshold and decreasing code values below the threshold. For example, in an 8 bit imaging system, code values above 120 for red, green or blue may be increased by 50% up to 256 and code values below 120 may be decreased by 50% down to 0. In a further example, the threshold 35 to 60% of the maximum code value possible in the imaging system. In this way, the color contrast is enhanced in the enhanced image by making saturated color areas more saturated and unsaturated areas are made less saturated. The advantage of these techniques of enhancing the images is that they are not computationally complex so that little power is required to enhance the images.

[0155] In embodiments, a removable auxiliary lens is provided for the camera on the head-worn display wherein a removable auxiliary lens is provided with a flexible mount so the auxiliary lens can be pivoted or swung out of the way. This enables the auxiliary lens to be moved in front of the camera when the user wants to be provided with a view of the surrounding environment that is different from what the camera can provide (e.g. a magnified view if the auxiliary lens is a telephoto lens) and moved to a position adjacent to the camera when the user wants to be provided with a view of the surrounding environment as provided by the camera in the head-worn display without the auxiliary lens. The flexible mount can include a pivot, a hinge or a slide to enable the auxiliary lens to be moved without being detached from the head-worn computer. FIGS. **42** through **46** show illustrations of an example of a head-worn computer including a display system **42020** that displays images and ear horns **42010** that attach the head-worn computer to the user head and position the display system **42020** in front of the user's eyes. Where the head-worn computer includes a camera **45035** with an auxillary lens **42030** that can be flipped down on a pivot **42032** to thereby position the auxiliary lens **42030** in front of the camera **45035**. The auxillary lens **42030** can be a telephoto lens or zoom lens to provide greater magnification in captured images of the environment, alternatively the auxiliary lens can be a wide angle lens such as a fish-eye lens to provide less magnification and a wider field of view in the images of the environment. FIGS. **42** and **43** show illustrations of the head-worn computer from the side and front respectively, with the auxiliary lens **42030** in the flipped down position where the auxiliary lens **42030** works in conjunction with the lens associated with the camera **45035** to enable the camera **45035** to capture images of the environment in front of the user that are different from what the camera **45035** alone can provide. FIGS. **44** and **45** show illustrations of the head-worn computer from the side and front respectively, with the auxiliary lens **42030** in the flipped up position wherein the auxiliary lens **42030** is parked so it doesn't interfere with the camera **45035** and the field of view of the smaller lens (e.g. a wide angle lens) associated with the camera **45035**. By providing a flipped up position for parking the auxiliary lens **42030** and a pivot **42032** that enables easy movement of the auxiliary lens from a flipped down position for use and a flipped up position for parking, the auxiliary lens **42030** is conveniently attached to the head-worn computer and accurately aligned with the camera **45035** to provide quality images in either position. The lateral alignment of the lens surface **45037** of the auxiliary lens **42030** with the camera **45035** can be seen in FIG. **45**. The alignment of lens surface **45037** to camera **45035** is such that the auxiliary lens **42030** swings on the pivot **42032** from the flipped up position to the flipped down position, the lens surface **45037** aligns in a concentric fashion with the camera **45035** so that the camera **45035** and the auxiliary lens **42030** share a common optical axis. A similar system can be provided (not shown) wherein the auxiliary lens **42030** has a sliding mount so that the auxiliary lens **42030** slides laterally from a use position to a parked position.

[0156] The flexible mount for the auxiliary lens can also include one or more magnetic couplers to positively and accurately position the auxiliary lens when it is positioned over the camera. Where the magnetic coupler can include a ring magnet, a tapered magnet or magnetic disks with adjacent alignment features to guide the auxiliary lens into position. The magnetic coupler can surround the rim of the auxiliary lens, so that light from the lens passes through a middle area of the magnetic coupler and the magnetic coupler then provides a more balanced force to hold the lens in place. By providing a magnetic coupler, the lens snaps into place due to the combined effects of the magnet and the alignment features. The magnetic coupler and flexible mount also allows for easy removal of the lens from in front of the camera. FIG. **46** shows an illustration of a head-worn computer with a display system **42020**, an auxiliary lens **42030** on a pivot **42032** wherein a magnet **46040** is included with the auxiliary lens **42030** and a corresponding magnetic mount **46042** is provided in the frame of the display system **42020** such that when the auxiliary lens **42030** is in the flipped down position, the auxiliary lens **42030** is held in position relative to the camera **45035**. The magnetic mount **46042** can include a magnetic material such as iron, or it can include a magnet with the opposite polarity of the magnet **46040** such that the magnet **46040** is attracted to the magnetic mount **46042** and the auxiliary lens **42030** is held in position relative to the camera **45035**. In addition, alignment features such as interlocking tapered surfaces can be included in the magnetic mount **46042**, the magnet **46040** or the faces of the auxiliary lens **42030** or the frame of the display system **42020** that is adjacent to the camera **45035**.

