(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 716 012 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
06.03.2024 Bulletin 2024/10

(21) Application number: **19206217.2**

(22) Date of filing: **30.10.2019**

(51) International Patent Classification (IPC):
G06F 3/00 (2006.01) ***G06F 1/16*** (2006.01)
G06F 3/01 (2006.01) ***G06F 3/03*** (2006.01)
G02B 27/01 (2006.01)

(52) Cooperative Patent Classification (CPC):
G06F 3/013; G02B 27/0093; G02B 27/017; G06F 1/163; G06F 3/011; G06F 3/0304;
G02B 2027/0187

(54) DETECTING RELOCATION OF A HEAD-MOUNTED DEVICE

ERKENNEN DER VERLAGERUNG EINER KOPFMONTIERTEN VORRICHTUNG

DÉTECTION DU REPOSITIONNEMENT D'UN DISPOSITIF MONTÉ SUR LA TÊTE

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **31.10.2018 SE 1851355**

(43) Date of publication of application:
30.09.2020 Bulletin 2020/40

(73) Proprietor: **Tobii AB**
182 17 Danderyd (SE)

(72) Inventors:
- **WANG, Tiesheng**
  182 17 Danderyd (SE)
- **KUMAR RANA, Pravin**
  182 17 Danderyd (SE)
- **WANG, Yimu**
  182 17 Danderyd (SE)
- **AINSLEY RYAN, Mark**
  182 17 Danderyd (SE)

(74) Representative: **Novagraaf Group**
Chemin de l'Echo 3
1213 Onex (CH)

(56) References cited:
EP-A1- 3 228 238
WO-A1-2013/067230
US-A1- 2018 032 133

- **SWIRSKI L ET AL: "A fully-automatic, temporal approach to single camera, glint-free 3D eye model fitting", INTERNET CITATION, 31 December 2013 (2013-12-31), pages 1-10, XP002785718, Retrieved from the Internet: URL:https://pdfs.semanticscholar.org/f0c0/bc74c1dc11e8a09fa4bd4c300cf21d7cc96d.pdf [retrieved on 2018-10-16]**
- **PLOPSKI ALEXANDER ET AL: "Corneal-Imaging Calibration for Optical See-Through Head-Mounted Displays", IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, IEEE SERVICE CENTER, LOS ALAMITOS, CA, US, vol. 21, no. 4, 18 April 2015 (2015-04-18) , pages 481-490, XP011576354, ISSN: 1077-2626, DOI: 10.1109/TVCG.2015.2391857 [retrieved on 2015-03-20]**
- **KAI DIERKES ET AL: "A novel approach to single camera, glint-free 3D eye model fitting including corneal refraction", EYE TRACKING RESEARCH & APPLICATIONS, ACM, 2 PENN PLAZA, SUITE 701NEW YORKNY10121-0701USA, 14 June 2018 (2018-06-14), pages 1-9, XP058409778, DOI: 10.1145/3204493.3204525 ISBN: 978-1-4503-5706-7**

EP 3 716 012 B1

Description

TECHNICAL FIELD

[0001] The present disclosure relates methods for detecting relocation of a head-mounted device. The present disclosure also relates to corresponding systems and storage media.

BACKGROUND

[0002] Performance of head-mounted devices such as virtual-reality (VR) headsets and augmented reality (AR) headsets may be affected if the head-mounted device is not properly mounted at the user's head. Even if the head-mounted device has initially been mounted at a correct position, the head-mounted device may be relocated (or repositioned) during use, for example due to slippage when the head of the user moves or rotates. Lenses or other optical equipment of the head-mounted device may for example be optimized or calibrated for a certain position relative to the user's eyes. If the head-mounted device is adapted to provide a three-dimensional (3D) experience to the user, this 3D experience may become distorted if the head-mounted device moves relative to the user's head. A VR experience provided by the head-mounted device may for example become less realistic, or virtual objects shown by an AR headset may not fit into the real environment as well as they could have done. If the head-mounted device is equipped with gaze tracking, then the gaze tracking performance may also be affected if the head-mounted device moves relative to the user's head. If the user detects that the head-mounted device has slipped, the user may reposition the head-mounted device. While this could restore the performance of the head-mounted device, it could be quite impractical and/or annoying if the user has to do it too often. Moreover, the user may not detect straight away that the head-mounted device has slipped. Hence, the user may potentially continue to use the head-mounted device with reduced performance, without realizing what has happened. It would be desirable to provide new ways to address one or more of the abovementioned issues.

[0003] EP 3 228 238 A1 discloses a method of estimating a centre of an eyeball and then subsequently detecting slippage of a head-mounted display if an eye axis vector deviates from the estimated centre of the eyeball.

[0004] SWIRSKI L ET AL, "A fully-automatic, temporal approach to single camera, glint-free 3D eye model fitting" (https://pdfs.semanticscholar.org/f0c0/bc74c1dc11e8a09fa4bd4c300cf21d7cc96d.pdf [retrieved on 2018-10-16] discloses the use of projected pupil ellipses to estimate the centre of an eyeball of a user wearing a head-mounted camera.

[0005] PLOPSKI ALEXANDER ET AL, "Corneal-Imaging Calibration for Optical See-Through Head-Mounted Displays", IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, IEEE SERVICE CENTER, LOS ALAMITOS, CA, US, vol. 21, no. 4, 18 April 2015, discloses the detection of drift of a head-mounted device by using a measure of cornea position and the radius of the eye to detect the centre of the eyeball.

[0006] US 2018/032133 A1 discloses a system whereby a vector is specified connecting the corneal curvature and a pupil centre, and displacement of a head-mounted display is detected based on the vector.

[0007] WO 2013/067230 A1 discloses embodiments for controlling brightness of a see-through near-eye mixed display device. Repositioning of the display device can be detected based on a gaze vector.

[0008] KAI DIERKES ET AL, "A novel approach to single camera, glint-free 3D eye model fitting including corneal refraction", EYE TRACKING RESEARCH & APPLICATIONS, ACM, 2 PENN PLAZA, SUITE 701 NEWYORK NY 10121-0701 USA, 14 June 2018, discloses a method including adapting an eye model based on gaze rays.

SUMMARY

[0009] Methods, systems and computer-readable storage media having the features defined in the independent claims are provided for addressing one or more of the abovementioned issues. Preferable embodiments are defined in the dependent claims.

[0010] Hence, a first aspect provides embodiments of a method for detecting relocation (or repositioning) of a head-mounted device relative to a user's head.

[0011] The inventors have realized that a change in the position of the center of the eye (as perceived from a camera of the head-mounted device, or as determined using images captured by a camera of the head-mounted device) may be employed as an indication that the head-mounted device has been relocated relative to the user's head. The detection of the relocation of the head-mounted device allows for appropriate measures to be taken for example to reduce the effect of this relocation on head-mounted device performance. The user may for example be prompted to reposition the head-mounted device to its original position, or the head-mounted device may for example be recalibrated for operation at the new position. Since at least some head-mounted devices are already equipped with cameras for gaze tracking, such cameras may for example be employed also for detecting relocation of the head-mounted device relative to the user's head. Hence, there may for example be no need for dedicated sensors such as proximity sensors to detect when the head-mounted device is moved out of position.

[0012] It should be noted that the references made throughout this description to an "embodiment," "example," "aspect," or "configuration" may refer to alternative aspects related to the invention but do not necessarily represent actual realizations of it. The actual embodiments of the invention are encompassed within the scope of the appended claims. It is to be understood that other examples can be implemented, and various modifications and structural changes can be made to these actual embodiments of the invention without departing from the scope of the claims, as would be understood by one of ordinary skill in the art. Other examples can be practiced and various modifications and structural changes can be made to these embodiments without departing from the scope of the present invention, as defined by the attached claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] In what follows, example embodiments will be described in greater detail with reference to the accompanying drawings, on which:

Fig. 1 is a front view of an eye;

Fig. 2 is a cross sectional view of the eye from Fig. 1 from the side of the eye;

Fig. 3 is a schematic overview of a system for detecting relocation of a head-mounted device relative to a user's head, according to an embodiment;

Fig. 4 shows optical axes intersecting at the center of an eye;

Fig. 5 shows optical axes intersecting at different locations;

Fig. 6 is a flow chart of a method for detecting relocation of a head-mounted device relative to a user's head, according to an embodiment;

Figs. 7-8 are flow charts of example implementations of how to compute estimated positions of a center of an eye in the method from Fig. 6, according to some embodiments;

Fig. 9 shows a projection of optical axes in a plane, according to an embodiment;

Figs. 10-11 show estimated optical axes in images of an eye, according to an embodiment;

Fig. 12 is a flow chart of a method which uses both eyes of a user for detecting relocation of a head-mounted device relative to the user's head, according to an embodiment; and

Fig. 13 shows a head-mounted device mounted at a user's head.

[0014] All the figures are schematic, not necessarily to scale, and generally only show parts which are necessary in order to elucidate the respective embodiments, whereas other parts may be omitted or merely suggested. Any reference number appearing in multiple drawings refers to the same object or feature throughout the drawings, unless otherwise indicated.

DETAILED DESCRIPTION

[0015] Throughout the present disclosure, the term "head-mounted display" or "HMD" refers to a display device adapted to be worn at the head of a user. In addition to the actual display optics, the HMD typically also includes other components. Such other components may for example include circuits for powering the HMD, sensors for detecting motion of the HMD, gaze tracking equipment, or a casing for protecting components of the HMD. In other words, the term "head-mounted display" or "HMD" should not necessarily be construed as only referring to the actual display optics intended to be arranged in front of an eye of the user, or in front of both eyes of the user.

[0016] Throughout the present disclosure, the term "head-mounted device" refers to a device adapted to be worn at the head of a user. A head-mounted device may for example be a head-mounted display (HMD). A head-mounted device may for example comprise a display of any type. However, there are also head-mounted devices which do not comprise a display.

[0017] Methods for detecting relocation of a head-mounted device as well as corresponding systems and storage media will be described below with reference to Figs. 3-13. First, certain features of an eye will be described with reference to Figs. 1-2.

[0018] Fig. 1 is a front view of an eye 100. Fig. 2 is a cross sectional view of the eye 100 from the side of the eye 100. While Fig. 2 shows more or less the entire eye 100, the front view presented in Fig. 1 only shows those parts of the eye 100 which are typically visible from in front of a person's face. The eye 100 has a cornea 101 and a pupil 102 with a pupil center 103. The cornea 101 is curved and has a center of curvature 104 which is referred as the center 104 of corneal curvature, or simply the cornea center 104. The cornea 101 has a radius of curvature referred to as the radius 105 of the cornea 101, or simply the cornea radius 105. The eye 100 has a center 106 which may also be referred to as the center 106 of the eye ball, or simply the eye ball center 106. The visual axis 107 of the eye 100 passes through the center 106 of the eye 100 to the fovea 108 of the eye 100. The optical axis 110 of the eye 100 passes through the pupil center 103 and the center 106 of the eye 100. The visual axis 107 forms an angle 109 relative to the optical axis 110. The deviation or offset between the visual axis 107 and the optical axis 110 is often referred to as the fovea offset 109. In the example shown in Fig. 2, the eye 100 is looking towards a display 111, and the eye 100 is gazing at a gaze point 112 at the display 111. Fig. 1 also shows a reflection 113 of an illuminator at the cornea 101. Such a reflection 113 is also known as a glint.

[0019] Fig. 3 is a schematic overview of a system 300 for detecting relocation of a head-mounted device 310 relative to a user's head, according to an embodiment. The head-mounted device 310 is a device which is adapted to be mounted (or arranged) at the head 1301 of a user, as shown in Fig. 13. The head-mounted device 310 comprises one or more displays 311. The head-mounted device may for example comprise a single display 311 which is intended to be positioned in front of the user's eyes (as show in Fig. 3), or the head-mounted device 310 may comprise separate displays which are intended to be positioned in front of the users left eye and right eye respectively. Alternatively, the head-mounted device 310 could comprise a single display adapted to be arranged in front of one of the user's eyes, so that one eye can watch the display of the head-mounted device while the other eye can watch the real world surroundings. The head-mounted device 310 may for example be head-mounted display (HMD) such as a virtual reality (VR) headset, an augmented reality (AR) headset or a mixed reality (MR) headset. The head-mounted device 310 may for example be glasses equipped with AR functionality.

[0020] The head-mounted device 310 comprises one or more cameras 312 for capturing images of the user's eyes while the user looks at the display(s) 311. The head-mounted device 310 may also comprise one or more illuminators 313 for illuminating the eyes of the user. The camera(s) 312 and illuminator(s) 313 may for example be employed for gaze tracking. The gaze tracking may for example involve estimating a gaze direction (corresponding to the visual axis 107) or estimating a gaze point 112.

[0021] The head-mounted device 310 may for example be comprised in the system 300, or may be regarded as separate from the system 300.

[0022] The system 300 comprises processing circuitry 320 configured to detect relocation of the head-mounted device 310 relative to a user's head. The processing circuitry 320 may for example also be configured to estimate a gaze direction (or gaze vector) of an eye 100 (corresponding to a direction of the visual axis 107), or a gaze point 112 of the eye 100.

[0023] The processing circuitry 320 may for example be comprised in the head-mounted device 310, or may be separate from the head-mounted device 320. The processing circuitry 320 may be communicatively connected to the head-mounted device 320, for example via a wired or wireless connection. For example, the processing circuitry 320 may be communicatively connected to the camera(s) 312, to the display 311 (for example for controlling or triggering the display 311 to show test stimulus points 314 for calibration of gaze tracking) and/or to the illuminator(s) 313.

