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Tzvieli et al.

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(54) **EYEGLASSES TO DETECT ABNORMAL MEDICAL EVENTS INCLUDING STROKE AND MIGRAINE**

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(73) Assignee: **Facense Ltd.**, Kiryat Tivon (IL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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A61B 5/01 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61B 5/015*** (2013.01); ***A61B 5/0075*** (2013.01); ***A61B 5/165*** (2013.01); ***A61B 5/6803*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC A61B 5/0075; A61B 5/0077; A61B 5/024; A61B 5/0816; A61B 2576/00; A61B 5/6814; A61B 5/02438; G01J 5/0265
See application file for complete search history.

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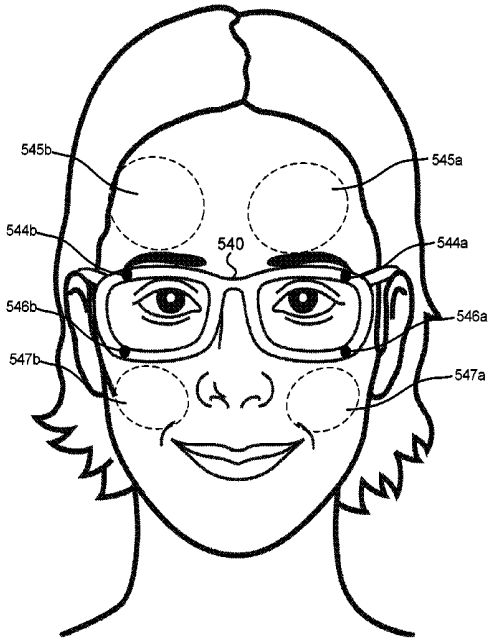
(57) **ABSTRACT**

System and Method to detect an abnormal medical event based on an asymmetrical change to blood flow. The system includes right-side and left-side head-mounted devices to measure signals indicative of photoplethysmographic signals (PPG signals) on the right and left sides of a user's head, and a computer that detects the abnormal medical event based on an asymmetrical change to blood flow recognizable in the PPG signals. Optionally, the asymmetrical change to the blood flow corresponds to a deviation of the PPG signals compared to a baseline that is based on previous measurements of PPG signals of the user, taken before the abnormal medical event.

20 Claims, 20 Drawing Sheets



Related U.S. Application Data

of application No. 16/375,841, filed on Apr. 4, 2019, now Pat. No. 10,376,163, which is a continuation-in-part of application No. 16/156,493, filed on Oct. 10, 2018, which is a continuation-in-part of application No. 15/635,178, filed on Jun. 27, 2017, now Pat. No. 10,136,856, and a continuation-in-part of application No. 15/231,276, filed on Aug. 8, 2016, and a continuation-in-part of application No. 15/832,855, filed on Dec. 6, 2017, now Pat. No. 10,130,308, which is a continuation-in-part of application No. 15/182,592, filed on Jun. 14, 2016, now Pat. No. 10,165,949, and a continuation-in-part of application No. 15/231,276, filed on Aug. 8, 2016, and a continuation-in-part of application No. 15/284,528, filed on Oct. 3, 2016, now Pat. No. 10,113,913, and a continuation-in-part of application No. 15/635,178, filed on Jun. 27, 2017, now Pat. No. 10,136,856, and a continuation-in-part of application No. 15/722,434, filed on Oct. 2, 2017, and a continuation-in-part of application No. 15/182,566, filed on Jun. 14, 2016, now Pat. No. 9,867,546, said application No. 16/156,493 is a continuation-in-part of application No. 15/833,115, filed on Dec. 6, 2017, now Pat. No. 10,130,261, which is a continuation-in-part of application No. 15/182,592, filed on Jun. 14, 2016, now Pat. No. 10,165,949, and a continuation-in-part of application No. 15/231,276, filed on Aug. 8, 2016, and a continuation-in-part of application No. 15/284,528, filed on Oct. 3, 2016, now Pat. No. 10,113,913, and a continuation-in-part of application No. 15/635,178, filed on Jun. 27, 2017, now Pat. No. 10,136,856, and a continuation-in-part of application No. 15/722,434, filed on Oct. 2, 2017, said application No. 16/453,993 is a continuation-in-part of application No. 16/147,695, filed on Sep. 29, 2018, now Pat. No. 10,376,153, which is a continuation of application No. 15/182,592, filed on Jun. 14, 2016, now Pat. No. 10,165,949.