[0157] In embodiments, the removable auxiliary lens can include a removable mount on the frame of the head-worn computer so the auxiliary lens can be attached or detached as needed. The removable mount can also include electrical connections as needed to run the auxiliary lens for cases wherein the auxiliary lens includes electronics such as for example a zoom lens motor, exposure sensors or aperture controls.

[0158] In embodiments, the auxiliary lens can be a camera system that includes a lens, an image sensor and lens controls for controlling for example zoom, exposure, auto-

focus and aperture. In this case, the auxiliary lens is attached to the head-worn computer with a removable mount that rigidly attaches the auxiliary lens and connects the auxiliary lens electrically to the head-worn computer. The auxiliary lens can include a variety of capabilities that enable enhanced images of the environment to be captured compared to what the camera in the head-worn computer can provide. Examples of capabilities that can be included in the auxiliary lens that are of benefit to a user with impaired vision include: an image sensor with larger pixels or a lens with a lower f# or larger aperture to provide enhanced images in low light conditions; an image sensor that includes wide spectrum pixels such as monochrome pixels or pixels that are sensitive to visible and infrared light to capture an image using a broader spectrum of available light.

[0159] Another aspect of the present disclosure relates to a miniature radar system (such as the TRX 120G available from Silicon Radar, Frankfurt Germany) mounted into the frame of the head-worn computer that can be used to measure the distance to objects adjacent to the head-worn computer within an angular field in front of the user. The measured distance information can then be used to provide feedback cues to the user, such as for example, enhanced images, audio information or haptic feedback related to the measured distance to the objects within the angular field. Then as the user moves his head from side to side, the measured distance information will change as different objects in the environment move in and out of the angular field. The user is then provided with feedback cues that communicate the distance to objects in a certain direction. By making the angular field of the radar relatively narrow (e.g. 40 degrees or less), the user is provided with a more accurate location of objects in the adjacent environment. The angular field of the radar can be reduced by adding lenses, waveguides and masks to the radar transmitter. By making the angular field narrow in both the vertical and horizontal directions, the user can be provided with feedback cues that relate the distance to objects as he moves his head from side to side and up and down to further improve the accuracy of the location and shape of objects in the adjacent environment. This is useful for visually impaired persons or people that can't see for any reason such as if the environment is dark, or the environment is hazy due to smoke, dust, fog, snow or sandstorm, as the user is navigating through the environment. In embodiments, the radar distance measurements may be combined with simultaneously gathered data related to the direction the user is looking (e.g. sight heading, compass heading and head tilt) so that a distance map or distance image can be generated by the head-worn computer. Wherein for example, objects that are located at a larger distance are shown with a different color than objects located at a shorter distance. In embodiments the radar system and a visible light sensor system (e.g. camera) operate in tandem within the head-worn computer to provide a combined image of the environment proximate the head-worn computer that shows objects along with the distance to the objects. In embodiments, the radar and visible light sensor system may operate at the same time or at different times, depending on the environmental conditions. For example, in a low light environment, the radar may provide distance measurements to objects in the environment and provide distance images in the augmented reality display to provide a user with visual indications of the locations of the objects with respect to himself. There may also be situations when the visible light sensor system can image the environment, but the radar imagery is used to augment the visible light images. In embodiments, the user may be blind (e.g. personally impaired or environmentally impaired) and the head-worn computer may not need displays, but rather the radar imagery or visible light sensor imagery may be interpreted and converted into audio commands or haptic feedback. For example, audio commands or haptic feedback which may include indications of the distance to surrounding objects and provide navigation commands or information. This can assist a blind person in walking through indoor and outdoor environments in any lighting condition. In embodiments, the radar or visual light imagery may be interpreted along with a prediction of a walking direction of a person wearing the head-worn computer such that audio commands or haptic feedback can be generated to assist the person in navigating the environment. For example, the haptic feedback can be vibration wherein the intensity of the vibration is in correspondence to the distance to an object directly in front of the user.