[0024] The illuminator(s) 313 may for example be infrared or near infrared illuminators, for example in the form of light emitting diodes (LEDs). However, other types of illuminators may also be envisaged. Fig. 3 shows example illuminators 313 located at either side of the display 311, but the illuminators 313 could be located elsewhere. The head-mounted device 310 may for example comprise illuminators 313 distributed around the display 311.

[0025] The cameras 312 may for example be charged-coupled device (CCD) cameras or Complementary Metal Oxide Semiconductor (CMOS) cameras. However, other types of cameras may also be envisaged. Fig. 3 shows example cameras 312 located above the display 311, but the cameras 312 could be located elsewhere, for example below the display 311. The head-mounted device 310 may for example comprise camera 312 distribute around the display 311.

[0026] The display 311 may for example be a liquid-crystal display (LCD) or a LED display. However, other types of displays may also be envisaged. The display may 311 may for example be flat or curved. The display 311 may for example be placed in front of one of the user's eyes. In other words, separate displays may be employed for the left and right eyes. Separate equipment (such cameras 312 and illuminators 313) may for example be employed for the left and right eyes.

[0027] The processing circuitry 320 may be employed for monitoring both eyes, or there may be separate processing circuitry 320 for the left and right eyes. The system 300 may for example perform gaze tracking for the left and right eyes separately, and may then determine a combined gaze point as an average of the gaze points determined for the left and right eyes.

[0028] The processing circuitry 320 may for example comprise one or more processors 321. The processor(s) 321 may for example be application-specific integrated circuits (ASIC) configured to perform a specific method. Alternatively, the processor(s) 321 may be configured to execute instructions (for example in the form of a computer program) stored in one or more memories 322. Such a memory 322 may for example be comprised in the circuitry 320 of the system 300, or may be external to (for example located remotely from) the system 300. The memory 322 may store instructions for causing the system 300 to detect relocation of the head-mounted device 310 relative to a user's head.

[0029] It will be appreciated that the system 300 described above with reference to Fig. 3 is provided as an example, and that many other systems may be envisaged. For example, the illuminator(s) 313 and/or the camera(s) 312 need not necessarily be regarded as part of the system 300. The system 300 may for example consist only of the processing circuitry 320.

[0030] As described above with reference to Fig. 2, the optical axis 110 of the eye 100 passes through the center 103 of the pupil 102 and the center 106 of the eye ball. If the center 106 of the eye 100 stays in a fixed position, but the eye 100 gazes in different directions at different time instances (or points in time), the optical axes for these time instances should intersect at the center 106 of the eye 100. This situation is illustrated in Fig. 4.

[0031] Fig. 4 shows optical axes 410, 420 and 430 intersecting at the center 401 of an eye 400. At a first time instance, the eye 400 is directed along a first optical axis

410 which passes through a first cornea center position 411 (or a first position 411 of the center of corneal curvature) and a first pupil center position 412 (or a first position 412 of the pupil center). At a second time instance, the eye 400 is directed along a second optical axis 420 which passes through a second cornea center position 421 and a second pupil center position 422. At a third time instance, the eye 400 is directed along a third optical axis 430 witch passes through a third cornea center position 431 and a third pupil center position 432. The optical axes 410, 420 and 430 all intersect at the same point 401 at the center of the eye 400. If, on the other hand, the center 401 of the eye 400 moves relative to an observer (for example relative to a camera capturing images of the eye 400), then optical axes for different time instances will appear not to intersect at the same point. Such a situation is illustrated in Fig. 5.

[0032] Fig. 5 shows optical axes 510, 520, 530 and 540 intersecting at different points as perceived in images captured by a camera 312 of a head-mounted device 310. This may indicate that the camera 312 (and thereby also the head-mounted device 310) has been relocated relative to the head of the user. Fig. 6 is a flow chart of a method 600 for detecting relocation of a head-mounted device 310 relative to a user's head, according to an embodiment. The method 600 will be described with reference to Figs. 2, 5 and 6.

[0033] The method 600 comprises obtaining 601 (or receiving) images of an eye 100 of the user captured at a sequence of time instances (or points in time) by a camera 312 of the head-mounted device 310. The images may for example be obtained in the form of snap shots, or as part of a video sequence. The images may for example be received from the camera 312, either directly from the camera 312 or indirectly from the camera 312 (for example via one or more other components of the system 300).

[0034] The camera 312 may be arranged at a fixed position relative to the display 311 of the head-mounted device 310. The camera 312 may for example be mounted at the head-mounted device 310 or may be integrated in the head-mounted device 310.

[0035] For each of the time instances, the method 600 comprises estimating 602 a position of a center 104 of a corneal curvature of the eye 100 using at least one image of the eye 100 captured at that time instance, and estimating 603 a position of a center 103 of a pupil 102 of the eye 100 using at least one image of the eye 100 captured at that time instance. In the example shown in Fig. 5, images have been captured at four time instances, so positions 511, 521, 531 and 541 of the center 104 of corneal curvature and positions 512, 522, 532, 542 of the pupil center 103 are estimated for these points in time. It will be appreciated that the positions determined at the step 602 are positions relative to the camera 312 (or relative to the head-mounted device 310), and that these relative positions would not change if the user's head changes position and/or orientation in three-dimensional space (unless the head-mounted device 310 slips).

[0036] The method 600 comprises determining 604 (or forming) a line (or optical axis) through the estimated position of the center 104 of the corneal curvature and the estimated position of the center 103 of the pupil 102 for each of time instances. Hence, in the example shown in Fig. 5, a first line 510 (or optical axis) is determined through the first position 511 of the center 104 of corneal curvature and through the first position 512 of the pupil center 103. Similarly, a second line 520, a third line 530 and a fourth line 540 are determined for the second, third and fourth time instances respectively.

[0037] The method 600 comprises computing 605 (or determining) a first estimated position 550 of a center 106 of the eye 100 based on the lines determined for time instances in a first time period. In the example shown in Fig. 5, the first time period comprises the first and second time instances, so the first estimated position 550 of a center 106 of the eye 100 is computed based on the first line 510 and the second line 520. In the example shown in Fig. 5, the first estimated position 550 is simply the intersection of the first line 510 and the second line 520. If, on the other hand, the first estimated position were to be estimated based on more than two lines, these lines would not necessarily intersect all at the same point. In such a situation, the first estimated position may be computed as an approximate intersection of the lines. An example implementation of how to compute such an approximate intersection is described below with reference to Fig. 7. Note also that two lines need not necessary intersect in three-dimensional space. Hence, even if only two lines are to be employed for computing the first estimated position of the center 106 of the eye 100, it may be necessary to compute (or determine) some kind of approximate intersection rather than an actual intersection of these lines.

[0038] The method 600 comprises computing 606 (or determining) a second estimated position 560 of the center 106 of the eye 100 based on the lines determined for time instances in a second time period. In the example shown in Fig. 5, the second time period comprises the third and fourth time instances, so the second estimated position 560 of the center 106 of the eye 100 is computed based on the third line 530 and the fourth line 540. In the example shown in Fig. 5, the second estimated position 560 is simply the intersection of the third line 530 and the fourth line 540. If, on the other hand, the second estimated position were to be estimated based on more than two lines, these lines would not necessarily intersect all at the same point. In such a situation, the second estimated position may be computed as an approximate intersection of the lines. An example implementation of how to compute such an approximate intersection is described below with reference to Fig. 8. Note also that two lines need not necessary intersect in three-dimensional space. Hence, even if only two lines are to be employed for computing the second estimated position of the center

106 of the eye 100, it may be necessary to compute (or determine) some kind of approximate intersection rather than an actual intersection of these lines.

[0039] It will be appreciated that the estimated positions computed at the steps 605 and 606 are positions relative to the camera 312 (or relative to the head-mounted device 310), and that these relative positions would not change if the user's head changes position and/or orientation in three-dimensional space (unless the head-mounted device 310 slips).

[0040] The method 600 comprises detecting 607, based on the first and second estimated positions of the center 106 of the eye 100, relocation (or repositioning) of the head-mounted device 310 relative to the user's head. In the example shown in Fig. 5, the first estimated position 550 of the center 106 of the eye 100 and the second estimated position 560 of the center 106 of the eye 100 are located at a distance from each other. This may indicate that the camera 312 (and thereby the head-mounted device 310) has been relocated (or moved) relative to the user's head.

[0041] In theory, the first estimated position 550 of the center 106 of the eye 100 and the second estimated position 560 of the center 106 of the eye 100 should coincide unless the head-mounted device 310 has moved relative to the user's head. However, these estimated positions may typically deviate somewhat due to various types of noise and/or approximations in the computations, even if the head-mounted device 310 remains at its original position. Hence, according to some embodiments, the step 607 of detecting relocation of the head-mounted device 310 relative to the user's head may involve checking whether a deviation between the first and second estimated positions 550 and 560 of the center 106 of the eye 100 exceeds a threshold. If the deviation is above the threshold, it may be concluded that the head-mounted device 310 has probably been relocated. If the deviation is below the threshold, it may be concluded that the head-mounted device 310 has probably not been relocated. The threshold may for example be set to 1mm, 2mm, 3mm, 4mm, 5mm, or 1cm.

[0042] The lines 510 and 520 employed to obtain the first estimated position 550 of the center of the eye may for example correspond to when the head-mounted device remains in its intended position relative to the user's head, so that the optical axes of the eye all intersect at the same point, as illustrated by the optical axes 410, 420 and 430 in Fig. 4. The lines 530 and 540 employed to obtain the second estimated position 560 of the center of the eye may for example correspond to when the head-mounted device has slipped relative to the user's head, so that the optical axes of the eye appear to intersect at a new position,

[0043] The method 600 has been described above with reference to Figs 5. It will be appreciated that the collection positions and lines shown in Fig. 5 are merely intended as an example. For example, the first estimated position of the center 106 of the eye 100 could be computed as an intersection of a first line (determined via an image captured at a first time instance) and a second line (determined via an image captured at a second time instance), and the second estimated position of the center of the eye could be computed as an intersection of the second line and a third line (determined via an image captured at a third time instance). In other words, relocation of the head-mounted device 310 could for example be detected using images captured at only three different time instances.

[0044] If it is detected that the head-mounted device 310 has been relocated relative to the user's head, some type of corrective action may be needed to restore performance of the head-mounted device 310. For example, the HMD 310 may have been calibrated for operation at a certain position relative to the user's head. When relocation of the head-mounted device 310 is detected, the head-mounted device 310 may therefore be recalibrated for operation at the new position. Hence, the method 600 may optionally comprise providing 608 signaling for calibration of the head-mounted device 310 in response to detecting relocation of the head-mounted device 310 relative to the user's head. The signaling may for example control (or trigger) the head-mounted device 310 to perform calibration, or may control (or trigger) some type of calibration equipment to perform calibration of the head-mounted device 310.

[0045] Another type of corrective action that may be performed to restore performance of the head-mounted device 310 is to reposition the head-mounted device 310 at its original position. Hence, the method 600 may optionally comprise providing 609 signaling for prompting the user to reposition the head-mounted device 310 in response to detecting relocation of the head-mounted device 310 relative to the user's head. The signaling may for example control the display 312 of the head-mounted device 310 to provide a visual instruction (for example in the form of a text message) to the user to arrange the head-mounted device 310 at its proper position. The signaling may for example control the head-mounted device 310 (or some other device) to provide an audio message instructing the user to arrange the head-mounted device 310 at its proper position.

[0046] As described above with reference to Figs. 5-6, more than two lines in a plane do not necessarily intersect at the same point, and two lines in three-dimensional space do not necessarily intersect at all. As described below with reference to Figs. 7-8, an approximate intersection point may be employed if no true intersection point can be found.

[0047] Fig. 7 is a flow chart of an example implementation of how to compute 605 the first estimated position 550 of a center 106 of an eye 100 in the method 600 described above with reference to Fig. 6, according to an embodiment. In the present embodiment, the step 605 of computing the first estimated position 550 of the center 106 of the eye 100 comprises:

- forming 701 a first set of distances between candidate positions and the lines 520 and 530 determined for time instances in the first time period,
- forming 702 a first cost function based on the first set of distances, and
- computing 703 the first estimated position 550 of the center 106 of the eye 100 as a candidate position minimizing the first cost function.

[0048] The distances employed by the cost function may for example be Euclidean distances, but other types of distances (or metrics) could also be employed. The cost function may for example be a sum of squares of the distances from a candidate position to the lines, but other cost functions could also be employed. The minimization may for example be performed among candidate positions in a plane, or among candidate positions in three-dimensional space. The first estimated position 550 of the center 106 of the eye 100 may for example be a least squares estimate among the candidate positions.

[0049] Fig. 8 is a flow chart of an example implementation of how to compute 606 the second estimated position 560 of a center 106 of an eye 100 in the method 600 described above with reference to Fig. 6, according to an embodiment. In the present embodiment, the step 606 of computing the second estimated position 560 of the center 106 of the eye 100 comprises:

- forming 801 a second set of distances between candidate positions and the lines 530 and 540 determined for time instances in the second time period,
- forming 802 a second cost function based on the second set of distances, and
- computing 803 the second estimated position 560 of the center 106 of the eye 100 as a candidate position minimizing the second cost function.

[0050] The distances employed by the second cost function may for example be Euclidean distances, but other types of distances (or metrics) could also be employed. The cost function may for example be a sum of squares of the distances from a candidate position to the lines, but other cost functions could also be employed. The minimization may for example be performed among candidate positions in a plane, or among candidate positions in three-dimensional space. The second estimated position 560 of the center 106 of the eye 100 may for example be a least squares estimate among the candidate positions.

[0051] According to some embodiments, the positions of the center 104 of the corneal curvature, the center 103 of the pupil 102, and the center 106 of the eye 100 estimated in the method 600 described above with reference to Figs. 5-6 are computed as positions in a three-dimensional (3D) space.

[0052] 3D positions of the center 104 of corneal curvature may for example be estimated via pupil center corneal reflection (PCCR) using a three-dimensional model of the eye 100. Hence, according to some embodiments, at least some of the images of the eye 100 are captured while the eye 100 is illuminated by an illuminator 313 (or multiple illuminators 313). For a time instance, the position of the center 104 of the corneal curvature is estimated based on a position of a reflection 113 of the illuminator 313 (or based on positions of reflections of multiple illuminators) at the cornea 101 of the eye 100 in an image captured at that time instance. Example equations for how to compute the estimated positions of the center 104 of corneal curvature may for example be found in the paper "General Theory of Remote Gaze Estimation Using the Pupil Center and Corneal Reflections" by E. D. Guestrin et al. in IEEE Transactions on biomedical engineering, vol. 53, no. 6, June 2006 (which is incorporated herein by reference in its entirety), where the center 104 of corneal curvature is denoted by "c".

[0053] 3D positions of the pupil center 103 may for example be estimated via PCCR. Hence, according to some embodiments at least some of the images of the eye 100 are captured while the eye 100 is illuminated by an illuminator 313 (or multiple illuminators). For a time instance, the position of the center 103 of the pupil 102 is estimated based on a position of the center 103 of the pupil 102 in an image of the eye 100 captured at that time instance and based on a reflection 113 of the illuminator 313 (or based on positions of reflections of multiple illuminators) at the cornea 101 of the eye 100 in an image captured at that time instance. Example equations for how to compute the estimated positions of the pupil center 103 may for example be found in the paper "General Theory of Remote Gaze Estimation Using the Pupil Center and Corneal Reflections" by E. D. Guestrin et al. in IEEE Transactions on biomedical engineering, vol. 53, no. 6, June 2006 (which is incorporated herein by reference in its entirety), where the pupil center 103 is denoted by "p".

[0054] Detection 607 of relocation of the head-mounted device 310 relative to the user's head may be performed using estimated 3D positions of the center 106 of the eye 100. However, 3D motion of the head-mounted device 310 has many degrees of freedom. The head-mounted device 310 could for example be rotated around three different axes, and could be translated along three different axes. Such translations and rotations may be difficult to distinguish from noise in a reliable way. Hence, if the estimated position of the center 106 of the eye 100 changes or fluctuates somewhat over time, it may be difficult to determine whether this is due to noise, or whether it is really due to a relocation of the head-mounted device 310 relative to the user's head. A projection down to a two-dimensional (2D) setting may therefore be useful.

[0055] Hence, according to some embodiments, the first and second estimated positions of the center 106 of the eye 100 are computed as positions in a predefined plane. Such an embodiment is illustrated in Fig. 9 which shows a projection, in a plane 900, of lines 901 (or optical axes) determined in the method 600 described above with reference to Fig. 6. Each of the optical axes 901 passes through an estimated position of the center 104 of corneal curvature (indicated by "o" in Fig. 9) and an estimated position of the pupil center 103 (indicated by "+" in Fig. 9). The optical axes 901 do not all intersect at the same point even in the 2D representation in the plane 900, but the behavior of the optical axes 901 (and their respective intersections) may be easier to analyze in the plane 900 than in a 3D representation.

[0056] The plane 900 may for example be predefined (or predetermined) in the sense that is defined (or determined) prior to computing the estimated positions of the center 106 of eye 100. The plane 900 may for example have a fixed orientation relative to the head-mounted device 310 and/or relative to the camera 312 capturing the images. The plane 900 may for example be parallel to a plane along which the head-mounted device 310 extends, or along which the display 311 of the head-mounted device 310 extends. If the head-mounted device 310 slips relative to the user's head, the head-mounted device 310 will then typically slip in a direction more or less parallel to the plane 900. From the perspective of the camera 312, it will appear as though the eyes of the user move along a direction in the plane 900. Slippage (or relocation) of the head-mounted device 310 relative to the user's head may therefore be easily detected in the two-dimensional representation provided in the plane 900. Using a two-dimensional representation to detect slippage of the head-mounted device 310 may for example be more reliable and/or computationally less demanding than using a 3D representation to detect slippage of the head-mounted device 310.

[0057] If a 2D-representation (like the one described above with reference to Fig. 9) is to be employed for detecting relocation of the head-mounted device 310, there is no need to estimate 3D positions of the pupil center 103. Hence, rather than employing PCCR to estimate 3D positions for the pupil center 103, 2D positions for the pupil center 103 may be estimated in the images captured by the camera 312, for example using image analysis. The edge (or at least part of the edge) of the pupil 102 may for example be detected in an image, and the position of the pupil center 103 may be estimated based on the detected pupil edge. In some images, the edge of the pupil 102 may be difficult to detect. This may for example happen if the iris is so dark that it is of similar color as the pupil 102. The edge (or at least part of the edge) of the iris may then be detected in the image, and the position of the pupil center 103 may be estimated based on the detected edge of the iris. The images captured by the camera 312 may for example be digital images. The position of the pupil center 103 in an image captured by the camera 312 may be estimated as one or more pixels in the image.

[0058] A 2D position of the center 104 of corneal curvature may be difficult to estimate directly in the images captured by the camera 312. PCCR may therefore be employed to estimate a 3D position of the center 104 of corneal curvature. This 3D position may then be projected down to a 2D position.

[0059] Hence, in a first example scenario, 2D positions of the center 104 of corneal curvature and the pupil center 103 are estimated in a plane 900, the optical axes 901 are formed in the plane 900, and the estimated positions of the center 106 of the eye 100 are computed in the plane 900 based on the optical axes 901.

[0060] In a second scenario, the positions of the center 104 of the corneal curvature and the positions of the center 103 of the pupil 102 are estimated as positions in a three-dimensional space, and the optical axes (or lines) are determined in the three-dimensional space. In this scenario, the optical axes are then projected in the plane 900 to form optical axes 901 in the plane 900. The estimated positions of the center 106 of the eye 100 are then computed in the pane 900 based on these projections of the optical axes in the plane 900.

[0061] In a third scenario, the positions of the center 104 of the corneal curvature and the positions of the center 103 of the pupil 102 are estimated as positions in a three-dimensional space, the lines (or optical axes) are determined in the three-dimensional space, the estimated positions of the center 106 of the eye 100 are computed as positions in the three-dimensional space, and are then projected in the plane 900 to obtain 2D positions in the plane 900.

[0062] The plane 900 described above with reference to Fig. 9 may for example be a plane of an image captured by the camera 312. Hence, according to some embodiments, the first and second estimated positions of the center 106 of the eye 100 are computed as positions in a plane of an image captured by the camera 312. In other words, the estimated positions of the center 106 of the eye 100 computed in the method 600 described above with reference to Fig. 6 may be computed as positions in a plane represented by an image captured by the camera 312. This plane may for example be referred to as an image plane. Such an embodiment will be described below with reference to Figs. 10-11.

[0063] Figs. 10-11 show estimated optical axes in images of an eye, according to an embodiment. Fig. 10 shows a first image 1000 of an eye, and optical axes 1001 estimated for time instances in a first time period. These optical axes 1001 indicate that the center of the eye may be located in a first region 1002, since that is where an approximate intersection of the optical axes is located. Fig. 11 shows a second image 1100 of the eye. Fig. 11 shows the optical axes 1001 from Fig. 10, and also new optical axes 1101 estimated for time instances in a second time period after the first time period. These new optical axes 1101 indicate that the center 106 of the eye 100 may be located in a second region 1102, since there is where an approximate intersection of the new optical axes 1101 is located. The center 106 of the eye 100 appears to have moved relative to the camera between the first time period (corresponding to the first region 1002) and the second time period (corresponding to the second region 1102). This is an indication of drift (or slippage) of a head-mounted device.

[0064] Fig. 12 is a flow chart of a method 1200 for detecting relocation of a head-mounted device 310 relative to a user's head using both eyes of the user, according to the current invention. The method 1200 comprises the initial six steps 601-606 of the method 600 described above with reference to Fig. 6. The description of those steps will not be repeated here. The method 1200 also comprises analog steps 1201-1206 for a second eye of the user. In other words, the method 1200 comprises:

- obtaining 1201 images of a second eye of the user captured at the sequence of time instances by a camera 132 of the head-mounted device 310;
- for each of the time instances:
  - estimating 1202, using at least one image of the second eye captured at that time instance, a position of a center of a corneal curvature of the second eye,
  - estimating 1203, using at least one image of the second eye captured at that time instance, a position of a center of a pupil of the second eye, and
  - determining 1204 a line through the estimated position of the center of the corneal curvature of the second eye and the estimated position of the center of the pupil of the second eye;
- computing 1205 a first estimated position of a center of the second eye based on the lines determined for the second eye for time instances in the first time period; and
- computing 1206 a second estimated position of the center of the second eye based on lines determined for the second eye for time instances in the second time period.

[0065] Similarly to the method 600 described above with reference to Fig. 6, the method 1200 comprises the step of detecting 607 relocation of the head-mounted device 310 relative to the user's head, but in the present method 1200, as in the current invention, this step 607 is based on the first and second estimated positions of the center of the first eye and the first and second estimated positions of the center of the second eye.

[0066] Use of both eyes to detect relocation of the head-mounted device 310 may make the detection more reliable than if only eye was to be employed for the detection. In some cases, head-mounted device 310 slippage may for example be more easily detected for one eye than for the other eye. Another advantage of using both eyes for detecting head-mounted device 310 slippage is that potential head-mounted device 310 slippage detected for the respective eyes may be compared to check that the slippages detected for the respective eyes are actually compatible with each other. This is the case in the current invention. If the slippages are not compatible with each other, this may indicate that some unexpected event has occurred (such as an error or malfunction of the slippage detection, or that the user has removed the head-mounted device 310), or that there is too much noise in the images captured by the camera 312. One thing that could be checked is that the distance between the eyes (which is also referred to as interocular distance) is preserved also after a potential relocation of the head-mounted device 310. Hence, the step 607 of detecting relocation of the head-mounted device 310 relative to the user's head may optionally comprise:

- forming 1207 (or computing) a first distance between the first estimated position of the center of the first eye and the first estimated position of the center of the second eye;
- forming 1208 (or computing) a second distance between the second estimated position of the center of the first eye and the second estimated position of the center of the second eye; and
- checking 1209 that a difference between the first and second distances is below a threshold.

[0067] In other words, a first interocular distance

$$d_1 = \sqrt{(e_{L1} - e_{R1})^T (e_{L1} - e_{R1})}$$

is computed for the first estimated position e_{L1} of the center of the left eye and the first estimated position e_{R1} of the center of the right eye, and a second interocular distance

$$d_2 = \sqrt{(e_{L2} - e_{R2})^T (e_{L2} - e_{R2})}$$

is computed for the second estimated position e_{L2} of the center of the left eye and the second estimated position e_{R2} of the center of the right eye.

[0068] If the difference between the first and second interocular distances d_1 and d_2 is below a threshold, a potential relocation of the head-mounted device 310 indicated by a deviation between the positions e_{R1} and e_{R2}, and/or by a deviation between the positions e_{L1} and e_{L2} may indeed be a relocation of the head-mounted device 310 since the interocular distance seems to be at least approximately preserved. The threshold may for example be set to 1mm, 2mm, 3mm, 4mm, 5mm, or 1cm.

[0069] If, on the other hand, the difference between the first and second interocular distances d_1 and d_2 exceeds the threshold, this may indicate that some unexpected event has occurred (such as an error or malfunction of the slippage detection, or that the user has removed the head-mounted device 310), or that there is too much noise in the images captured by the camera 312. In this situation, a warning or error message may be signaled, instead of signaling that a slippage of the head-mounted device 310 has occurred.

[0070] The methods described above with reference to Figs. 5-12 represent a first aspect of the present disclosure. The system 300 described above with reference to Figs. 3 and 13 represents a second aspect of the present disclosure. The system 300 (or the processing circuitry 320 of the system 300) may for example be configured to perform the method of any of the embodiments of the first aspect described above. The system 300 may for example be configured to perform the method 600 described above with reference to Fig. 6 or the method 1200 described above with reference to Fig. 12.

[0071] According to an embodiment, the system 300 comprising processing circuitry 320 configured to:

a) obtain images of an eye captured at a sequence of time instances by a camera of the head-mounted device;
b) for each of the time instances:

- estimate, using at least one image of the eye captured at that time instance, a position of a center of a corneal curvature of the eye,
- estimate, using at least one image of the eye captured at that time instance, a position of a center of a pupil of the eye, and
- determine a line through the estimated position of the center of the corneal curvature and the estimated position of the center of the pupil;

c) compute a first estimated position of a center of the eye based on the lines determined for time instances in a first time period;
d) compute a second estimated position of the center of the eye based on the lines determined for time instances in a second time period; and
e) detect, based on the first and second estimated positions of the center of the eye, relocation of the head-mounted device relative to the user's head.

[0072] As described above with reference to Fig. 3, the system 300 need not necessarily comprise all the elements shown in Fig. 3. The system 300 may for example be a gaze tracking system.

[0073] A third aspect of the present disclosure is represented by embodiments of a non-transitory computer-readable storage medium 322 storing instructions which, when executed by processing circuitry 320 of the system 300, cause the system 300 to perform the method of any of the embodiments of the first aspect described above (such as the method 600 described above with reference to Fig. 6, or the method 1200 described above with reference to Fig. 12).