[0160] In embodiments, two radar devices can be mounted into the corners of the head-worn computer pointing in diverging directions so that the angular fields of measurement associated with the two radar devices only partially overlap with one another. In this way, the distance measurement information for a given adjacent object will be different for each of the two radar devices unless the user is facing so that the object is directly in front of the user. The image, audio or haptic feedback associated with the two radar devices can then be used by the user to determine when an object at a given distance is located directly in front of the user. The user can then move his head to survey the adjacent environment for objects at a given distance away.

[0161] While many of the embodiments herein describe see-through computer displays, the scope of the disclosure is not limited to see-through computer displays. In embodiments, the head-worn computer may have a display that is not see-through. For example, the head-worn computer may have a sensor system (e.g. camera, ultrasonic system, radar, etc.) that images the environment proximate the head-worn computer and then presents the images to the user such that the user can understand the local environment through the images as opposed to seeing the environment directly. In embodiments, the local environment images may be augmented with additional information and content such that an augmented image of the environment is presented to the user. In general, in this disclosure, such see-through and non-see through systems may be referred to as head-worn augmented reality systems, augmented reality displays, augmented reality computer displays, etc.

[0162] Although embodiments of HWC have been described in language specific to features, systems, computer processes and/or methods, the appended claims are not necessarily limited to the specific features, systems, computer processes and/or methods described. Rather, the specific features, systems, computer processes and/or and methods are disclosed as non-limited example implementations of HWC. All documents referenced herein are hereby incorporated by reference.

[0163] The methods and systems described herein may be deployed in part or in whole through a machine that executes computer software, program codes, and/or instructions on a processor. The processor may be part of a server, cloud server, client, network infrastructure, mobile computing

platform, stationary computing platform, or other computing platform. A processor may be any kind of computational or processing device capable of executing program instructions, codes, binary instructions and the like. The processor may be or include a signal processor, digital processor, embedded processor, microprocessor or any variant such as a co-processor (math co-processor, graphic co-processor, communication co-processor and the like) and the like that may directly or indirectly facilitate execution of program code or program instructions stored thereon. In addition, the processor may enable execution of multiple programs, threads, and codes. The threads may be executed simultaneously to enhance the performance of the processor and to facilitate simultaneous operations of the application. By way of implementation, methods, program codes, program instructions and the like described herein may be implemented in one or more thread. The thread may spawn other threads that may have assigned priorities associated with them; the processor may execute these threads based on priority or any other order based on instructions provided in the program code. The processor may include memory that stores methods, codes, instructions and programs as described herein and elsewhere. The processor may access a storage medium through an interface that may store methods, codes, and instructions as described herein and elsewhere. The storage medium associated with the processor for storing methods, programs, codes, program instructions or other type of instructions capable of being executed by the computing or processing device may include but may not be limited to one or more of a CD-ROM, DVD, memory, hard disk, flash drive, RAM, ROM, cache and the like.

[0164] A processor may include one or more cores that may enhance speed and performance of a multiprocessor. In embodiments, the process may be a dual core processor, quad core processors, other chip-level multiprocessor and the like that combine two or more independent cores (called a die).

[0165] The methods and systems described herein may be deployed in part or in whole through a machine that executes computer software on a server, client, firewall, gateway, hub, router, or other such computer and/or networking hardware. The software program may be associated with a server that may include a file server, print server, domain server, internet server, intranet server and other variants such as secondary server, host server, distributed server and the like. The server may include one or more of memories, processors, computer readable transitory and/or non-transitory media, storage media, ports (physical and virtual), communication devices, and interfaces capable of accessing other servers, clients, machines, and devices through a wired or a wireless medium, and the like. The methods, programs or codes as described herein and elsewhere may be executed by the server. In addition, other devices required for execution of methods as described in this application may be considered as a part of the infrastructure associated with the server.