[0074] According to an embodiment, the non-transitory computer-readable storage medium 322 stores instructions which, when executed by processing circuitry 320 of the system 300, cause the system 300 to:

a) obtain images of an eye captured at a sequence of time instances by a camera of the head-mounted device;
b) for each of the time instances:

- estimate, using at least one image of the eye captured at that time instance, a position of a center of a corneal curvature of the eye,
- estimate, using at least one image of the eye captured at that time instance, a position of a center of a pupil of the eye, and
- determine a line through the estimated position of the center of the corneal curvature and the estimated position of the center of the pupil;

c) compute a first estimated position of a center of the eye based on the lines determined for time instances in a first time period;
d) compute a second estimated position of the center of the eye based on the lines determined for time instances in a second time period; and
e) detect, based on the first and second estimated positions of the center of the eye, relocation of the head-mounted device relative to the user's head.

[0075] As described above with reference to Fig. 3, the storage medium 322 need not necessarily be comprised in the system 300.

[0076] The person skilled in the art realizes that the present invention is by no means limited to the preferred embodiments described above. On the contrary, many modifications and variations are possible within the scope of the appended claims. For example, the embodiments described above with reference to Figs. 1-13 may be combined to form further embodiments. Further, it will be appreciated that the system 300 shown in Fig. 300 is merely intended as an example, and that other systems may also perform the methods described above with reference to Figs. 5-12. It will also be appreciated that the method steps described with reference to Figs. 6, 7, 8 and 12 need not necessarily be performed in the specific order shown in these figures.

[0077] It will be appreciated that processing circuitry 320 (or a processor) may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, software and/or encoded logic operable to provide computer functionality, either alone or in conjunction with other computer components (such as a memory or storage medium).

[0078] It will also be appreciated that a memory or storage medium 322 (or a computer-readable medium) may comprise any form of volatile or non-volatile computer readable memory including, without limitation, persistent storage, solid-state memory, remotely mounted memory, magnetic media, optical media, random access memory

(RAM), read-only memory (ROM), mass storage media (for example, a hard disk), removable storage media (for example, a flash drive, a Compact Disk (CD) or a Digital Video Disk (DVD)), and/or any other volatile or non-volatile, non-transitory device readable and/or computer-executable memory devices that store information, data, and/or instructions that may be used by a processor or processing circuitry.

[0079] Additionally, variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. In the claims, the word "or" is not to be interpreted as an exclusive or (sometimes referred to as "XOR"). On the contrary, expressions such as "A or B" covers all the cases "A and not B", "B and not A" and "A and B", unless otherwise indicated. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A method (600) for detecting relocation of a head-mounted device (310) relative to a user's head (1301), the method comprising:

obtaining (601) images of a first eye of the user (100, 400) captured at a sequence of time instances by a camera (312) of the head-mounted device;
for each of the time instances:

estimating (602), using at least one image of the first eye captured at that time instance, a position (511) of a center (104, 411, 421, 431) of a corneal curvature of the first eye,
estimating (603), using at least one image of the first eye captured at that time instance, a position (512) of a center (103, 412, 422, 432) of a pupil (102) of the first eye, and
determining (604) for the first eye a line (510) through the estimated position of the center of the corneal curvature of the first eye and the estimated position of the center of the pupil of the first eye;

computing (605) a first estimated position (550) of a center (106, 401) of the first eye based on the lines (510, 520, 410, 420, 430) determined for the first eye for time instances in a first time period;
computinq (606) a second estimated position (560) of the center of the first eye based on the lines (530, 540) determined for the first eye for time instances in a second time period; and the method further comprising:

obtaining (1201) images of a second eye captured at the sequence of time instances by a camera of the head-mounted device;
for each of the time instances:

estimating (1202), using at least one image of the second eye captured at that time instance, a position of a center of a corneal curvature of the second eye, estimating (1203), using at least one image of the second eye captured at that time instance, a position of a center of a pupil of the second eye, and determining (1204) for the second eye a line through the estimated position of the center of the corneal curvature of the second eye and the estimated position of the center of the pupil of the second eye;

computing (1205) a first estimated position of a center of the second eye based on the lines determined for the second eye for time instances in the first time period; and
computing (1206) a second estimated position of the center of the second eye based on lines determined for the second eye for time instances in the second time period,

detecting (607), based on the first and second estimated positions of the center of the first eye, relocation of the head-mounted device relative to the user's head, wherein the detection of relocation of the head-mounted device relative to the user's head is also based on the first and second estimated positions of the center of the second eye; and wherein detecting relocation of the head-mounted device relative to the user's head comprises:

forming (1207) a first distance between the first estimated position of the center of the first eye and the first estimated position of the center of the second eye;
forming (1208) a second distance between the second estimated position of the center of the first eye and the second estimated position of the center of the second eye; and
checking (1209) that a difference between the first and second distances is below a threshold.

2. The method of claim 1, wherein:

the first estimated position of the center of the first eye is computed based on an approximated intersection point between the lines determined for the first eye for time instances in the first time period and/or
the second estimated position of the center of the first eye is computed based on an approximated intersection point between the lines determined for the first eye for time instances in the second time period.

3. The method of any of the preceding claims, wherein computing the first estimated position of the center of the first eye comprises:

forming (701) a first set of distances between candidate positions and the lines determined for the first eye for time instances in the first time period
forming (702) a first cost function based on the first set of distances; and computing (703) the first estimated position of the center of the first eye as a candidate position minimizing the first cost function, and/or wherein computing the second estimated position of the center of the first eye comprises:

forming (801) a second set of distances between candidate positions and the lines determined for the first eye for time instances in the second time period
forming (802) a second cost function based on the second set of distances; and computing (803) the second estimated position of the center of the first eye as a candidate position minimizing the second cost function.

4. The method of any of the preceding claims, wherein the first and second estimated positions of the center of the first eye are computed as positions in a predefined plane (900).

5. The method of claim 4, wherein the predefined plane is a plane of an image (1100) captured by said camera.

6. The method of any of claims 4-5, wherein the positions of the center of the corneal curvature of the first eye and the positions of the center of the pupil of the first eye are estimated in said plane, and wherein the lines determined for the first eye are determined in said plane.

7. The method of any of claims 4-5, wherein:

a) the positions of the center of the corneal curvature of the first eye and the positions of the center of the pupil of the first eye are estimated as positions in a three-dimensional space the lines determined for the first eye are determined in the three-dimensional space, and the first and second estimated positions of the center of the first eye are computed based on projections of the lines determined for the first eye in said plane; or
b) the positions of the center of the corneal curvature of the first eye and the positions of the center of the pupil of the first eye are estimated as positions in a three-dimensional space the lines determined for the first eye are determined in the three-dimensional space, and the first and second estimated positions of the center of the first eye are computed in the three-dimensional space and are then projected down to said plane.

8. The method of any of clams 1-3, wherein the positions of the center of the corneal curvature of the first eye, the positions of the center of the pupil of the first eye, and the positions of the center of the first eye are estimated as positions in a three-dimensional space

9. The method of any of the preceding claims, wherein at least some of the images of

the first eye are captured while the first eye is illuminated by an illuminator (313), and
wherein, for a time instance, the position of the center of the corneal curvature of the first eye is estimated based on a position of a reflection (113) of the illuminator at a cornea (101) of the first eye in an image captured at that time instance

10. The method of any of the preceding claims, wherein at least some of the images of the first eye are captured while the first eye is illuminated by an illuminator (313) and wherein, for a time instance, the position of the center of the pupil of the first eye is estimated based on a position of the center of the pupil of the first eye in an image of the first eye captured at that time instance and based on a reflection (113) of the illuminator at a cornea (101) of the first eye in an image captured at that time instance.

11. The method of any of the preceding claims, wherein detecting relocation of the head-mounted device relative to the user's head comprises:
detecting relocation of the head-mounted device in response to a deviation between the first and second estimated positions of the center of the first eye exceeding a threshold.

12. The method of any of the preceding claims, further comprising, in response to detecting relocation of the head-mounted device relative to the user's head:

providing (608) signaling for calibration of the head-mounted device; or
providing (609) signaling for prompting the user to reposition the head-mounted device.

13. A system (300) for detecting relocation of a head-mounted device (310) relative to a user's head (1301), the system comprising processing circuitry (320) configured to:

obtain images of a first eye of the user (100, 400) captured at a sequence of time instances by a camera (312) of the head-mounted device;
for each of the time instances:

estimate, using at least one image of the first eye captured at that time instance, a position (511) of a center (104, 411, 421, 431) of a corneal curvature of the first eye,
estimate, using at least one image of the first eye captured at that time instance, a position (512) of a center (103, 412, 422, 432) of a pupil (102) of the first eye, and
determine for the first eye a line (510) through the estimated position of the center of the corneal curvature of the first eye and the estimated position of the center of the pupil of the first eye;

compute a first estimated position (550) of a center (106, 401) of the first eye based on the lines (510, 520, 410, 420, 430) determined for the first eye for time instances in a first time period;
compute a second estimated position (560) of the center of the first eye based on the lines (530, 540) determined for the first eye for time instances in a second time period and further
obtain images of a second eye captured at the sequence of time instances by a camera of the head-mounted device;
for each of the time instances:

estimate, using at least one image of the second eye captured at that time instance, a position of a center of a corneal curvature of the second eye,
estimate, using at least one image of the second eye captured at that time instance, a position of a center of a pupil of the second eye, and
determine for the second eye a line through the estimated position of the center of the corneal curvature of the second eye and the estimated position of the center of the pupil of the second eye;

compute a first estimated position of a center of the second eye based on the lines determined for the second eye for time instances in the first time period; and
compute a second estimated position of the center of the second eye based on lines determined for the second eye for time instances in the second time period, detect, based on the first and second estimated positions of the center of the first eye relocation of the head-mounted device relative to the user's head, wherein the detection of relocation of the head-mounted device relative to the user's head is also based on the first and second estimated positions of the center of the second eye; and wherein the system comprising processing circuitry (320) configured to detect relocation of the head-mounted device relative to the user's head is further configured to:

form a first distance between the first estimated position of the center of the first eye and the first estimated position of the center of the second eye;
form a second distance between the second estimated position of the center of the first eye and the second estimated position of the center of the second eye; and
check that a difference between the first and second distances is below a threshold.

14. A non-transitory computer-readable storage medium storing instructions which, when executed by a processing circuitry of a system, cause the system to perform the method of any one of claims 1 to 12.

15. A computer program product comprising a non-transitory computer-readable storage medium storing instructions which, when executed by a processing circuitry of a system, cause the system to perform the method of any one of claims 1 to 12.

Patentansprüche

1. Verfahren (600) zum Erfassen einer Verlagerung einer kopfmontierten Vorrichtung (310) relativ zu einem Kopf eines Benutzers (1301), das Verfahren umfassend:

Erhalten (601) von Bildern eines ersten Auges des Benutzers (100, 400), die zu einer Folge von Zeitpunkten durch eine Kamera (312) der kopfmontierten Vorrichtung erfasst werden;
für jeden der Zeitpunkte:

Schätzen (602), unter Verwendung mindestens eines Bildes des ersten Auges, das zu diesem Zeitpunkt erfasst wird, einer Position (511) eines Zentrums (104, 411, 421, 431) einer Hornhautkrümmung des ersten Auges,
Schätzen (603), unter Verwendung mindestens eines Bildes des ersten Auges, das zu diesem Zeitpunkt erfasst wird, einer Position (512) eines Zentrums (103, 412, 422, 432) einer Pupille (102) des ersten Auges, und
Bestimmen (604) für das erste Auge einer Linie (510) durch die geschätzte Position des Zentrums der Hornhautkrümmung des ersten Auges und die geschätzte Position des Zentrums der Pupille des ersten Auges;
Berechnen (605) einer ersten geschätzten Position (550) eines Zentrums (106, 401) des ersten Auges basierend auf den Linien (510, 520, 410, 420, 430), die für das erste Auge für Zeitpunkte in einem ersten Zeitraum bestimmt werden;
Berechnen (606) einer zweiten geschätzten Position (560) des Zentrums des ersten Auges basierend auf den Linien (530, 540), die für das erste Auge für Zeitpunkte in einem zweiten Zeitraum bestimmt werden, und das Verfahren ferner umfassend:

Erhalten (1201) von Bildern eines zweiten Auges, die zu der Folge von Zeitpunkten durch eine Kamera der kopfmontierten Vorrichtung aufgenommen werden;
für jeden der Zeitpunkte:

Schätzen (1202), unter Verwendung mindestens eines Bildes des zweiten Auges, das zu diesem Zeitpunkt erfasst wird, einer Position eines Zentrums einer Hornhautkrümmung des zweiten Auges,
Schätzen (1203), unter Verwendung mindestens eines Bildes des zweiten Auges, das zu diesem Zeitpunkt erfasst wird, einer Position eines Zentrums einer Pupille des zweiten Auges, und
Bestimmen (1204) für das zweite Auge einer Linie durch die geschätzte Position des Zentrums der Hornhautkrümmung des zweiten Auges und die geschätzte Position des Zentrums der Pupille des zweiten Auges;
Berechnen (1205) einer ersten geschätzten Position eines Zentrums des zweiten Auges basierend auf Linien, die für das zweite Auge für Zeitpunkte in dem ersten Zeitraum bestimmt werden; und
Berechnen (1206) einer zweiten geschätzten Position des Zentrums des zweiten Auges basierend auf Linien, die für das zweite Auge für Zeitpunkte in dem zweiten Zeitraum bestimmt werden,
Erfassen (607), basierend auf der ersten und der zweiten geschätzten Position des Zentrums des ersten Auges, der Verlagerung der kopfmontierten Vorrichtung relativ zu dem Kopf des Benutzers, wobei die Erfassung der Verlagerung der kopfmontierten Vorrichtung relativ zu dem Kopf des Benutzers auch auf der ersten und der zweiten geschätzten Position des Zentrums des zweiten Auges basiert, und wobei das Erfassen der Verlagerung der kopfmontierten Vorrichtung relativ zu dem Kopf des Benutzers umfasst:

Ausbilden (1207) eines ersten Abstands zwischen der ersten geschätzten Position des Zentrums des ersten Auges und der ersten geschätzten Position des Zentrums des zweiten Auges;
Ausbilden (1208) eines zweiten Abstands zwischen der zweiten geschätzten Position des Zentrums des ersten Auges und der zweiten geschätzten Position des Zentrums des zweiten Auges; und
Prüfen (1209), dass eine Differenz zwischen dem ersten und dem zweiten Abstand unter einem Schwellenwert liegt.

2. Verfahren nach Anspruch 1, wobei:

die erste geschätzte Position des Zentrums des ersten Auges basierend auf einem angenäherten Schnittpunkt zwischen den Linien berechnet wird, die für das erste Auge für Zeitpunkte in dem ersten Zeitraum bestimmt werden;
und/oder
die zweite geschätzte Position des Zentrums des ersten Auges basierend auf einem angenäherten Schnittpunkt zwischen den Linien be-

rechnet wird, die für das erste Auge für Zeitpunkte in dem zweiten Zeitraum bestimmt werden.

3. Verfahren nach einem der vorstehenden Ansprüche, wobei das Berechnen der ersten geschätzten Position des Zentrums des ersten Auges umfasst:

Ausbilden (701) eines ersten Satzes von Abständen zwischen Kandidatenpositionen und den Linien, die für das erste Auge für Zeitpunkte in dem ersten Zeitraum bestimmt werden;
Ausbilden (702) einer ersten Kostenfunktion basierend auf dem ersten Satz von Abständen; und
Berechnen (703) der ersten geschätzten Position des Zentrums des ersten Auges als eine Kandidatenposition, die die erste Kostenfunktion minimiert, und/oder wobei das Berechnen der zweiten geschätzten Position des Zentrums des ersten Auges umfasst:

Ausbilden (801) eines zweiten Satzes von Abständen zwischen Kandidatenpositionen und den Linien, die für das erste Auge für Zeitpunkte in dem zweiten Zeitraum bestimmt werden;
Ausbilden (802) einer zweiten Kostenfunktion basierend auf dem zweiten Satz von Abständen; und
Berechnen (803) der zweiten geschätzten Position des Zentrums des ersten Auges als eine Kandidatenposition, die die zweite Kostenfunktion minimiert.

4. Verfahren nach einem der vorstehenden Ansprüche, wobei die erste und die zweite geschätzte Position des Zentrums des ersten Auges als Positionen in einer vordefinierten Ebene (900) berechnet werden.

5. Verfahren nach Anspruch 4, wobei die vordefinierte Ebene eine Ebene eines Bildes ist, das durch die Kamera (1100) erfasst wird.

6. Verfahren nach einem der Ansprüche 4 bis 5, wobei die Positionen des Zentrums der Hornhautkrümmung des ersten Auges und die Positionen des Zentrums der Pupille des ersten Auges in der Ebene geschätzt werden, und wobei die Linien, die für das erste Auge bestimmt werden, in der Ebene bestimmt werden.

7. Verfahren nach einem der Ansprüche 4 bis 5, wobei:

a) die Positionen des Zentrums der Hornhautkrümmung des ersten Auges und die Positionen des Zentrums der Pupille des ersten Auges als Positionen in einem dreidimensionalen Raum geschätzt werden, wobei die Linien, die für das erste Auge bestimmt werden, in dem dreidimensionalen Raum bestimmt werden, und die erste und die zweite geschätzte Position des Zentrums des ersten Auges basierend auf Projektionen der Linien berechnet werden, die für das erste Auge in der Ebene bestimmt werden; oder
b) die Positionen des Zentrums der Hornhautkrümmung des ersten Auges und die Positionen des Zentrums der Pupille des ersten Auges als Positionen in einem dreidimensionalen Raum geschätzt werden, wobei die Linien, die für das erste Auge bestimmt werden, in dem dreidimensionalen Raum bestimmt werden, und die erste und die zweite geschätzte Position des Zentrums des ersten Auges in dem dreidimensionalen Raum berechnet werden und dann auf die Ebene hinunter projiziert werden.

8. Verfahren nach einem der Ansprüche 1 bis 3, wobei die Positionen des Zentrums der Hornhautkrümmung des ersten Auges, die Positionen des Zentrums der Pupille des ersten Auges und die Positionen des Zentrums des ersten Auges als Positionen in einem dreidimensionalen Raum geschätzt werden.

9. Verfahren nach einem der vorstehenden Ansprüche, wobei mindestens einige der Bilder des ersten Auges erfasst werden, während das erste Auge durch eine Beleuchtungseinrichtung (313) beleuchtet wird, und wobei für einen Zeitpunkt die Position des Zentrums der Hornhautkrümmung des ersten Auges basierend auf einer Position einer Reflexion (113) der Beleuchtungseinrichtung an einer Hornhaut (101) des ersten Auges in einem Bild geschätzt wird, das zu diesem Zeitpunkt erfasst wird.

10. Verfahren nach einem der vorstehenden Ansprüche, wobei mindestens einige der Bilder des ersten Auges erfasst werden, während das erste Auge durch eine Beleuchtungseinrichtung (313) beleuchtet wird, und wobei für einen Zeitpunkt die Position des Zentrums der Pupille des ersten Auges basierend auf einer Position des Zentrums der Pupille des ersten Auges in einem Bild des ersten Auges, das zu diesem Zeitpunkt erfasst wird, und basierend auf einer Reflexion (113) der Beleuchtungseinrichtung an einer Hornhaut (101) des ersten Auges in einem Bild geschätzt wird, das zu diesem Zeitpunkt aufgenommen wird.

11. Verfahren nach einem der vorstehenden Ansprüche, wobei das Erfassen der Verlagerung der kopfmontierten Vorrichtung relativ zu dem Kopf des Benutzers umfasst:
Erfassen der Verlagerung der kopfmontierten Vorrichtung als Reaktion auf eine Abweichung zwischen der ersten und der zweiten geschätzten Position des

Zentrums des ersten Auges, die einen Schwellenwert überschreitet.

12. Verfahren nach einem der vorstehenden Ansprüche, ferner umfassend, als Reaktion auf das Erfassen der Verlagerung der kopfmontierten Vorrichtung relativ zu dem Kopf des Benutzers:

Bereitstellen (608) einer Signalisierung für eine Kalibrierung der kopfmontierten Vorrichtung; oder
Bereitstellen (609) der Signalisierung zum Auffordern des Benutzers, die kopfmontierte Vorrichtung neu zu positionieren.

13. System (300) zum Erfassen der Verlagerung einer kopfmontierten Vorrichtung (310) relativ zu einem Kopf des Benutzers (1301), das System umfassend eine Verarbeitungsschaltung (320), die konfiguriert ist zum:

Erhalten von Bildern eines ersten Auges des Benutzers (100, 400), die zu einer Folge von Zeitpunkten durch eine Kamera (312) der kopfmontierten Vorrichtung erfasst werden;
für jeden der Zeitpunkte:

Schätzen, unter Verwendung mindestens eines Bildes des ersten Auges, das zu diesem Zeitpunkt erfasst wird, einer Position (511) eines Zentrums (104, 411, 421, 431) einer Hornhautkrümmung des ersten Auges,
Schätzen, unter Verwendung mindestens eines Bildes des ersten Auges, das zu diesem Zeitpunkt erfasst wird, einer Position (512) eines Zentrums (103, 412, 422, 432) einer Pupille (102) des ersten Auges, und
Bestimmen für das erste Auge einer Linie (510) durch die geschätzte Position des Zentrums der Hornhautkrümmung des ersten Auges und die geschätzte Position des Zentrums der Pupille des ersten Auges;
Berechnen einer ersten geschätzten Position (550) eines Zentrums (106, 401) des ersten Auges basierend auf den Linien (510, 520, 410, 420, 430), die für das erste Auge für Zeitpunkte in einem ersten Zeitraum bestimmt werden;
Berechnen einer zweiten geschätzten Position (560) des Zentrums des ersten Auges basierend auf den Linien (530, 540), die für das erste Auge für Zeitpunkte in einem zweiten Zeitraum bestimmt werden, und ferner
Erhalten von Bildern eines zweiten Auges, die zu der Folge von Zeitpunkten durch eine Kamera der kopfmontierten Vorrichtung erfasst werden;
für jeden der Zeitpunkte:

Schätzen, unter Verwendung mindestens eines Bildes des zweiten Auges, das zu diesem Zeitpunkt erfasst wird, einer Position eines Zentrums einer Hornhautkrümmung des zweiten Auges,
Schätzen, unter Verwendung mindestens eines Bildes des zweiten Auges, das zu diesem Zeitpunkt erfasst wird, einer Position eines Zentrums einer Pupille des zweiten Auges, und
Bestimmen für das zweite Auge einer Linie durch die geschätzte Position des Zentrums der Hornhautkrümmung des zweiten Auges und die geschätzte Position des Zentrums der Pupille des zweiten Auges;
Berechnen einer ersten geschätzten Position eines Zentrums des zweiten Auges basierend auf den Linien, die für das zweite Auge für Zeitpunkte in dem ersten Zeitraum bestimmt werden; und
Berechnen einer zweiten geschätzten Position des Zentrums des zweiten Auges basierend auf Linien, die für das zweite Auge für Zeitpunkte in dem zweiten Zeitraum bestimmt werden,
Erfassen, basierend auf der ersten und der zweiten geschätzten Position des Zentrums des ersten Auges, der Verlagerung der kopfmontierten Vorrichtung relativ zu dem Kopf des Benutzers, wobei die Erfassung der Verlagerung der kopfmontierten Vorrichtung relativ zu dem Kopf des Benutzers auch auf der ersten und der zweiten geschätzten Position des Zentrums des zweiten Auges basiert, und wobei das System, umfassend die Verarbeitungsschaltung (320), das konfiguriert ist, um die Verlagerung der kopfmontierten Vorrichtung relativ zu dem Kopf des Benutzers zu erfassen, ferner konfiguriert ist zum:

Ausbilden eines ersten Abstands zwischen der ersten geschätzten Position des Zentrums des ersten Auges und der ersten geschätzten Position des Zentrums des zweiten Auges;
Ausbilden eines zweiten Abstands zwischen der zweiten geschätzten Position des Zentrums des ersten Auges und der zweiten geschätz-

ten Position des Zentrums des zweiten Auges; und
Prüfen, dass eine Differenz zwischen dem ersten und dem zweiten Abstand unter einem Schwellenwert liegt.

14. Nichtflüchtiges computerlesbares Speichermedium, das Anweisungen speichert, die, wenn sie durch eine Verarbeitungsschaltung eines Systems ausgeführt werden, das System veranlassen, das Verfahren nach einem der Ansprüche 1 bis 12 durchzuführen.

15. Computerprogrammprodukt, umfassend ein nichtflüchtiges computerlesbares Speichermedium, das Anweisungen speichert, die, wenn sie durch eine Verarbeitungsschaltung eines Systems ausgeführt werden, das System veranlassen, das Verfahren nach einem der Ansprüche 1 bis 12 durchzuführen.

Revendications

1. Procédé (600) permettant de détecter le déplacement d'un dispositif monté sur une tête (310) par rapport à une tête d'un utilisateur (1301), le procédé comprenant :

l'obtention (601) d'images d'un premier oeil de l'utilisateur (100, 400) capturées à une séquence d'instances temporelles par une caméra (312) du dispositif monté sur une tête ;
pour chacune des instances temporelles :

l'estimation (602), à l'aide d'au moins une image du premier oeil capturée à cette instance temporelle, d'une position (511) d'un centre (104, 411, 421, 431) d'une courbure cornéenne du premier œil,
l'estimation (603), à l'aide d'au moins une image du premier oeil capturée à cette instance temporelle, d'une position (512) d'un centre (103, 412, 422, 432) d'une pupille (102) du premier œil, et
la détermination (604) pour le premier oeil d'une ligne (510) par la position estimée du centre de la courbure cornéenne du premier oeil et de la position estimée du centre de la pupille du premier oeil ;
le calcul (605) d'une première position estimée (550) d'un centre (106, 401) du premier oeil sur la base des lignes (510, 520, 410, 420, 430) déterminées pour le premier oeil pour des instances temporelles dans une première période de temps ;
le calcul (606) d'une seconde position estimée (560) du centre du premier oeil sur la base des lignes (530, 540) déterminées pour le premier oeil pour des instances temporelles dans une seconde période de temps ; et le procédé comprenant en outre :

l'obtention (1201) d'images d'un second oeil capturé au niveau de la séquence d'instances temporelles par une caméra du dispositif monté sur unetête ;
pour chacune des instances temporelles :

l'estimation (1202), à l'aide d'au moins une image du second oeil capturée à cette instance temporelle, d'une position d'un centre d'une courbure cornéenne du second œil,
l'estimation (1203), à l'aide d'au moins une image du second oeil capturée à cette instance temporelle, d'une position d'un centre d'une pupille du second oeil, et
la détermination (1204) pour le second oeil d'une ligne par la position estimée du centre de la courbure cornéenne du second oeil et de la position estimée du centre de la pupille du second oeil ;
le calcul (1205) d'une première position estimée d'un centre du second oeil sur la base des lignes déterminées pour le second oeil pour des instances temporelles dans la première période de temps ; et
le calcul (1206) d'une seconde position estimée du centre du second oeil sur la base de lignes déterminées pour le second oeil pour des instances temporelles dans la seconde période de temps,
la détection (607), sur la base des première et seconde positions estimées du centre du premier oeil, du déplacement du dispositif monté sur une tête par rapport à la tête de l'utilisateur, dans lequel la détection de déplacement du dispositif monté sur une tête par rapport à la tête de l'utilisateur est également basée sur les première et seconde positions estimées du centre du second oeil ; et dans lequel la détection du déplacement du dispositif monté sur le casque par rapport à la tête de l'utilisateur comprend :

la formation (1207) d'une première distance entre la première position estimée du centre du premier oeil et la première position estimée du centre du second oeil ;
la formation (1208) d'une seconde distance entre la seconde position estimée du centre du premier oeil et la seconde position estimée du centre du second oeil ; et
la vérification (1209) qu'une différence entre les première et seconde distances est inférieure à un seuil.