[0166] The server may provide an interface to other devices including, without limitation, clients, other servers, printers, database servers, print servers, file servers, communication servers, distributed servers and the like. Additionally, this coupling and/or connection may facilitate remote execution of program across the network. The networking of some or all of these devices may facilitate parallel processing of a program or method at one or more location without deviating from the scope of the invention. In addition, all the devices attached to the server through an interface may include at least one storage medium capable of storing methods, programs, code and/or instructions. A central repository may provide program instructions to be executed on different devices. In this implementation, the remote repository may act as a storage medium for program code, instructions, and programs.

[0167] The software program may be associated with a client that may include a file client, print client, domain client, internet client, intranet client and other variants such as secondary client, host client, distributed client and the like. The client may include one or more of memories, processors, computer readable transitory and/or non-transitory media, storage media, ports (physical and virtual), communication devices, and interfaces capable of accessing other clients, servers, machines, and devices through a wired or a wireless medium, and the like. The methods, programs or codes as described herein and elsewhere may be executed by the client. In addition, other devices required for execution of methods as described in this application may be considered as a part of the infrastructure associated with the client.

[0168] The client may provide an interface to other devices including, without limitation, servers, other clients, printers, database servers, print servers, file servers, communication servers, distributed servers and the like. Additionally, this coupling and/or connection may facilitate remote execution of program across the network. The networking of some or all of these devices may facilitate parallel processing of a program or method at one or more location without deviating from the scope of the invention. In addition, all the devices attached to the client through an interface may include at least one storage medium capable of storing methods, programs, applications, code and/or instructions. A central repository may provide program instructions to be executed on different devices. In this implementation, the remote repository may act as a storage medium for program code, instructions, and programs.

[0169] The methods and systems described herein may be deployed in part or in whole through network infrastructures. The network infrastructure may include elements such as computing devices, servers, routers, hubs, firewalls, clients, personal computers, communication devices, routing devices and other active and passive devices, modules and/or components as known in the art. The computing and/or non-computing device(s) associated with the network infrastructure may include, apart from other components, a storage medium such as flash memory, buffer, stack, RAM, ROM and the like. The processes, methods, program codes, instructions described herein and elsewhere may be executed by one or more of the network infrastructural elements.

[0170] The methods, program codes, and instructions described herein and elsewhere may be implemented on a cellular network having multiple cells. The cellular network may either be frequency division multiple access (FDMA) network or code division multiple access (CDMA) network. The cellular network may include mobile devices, cell sites, base stations, repeaters, antennas, towers, and the like.

[0171] The methods, programs codes, and instructions described herein and elsewhere may be implemented on or through mobile devices. The mobile devices may include navigation devices, cell phones, mobile phones, mobile personal digital assistants, laptops, palmtops, netbooks, pag-

ers, electronic books readers, music players and the like. These devices may include, apart from other components, a storage medium such as a flash memory, buffer, RAM, ROM and one or more computing devices. The computing devices associated with mobile devices may be enabled to execute program codes, methods, and instructions stored thereon. Alternatively, the mobile devices may be configured to execute instructions in collaboration with other devices. The mobile devices may communicate with base stations interfaced with servers and configured to execute program codes. The mobile devices may communicate on a peer to peer network, mesh network, or other communications network. The program code may be stored on the storage medium associated with the server and executed by a computing device embedded within the server. The base station may include a computing device and a storage medium. The storage device may store program codes and instructions executed by the computing devices associated with the base station.

[0172] The computer software, program codes, and/or instructions may be stored and/or accessed on machine readable transitory and/or non-transitory media that may include: computer components, devices, and recording media that retain digital data used for computing for some interval of time; semiconductor storage known as random access memory (RAM); mass storage typically for more permanent storage, such as optical discs, forms of magnetic storage like hard disks, tapes, drums, cards and other types; processor registers, cache memory, volatile memory, non-volatile memory; optical storage such as CD, DVD; removable media such as flash memory (e.g. USB sticks or keys), floppy disks, magnetic tape, paper tape, punch cards, standalone RAM disks, Zip drives, removable mass storage, off-line, and the like; other computer memory such as dynamic memory, static memory, read/write storage, mutable storage, read only, random access, sequential access, location addressable, file addressable, content addressable, network attached storage, storage area network, bar codes, magnetic ink, and the like.

[0173] The methods and systems described herein may transform physical and/or or intangible items from one state to another. The methods and systems described herein may also transform data representing physical and/or intangible items from one state to another, such as from usage data to a normalized usage dataset.

[0174] The elements described and depicted herein, including in flow charts and block diagrams throughout the figures, imply logical boundaries between the elements. However, according to software or hardware engineering practices, the depicted elements and the functions thereof may be implemented on machines through computer executable transitory and/or non-transitory media having a processor capable of executing program instructions stored thereon as a monolithic software structure, as standalone software modules, or as modules that employ external routines, code, services, and so forth, or any combination of these, and all such implementations may be within the scope of the present disclosure. Examples of such machines may include, but may not be limited to, personal digital assistants, laptops, personal computers, mobile phones, other handheld computing devices, medical equipment, wired or wireless communication devices, transducers, chips, calculators, satellites, tablet PCs, electronic books, gadgets, electronic devices, devices having artificial intelligence, computing devices, networking equipment, servers, routers and the like. Furthermore, the elements depicted in the flow chart and block diagrams or any other logical component may be implemented on a machine capable of executing program instructions. Thus, while the foregoing drawings and descriptions set forth functional aspects of the disclosed systems, no particular arrangement of software for implementing these functional aspects should be inferred from these descriptions unless explicitly stated or otherwise clear from the context. Similarly, it will be appreciated that the various steps identified and described above may be varied, and that the order of steps may be adapted to particular applications of the techniques disclosed herein. All such variations and modifications are intended to fall within the scope of this disclosure. As such, the depiction and/or description of an order for various steps should not be understood to require a particular order of execution for those steps, unless required by a particular application, or explicitly stated or otherwise clear from the context.

[0175] The methods and/or processes described above, and steps thereof, may be realized in hardware, software or any combination of hardware and software suitable for a particular application. The hardware may include a dedicated computing device or specific computing device or particular aspect or component of a specific computing device. The processes may be realized in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable device, along with internal and/or external memory. The processes may also, or instead, be embodied in an application specific integrated circuit, a programmable gate array, programmable array logic, or any other device or combination of devices that may be configured to process electronic signals. It will further be appreciated that one or more of the processes may be realized as a computer executable code capable of being executed on a machine readable medium.

[0176] The computer executable code may be created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software, or any other machine capable of executing program instructions.

[0177] Thus, in one aspect, each method described above and combinations thereof may be embodied in computer executable code that, when executing on one or more computing devices, performs the steps thereof. In another aspect, the methods may be embodied in systems that perform the steps thereof, and may be distributed across devices in a number of ways, or all of the functionality may be integrated into a dedicated, standalone device or other hardware. In another aspect, the means for performing the steps associated with the processes described above may include any of the hardware and/or software described above. All such permutations and combinations are intended to fall within the scope of the present disclosure.

[0178] While the invention has been disclosed in connection with the preferred embodiments shown and described in detail, various modifications and improvements thereon will

become readily apparent to those skilled in the art. Accordingly, the spirit and scope of the present invention is not to be limited by the foregoing examples, but is to be understood in the broadest sense allowable by law.

We claim:

1. An apparatus to assist a visually impaired person in navigating an environment, comprising:

a. a head-worn computer;

b. a radar system mounted on the head-worn computer and positioned to measure distances to objects in the environment within an angular field in front of the visually impaired person wearing the head-worn computer; and

c. a processor adapted to process the measured distances from the radar system and to identify objects in the environment that are within the angular field in front of the visually impaired person, the processor further adapted to generate feedback cues to the visually impaired person in correspondence to the measured distances within the angular field in front of the visually impaired person as the visually impaired person moves his head from side to side while navigating the environment.

2. The apparatus of claim **1**, wherein the processor is further adapted to interpret movements of the visually impaired person to make a prediction of a direction in which the visually impaired person is walking to assist in the person in navigating the environment.

3. The apparatus of claim **1**, wherein the feedback cues are visual.

4. The apparatus of claim **1**, wherein the feedback cues are audio based.

5. The apparatus of claim **1**, wherein the feedback is haptic based.

6. The apparatus of claim **1**, further comprising a second radar system having a second angular field that overlaps at least a portion of the angular field.

7. The apparatus of claim **1**, further comprising a visual light camera, wherein the visual light camera is used to capture an image of an object in the environment in front of the person, wherein the processor is further adapted to identify the object; and wherein the radar system is adapted to identify a distance between the head-worn computer and the object.

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