2. Procédé selon la revendication 1, dans lequel :

la première position estimée du centre du premier oeil est calculée sur la base d'un point d'intersection approximé entre les lignes déterminées pour le premier oeil pour des instances temporelles dans la première période de temps ; et/ou
la seconde position estimée du centre du premier oeil est calculée sur la base d'un point d'intersection approximé entre les lignes déterminées pour le premier oeil pour des instances temporelles dans la seconde période de temps.

3. Procédé selon l'une quelconque des revendications précédentes, dans lequel le calcul de la première position estimée du centre du premier oeil comprend :

la formation (701) d'un premier ensemble de distances entre des positions candidates et des lignes déterminées pour le premier oeil pour des instances temporelles dans la première période de temps ;
la formation (702) d'une première fonction de coût sur la base du premier ensemble de distances ; et
le calcul (703) de la première position estimée du centre du premier oeil en tant que position candidate minimisant la première fonction de coût, et/ou dans lequel le calcul de la seconde position estimée du centre du premier oeil comprend :

la formation (801) d'un second ensemble de distances entre des positions candidates et des lignes déterminées pour le premier oeil pour des instances temporelles dans la seconde période de temps ;
la formation (802) d'une seconde fonction de coût sur la base du second ensemble de distances ; et
le calcul (803) de la seconde position estimée du centre du premier oeil en tant que position candidate minimisant la seconde fonction de coût.

4. Procédé selon l'une quelconque des revendications précédentes, dans lequel les première et seconde positions estimées du centre du premier œil sont calculées comme des positions dans un plan prédéfini (900).

5. Procédé selon la revendication 4, dans lequel le plan prédéfini est un plan d'une image (1100) capturée par ladite caméra.

6. Procédé selon l'une quelconque des revendications 4 à 5, dans lequel les positions du centre de la courbure cornéenne du premier oeil et les positions du centre de la pupille du premier oeil sont estimées dans ledit plan, et dans lequel les lignes déterminées pour le premier oeil sont déterminées dans ledit plan.

7. Procédé selon l'une quelconque des revendications 4 à 5, dans lequel :

a) les positions du centre de la courbure cornéenne du premier oeil et des positions du centre de la pupille du premier oeil sont estimées en tant que positions dans un espace tridimensionnel, les lignes déterminées pour le premier oeil sont déterminées dans l'espace tridimensionnel, et les première et seconde positions estimées du centre du premier oeil sont calculées sur la base de projections des lignes déterminées pour le premier oeil dans ledit plan ; ou
b) les positions du centre de la courbure cornéenne du premier oeil et les positions du centre de la pupille du premier oeil en tant que positions dans un espace tridimensionnel, les lignes déterminées pour le premier oeil sont déterminées dans l'espace tridimensionnel, et les première et seconde positions estimées du centre du premier oeil sont calculées dans l'espace tridimensionnel puis projetées vers le bas dudit plan.

8. Procédé selon l'une quelconque des revendications 1 à 3, dans lequel les positions du centre de la courbure cornéenne du premier oeil, les positions du centre de la pupille du premier oeil, et les positions du centre du premier oeil sont estimées comme des positions dans un espace tridimensionnel.

9. Procédé selon l'une quelconque des revendications précédentes, dans lequel au moins certaines des images du premier oeil sont capturées alors que le premier oeil est éclairé par un dispositif d'éclairage (313), et dans lequel, pour une instance temporelle,

la position du centre de la courbure cornéenne du premier oeil est estimée sur la base d'une position d'une réflexion (113) du dispositif d'éclairage au niveau d'une cornée (101) du premier oeil dans une image capturée à cette instance temporelle.

10. Procédé selon l'une quelconque des revendications précédentes, dans lequel au moins certaines des images du premier oeil sont capturées alors que le premier oeil est éclairé par un dispositif d'éclairage (313), et dans lequel, pour une instance temporelle, la position du centre de la pupille du premier oeil est estimée sur la base d'une position du centre de la pupille du premier oeil dans une image du premier oeil capturée à cette instance temporelle et sur la base d'une réflexion (113) du dispositif d'éclairage au niveau d'une cornée (101) du premier oeil dans une image capturée à cette instance temporelle.

11. Procédé selon l'une quelconque des revendications précédentes, dans lequel la détection de déplacement du dispositif monté sur une tête par rapport à la tête de l'utilisateur comprend :
la détection du déplacement du dispositif monté sur une tête en réponse à un écart entre les première et seconde positions estimées du centre du premier oeil dépassant un seuil.

12. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre, en réponse à la détection du déplacement du dispositif monté sur une tête par rapport à la tête de l'utilisateur ;

la fourniture (608) d'une signalisation pour un étalonnage du dispositif monté sur une tête ; ou
la fourniture (609) d'une signalisation pour inviter l'utilisateur à repositionner le dispositif monté sur une tête.

13. Système (300) permettant de détecter le déplacement d'un dispositif monté sur une tête (310) par rapport à une tête d'un utilisateur (1301), le système comprenant un circuit de traitement (320) configuré pour :

obtenir des images d'un premier oeil de l'utilisateur (100, 400) capturées à une séquence d'instances temporelles par une caméra (312) du dispositif monté sur une tête ;
pour chacune des instances temporelles :

estimer, à l'aide d'au moins une image du premier oeil capturée à cette instance temporelle, une position (511) d'un centre (104, 411, 421, 431) d'une courbure cornéenne du premier œil,
estimer, à l'aide d'au moins une image du premier oeil capturée à cette instance temporelle, une position (512) d'un centre (103, 412, 422, 432) d'une pupille (102) du premier œil, et
déterminer pour le premier oeil une ligne (510) par la position estimée du centre de la courbure cornéenne du premier oeil et de la position estimée du centre de la pupille du premier oeil ;
calculer une première position estimée (550) d'un centre (106, 401) du premier oeil sur la base des lignes (510, 520, 410, 420, 430) déterminées pour le premier oeil pour des instances temporelles dans une première période de temps ;
calculer une seconde position estimée (560) du centre du premier oeil sur la base des lignes (530, 540) déterminées pour le premier oeil pour des instances temporelles dans une seconde période de temps ; et en outre
obtenir des images d'un second oeil capturées au niveau de la séquence d'instances temporelles par une caméra du dispositif monté sur une tête ;
pour chacune des instances temporelles :

estimer, à l'aide d'au moins une image du second oeil capturée à cette instance temporelle, une position d'un centre d'une courbure cornéenne du second œil,
estimer, à l'aide d'au moins une image du second oeil capturée à cette instance temporelle, une position d'un centre d'une pupille du second oeil, et
déterminer pour le second oeil une ligne par la position estimée du centre de la courbure cornéenne du second oeil et la position estimée du centre de la pupille du second oeil ;
calculer une première position estimée d'un centre du second oeil sur la base des lignes déterminées pour le second oeil pour des instances temporelles dans la première période de temps ; et
calculer une seconde position estimée du centre du second oeil sur la base de lignes déterminées pour le second oeil pour des instances temporelles dans la seconde période de temps,
détecter, sur la base des première et seconde positions estimées du centre du premier oeil, le déplacement du dispositif monté sur une tête par rapport à la tête de l'utilisateur, dans lequel la détection du déplacement du dispositif monté sur une tête par rapport à la tête de l'utilisateur est également basée sur

les première et seconde positions estimées du centre du second oeil ; et dans lequel le système comprenant un circuit de traitement (320) configuré pour détecter le déplacement du dispositif monté sur une tête par rapport à la tête de l'utilisateur est en outre configuré pour :

former une première distance entre la première position estimée du centre du premier oeil et la première position estimée du centre du second oeil ;
former une seconde distance entre la seconde position estimée du centre du premier oeil et la seconde position estimée du centre du second oeil ; et
vérifier qu'une différence entre les première et seconde distances est inférieure à un seuil.

14. Support de stockage non transitoire lisible par ordinateur stockant des instructions qui, lorsqu'elles sont exécutées par un circuit de traitement d'un système, amènent le système à réaliser le procédé selon l'une quelconque des revendications 1 à 12.

15. Produit de programme informatique comprenant un support de stockage non transitoire lisible par ordinateur stockant des instructions qui, lorsqu'elles sont exécutées par un circuit de traitement d'un système, amènent le système à mettre en oeuvre le procédé selon l'une quelconque des revendications 1 à 12.

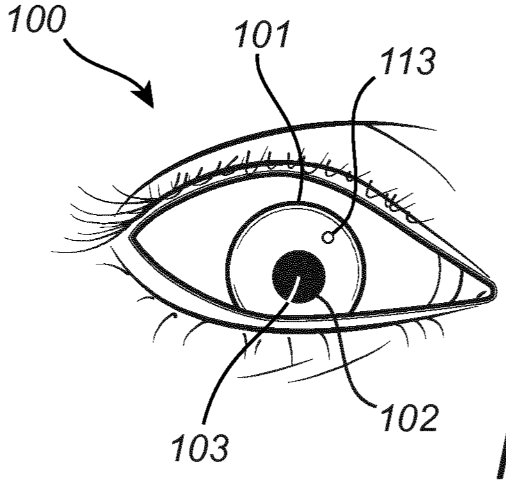
100
101
113
103
102

Fig. 1

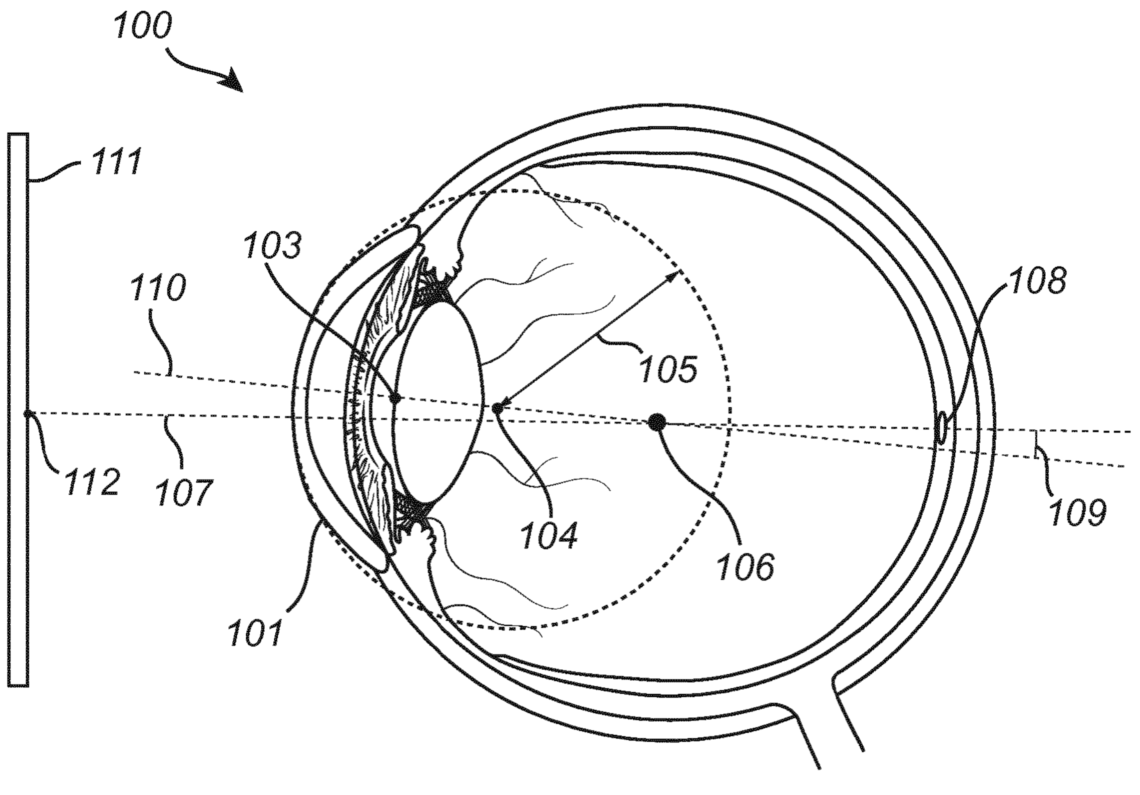
100
111
103
110
108
105
112
107
104
106
109
101

Fig. 2

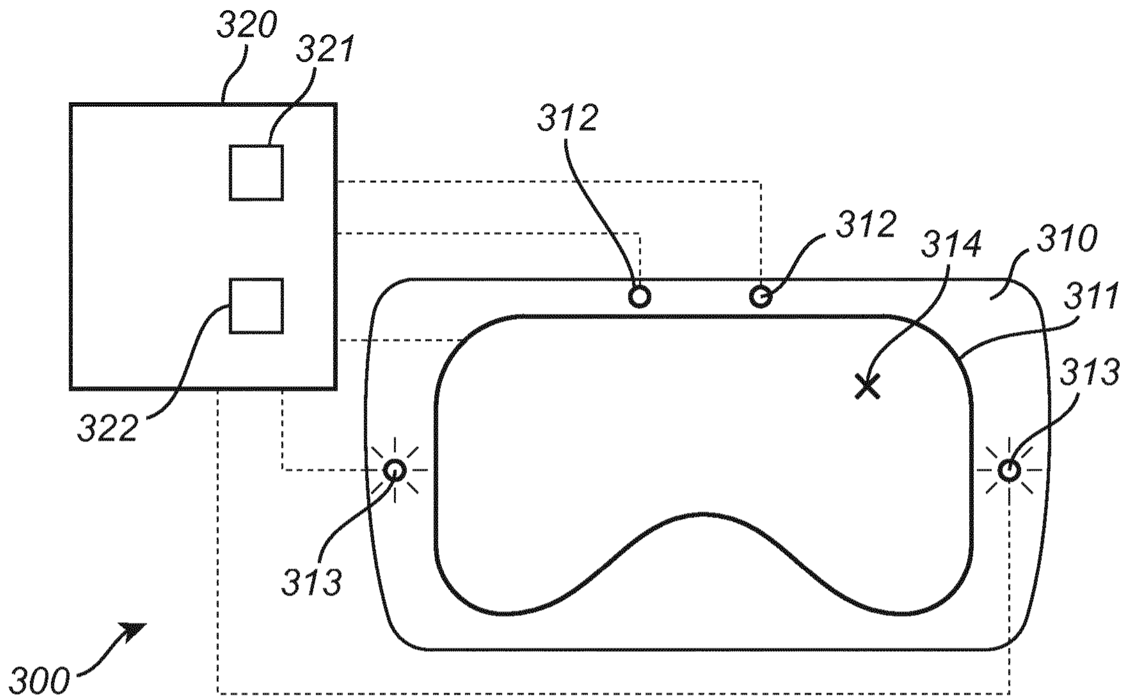
320
321
312
312
314
310
311
313
322
313
300

Fig. 3

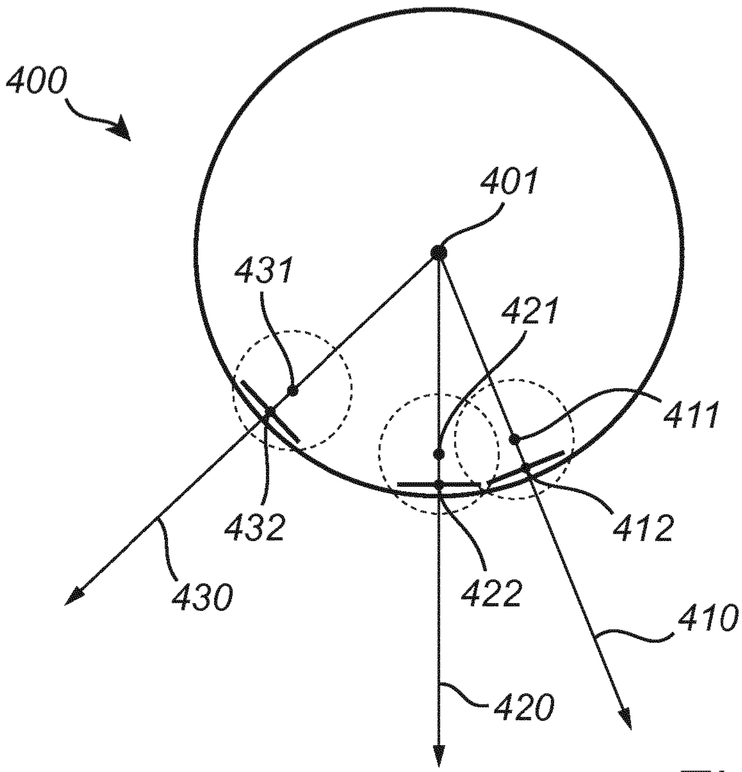
400
401
431
421
411
432
412
430
422
410
420

Fig. 4

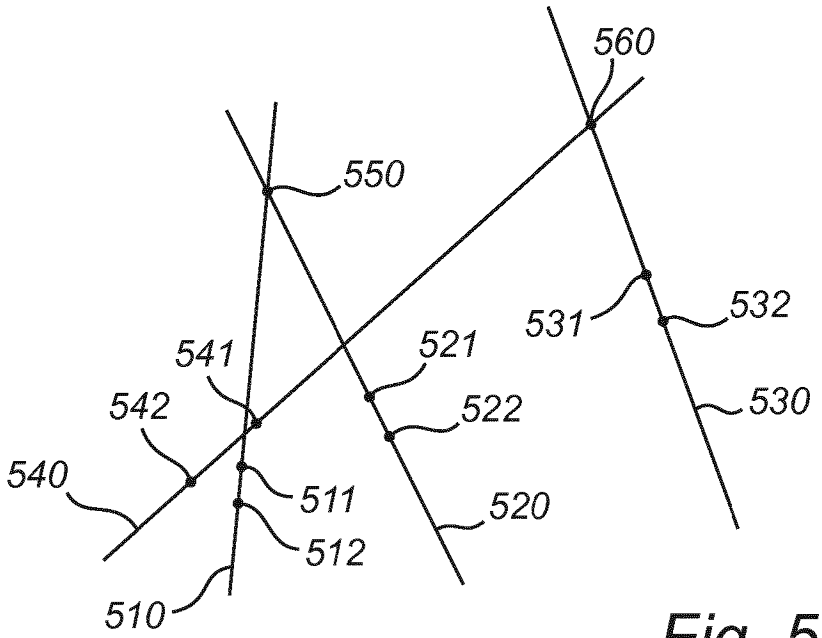

Fig. 5

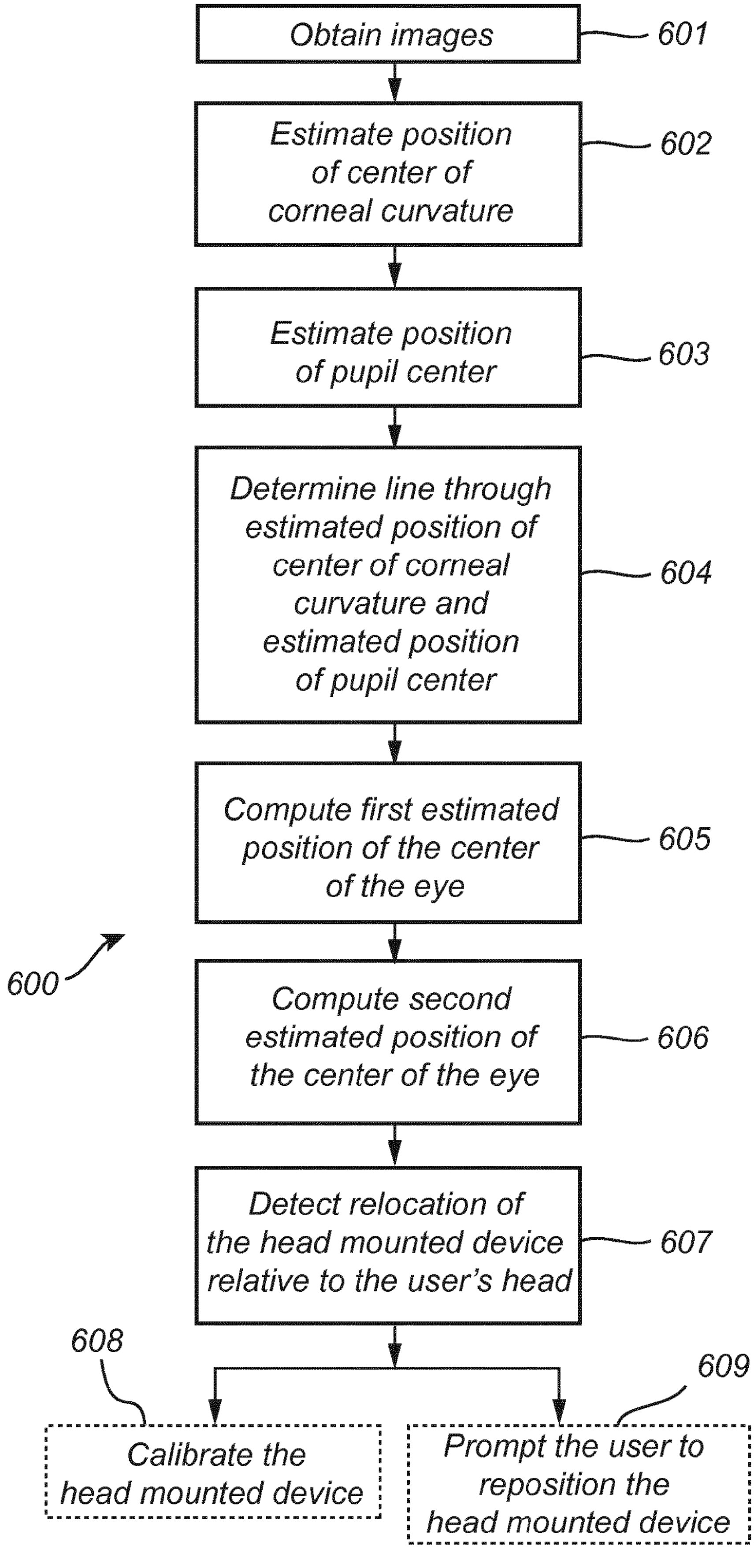
Obtain images
601
Estimate position of center of corneal curvature
602
Estimate position of pupil center
603
Determine line through estimated position of center of corneal curvature and estimated position of pupil center
604
Compute first estimated position of the center of the eye
605
600
Compute second estimated position of the center of the eye
606
Detect relocation of the head mounted device relative to the user's head
607
608
609
Calibrate the head mounted device
Prompt the user to reposition the head mounted device

Fig. 6

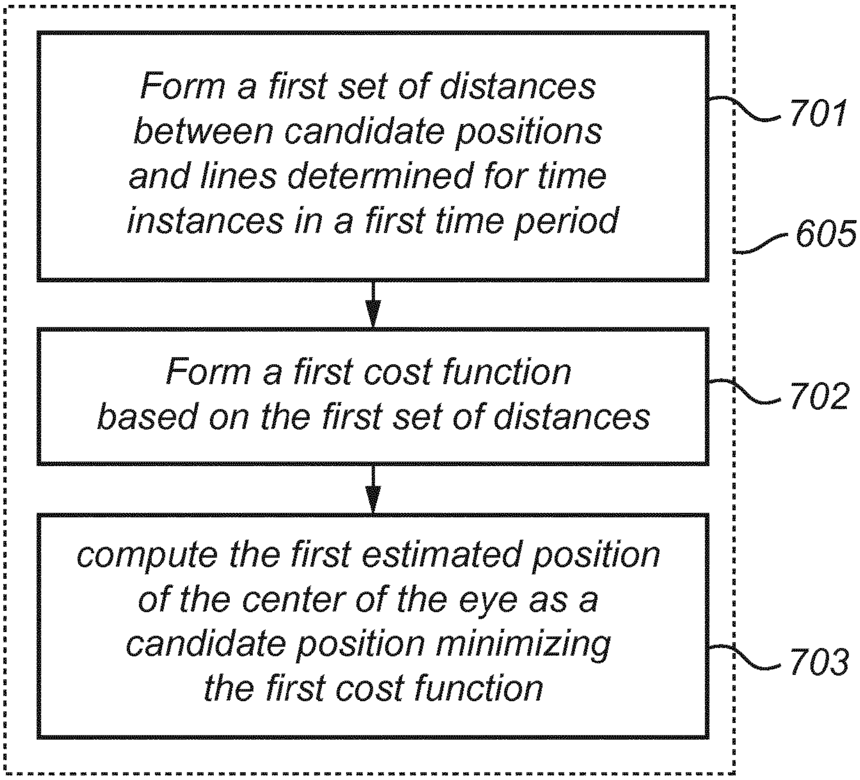
Form a first set of distances between candidate positions and lines determined for time instances in a first time period
701
605
Form a first cost function based on the first set of distances
702
compute the first estimated position of the center of the eye as a candidate position minimizing the first cost function
703

Fig. 7

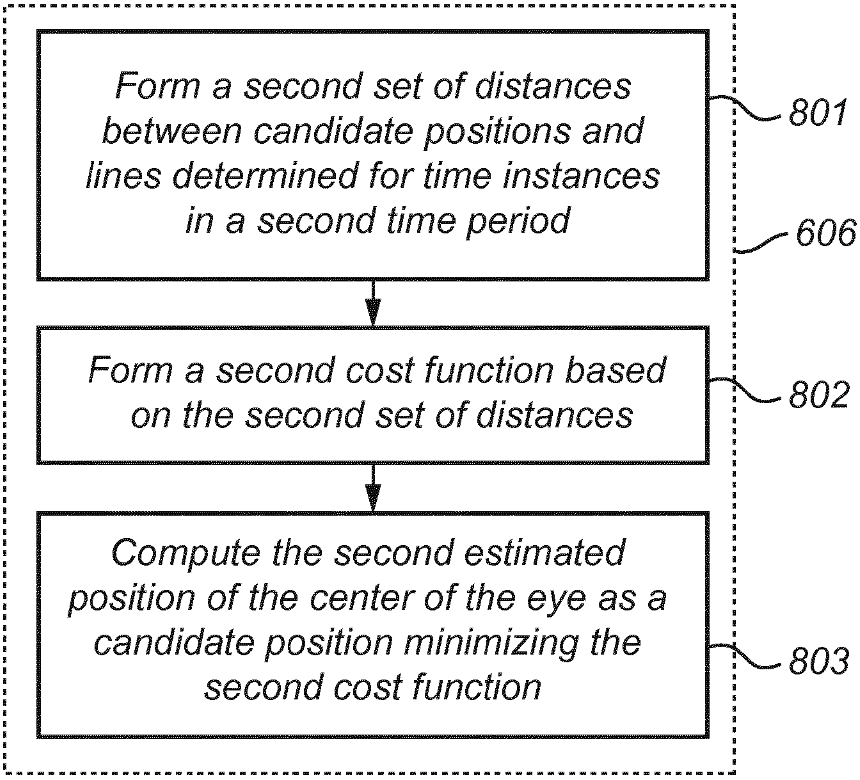
Form a second set of distances between candidate positions and lines determined for time instances in a second time period
801
606
Form a second cost function based on the second set of distances
802
Compute the second estimated position of the center of the eye as a candidate position minimizing the second cost function
803

Fig. 8

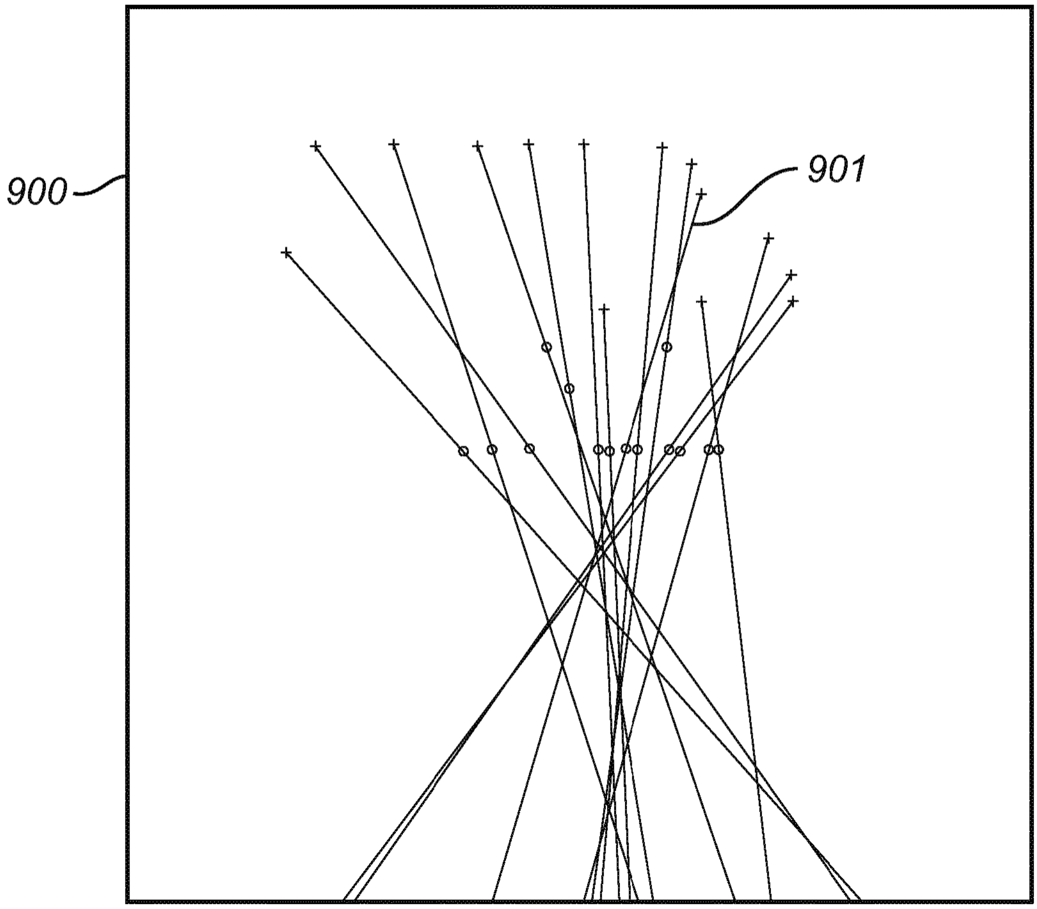

Fig. 9

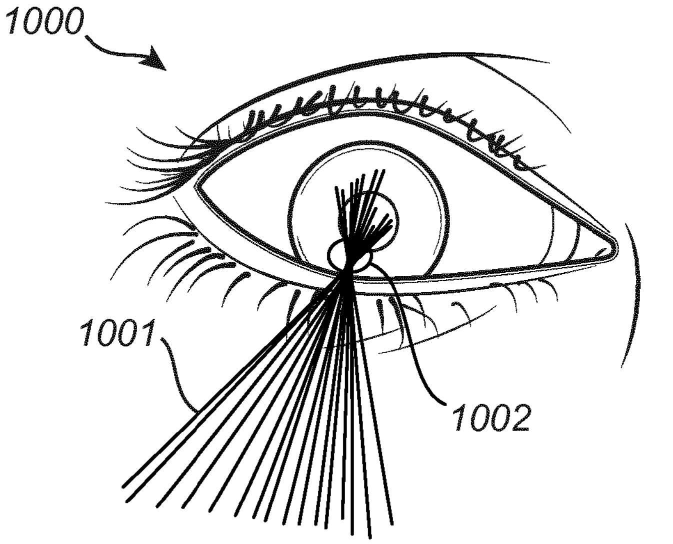

Fig. 10

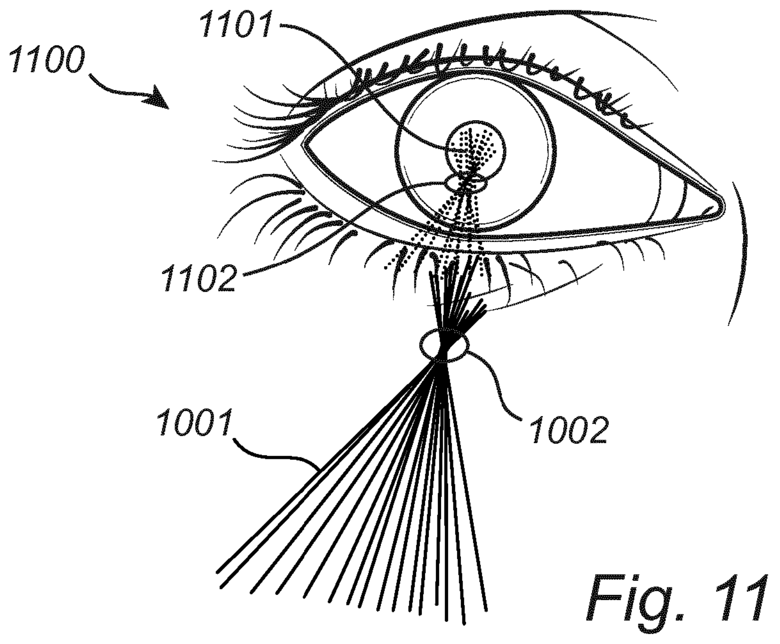

Fig. 11

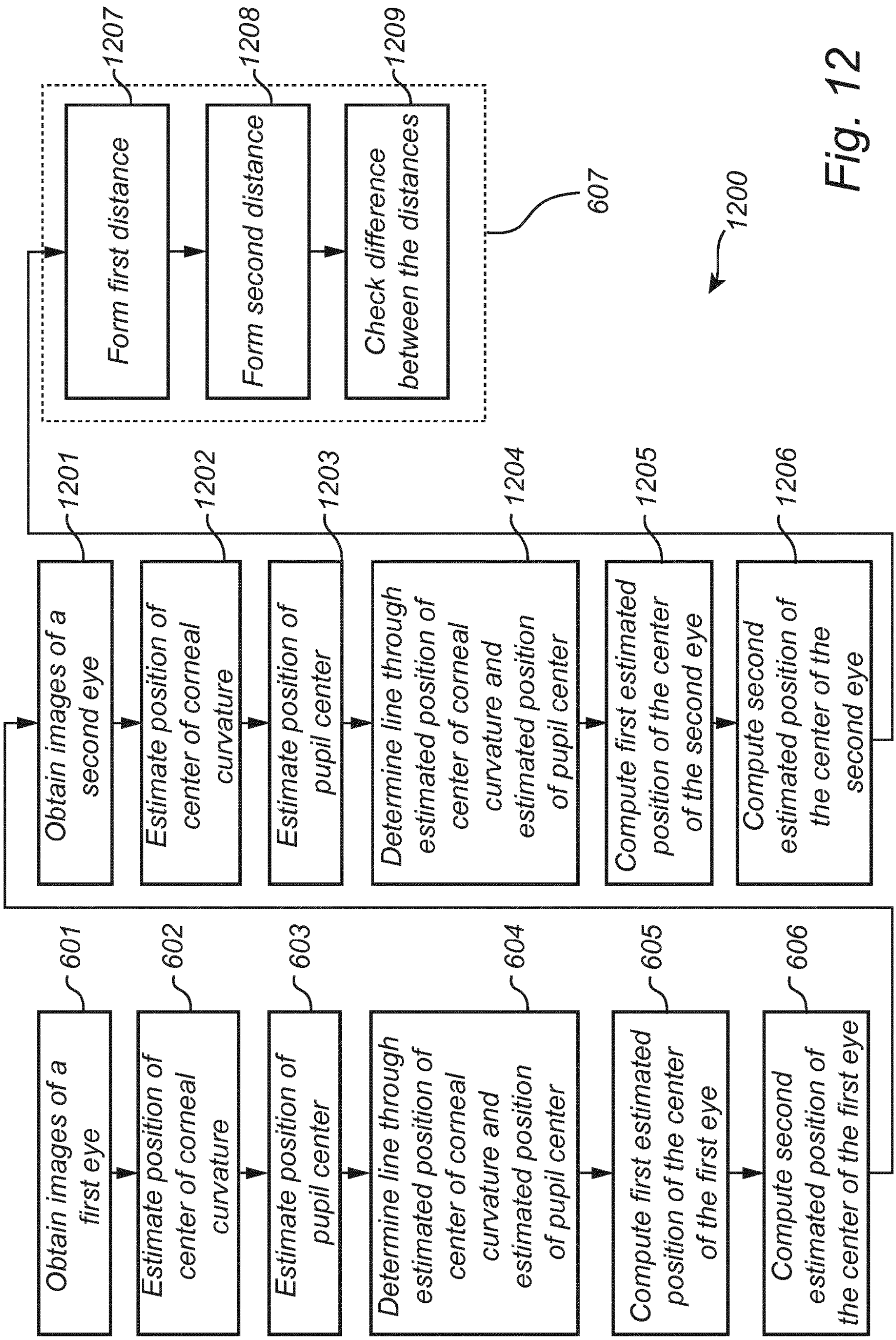
Obtain images of a first eye
601
Estimate position of center of corneal curvature
602
Estimate position of pupil center
603
Determine line through estimated position of center of corneal curvature and estimated position of pupil center
604
Compute first estimated position of the center of the first eye
605
Compute second estimated position of the center of the first eye
606
Obtain images of a second eye
1201
Estimate position of center of corneal curvature
1202
Estimate position of pupil center
1203
Determine line through estimated position of center of corneal curvature and estimated position of pupil center
1204
Compute first estimated position of the center of the second eye
1205
Compute second estimated position of the center of the second eye
1206
Form first distance
1207
Form second distance
1208
Check difference between the distances
1209
607
1200

Fig. 12

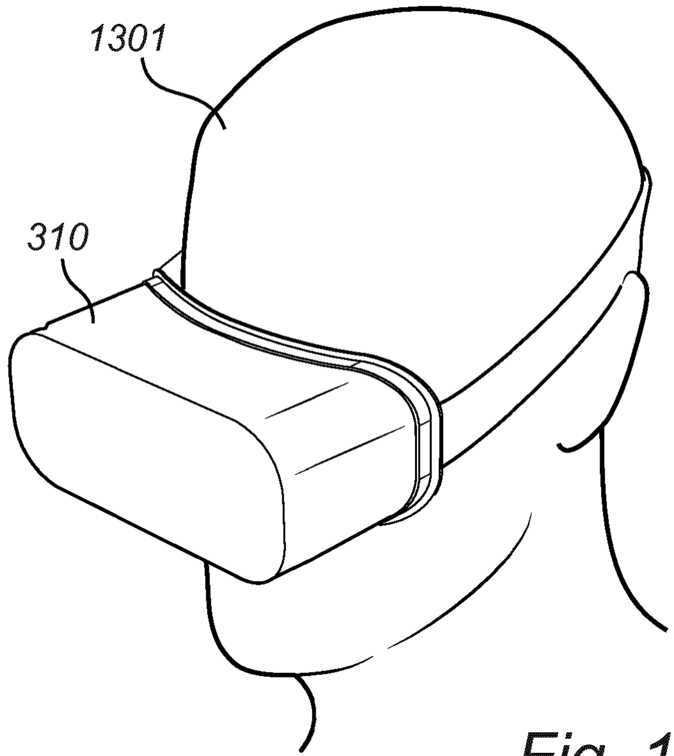

Fig. 13

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- EP 3228238 A1 **[0003]**
- US 2018032133 A1 **[0006]**
- WO 2013067230 A1 **[0007]**

Non-patent literature cited in the description

- **SWIRSKI L et al.** *A fully-automatic, temporal approach to single camera, glint-free 3D eye model fitting,* 16 October 2018, https://pdfs.semanticscholar.org/f0c0/bc74c1dc11e8a09fa4bd4c300cf21d7cc96d.pdf **[0004]**
- Corneal-Imaging Calibration for Optical See-Through Head-Mounted Displays. **PLOPSKI ALEXANDER et al.** IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS. IEEE SERVICE CENTER, 18 April 2015, vol. 21 **[0005]**
- A novel approach to single camera, glint-free 3D eye model fitting including corneal refraction. **KAI DIERKES et al.** EYE TRACKING RESEARCH & APPLICATIONS. ACM, 14 June 2018 **[0008]**
- **E. D. GUESTRIN et al.** General Theory of Remote Gaze Estimation Using the Pupil Center and Corneal Reflections. *IEEE Transactions on biomedical engineering,* June 2006, vol. 53 (6 **[0052] [0053]**