(60) Provisional application No. 62/874,430, filed on Jul. 15, 2019, provisional application No. 62/722,655, filed on Aug. 24, 2018, provisional application No. 62/354,833, filed on Jun. 27, 2016, provisional application No. 62/372,063, filed on Aug. 8, 2016, provisional application No. 62/652,348, filed on Apr. 4, 2018, provisional application No. 62/667,453, filed on May 5, 2018, provisional application No. 62/202,808, filed on Aug. 8, 2015, provisional application No. 62/236,868, filed on Oct. 3, 2015, provisional application No. 62/456,105, filed on Feb. 7, 2017, provisional application No. 62/480,496, filed on Apr. 2, 2017, provisional application No. 62/566,572, filed on Oct. 2, 2017, provisional application No. 62/175,319, filed on Jun. 14, 2015.

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G01J 5/00	(2006.01)

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CPC ***A61B 5/6814*** (2013.01); ***A61B 5/7282*** (2013.01); ***A61B 5/748*** (2013.01); ***G01J 5/0265*** (2013.01); ***G01J 5/12*** (2013.01); *A61B 5/0077* (2013.01); *A61B 2562/0271* (2013.01); *A61B 2562/0276* (2013.01); *A61B 2576/00* (2013.01); *G01J 2005/0077* (2013.01); *G01J 2005/0085* (2013.01)

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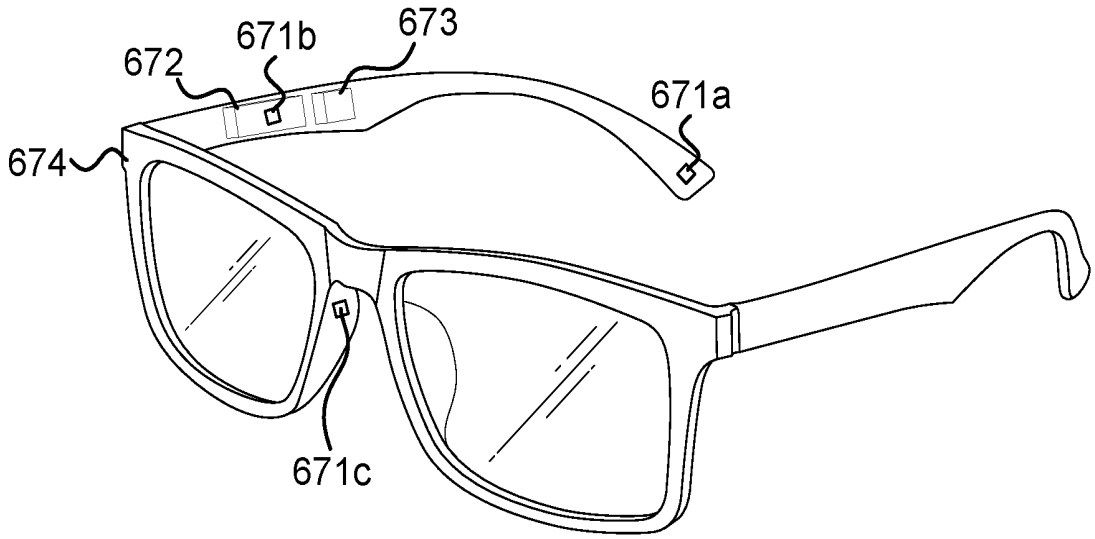

FIG. 1a

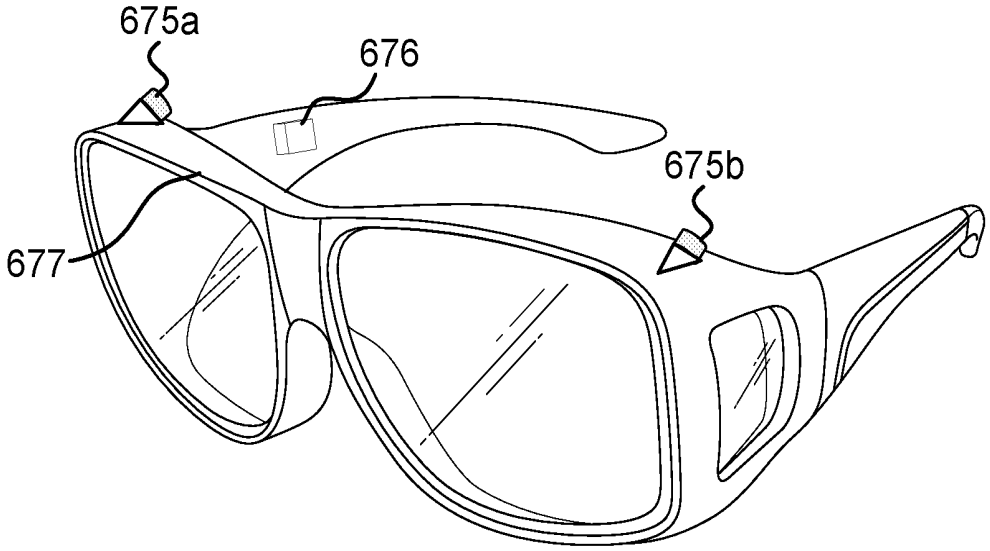

FIG. 1b

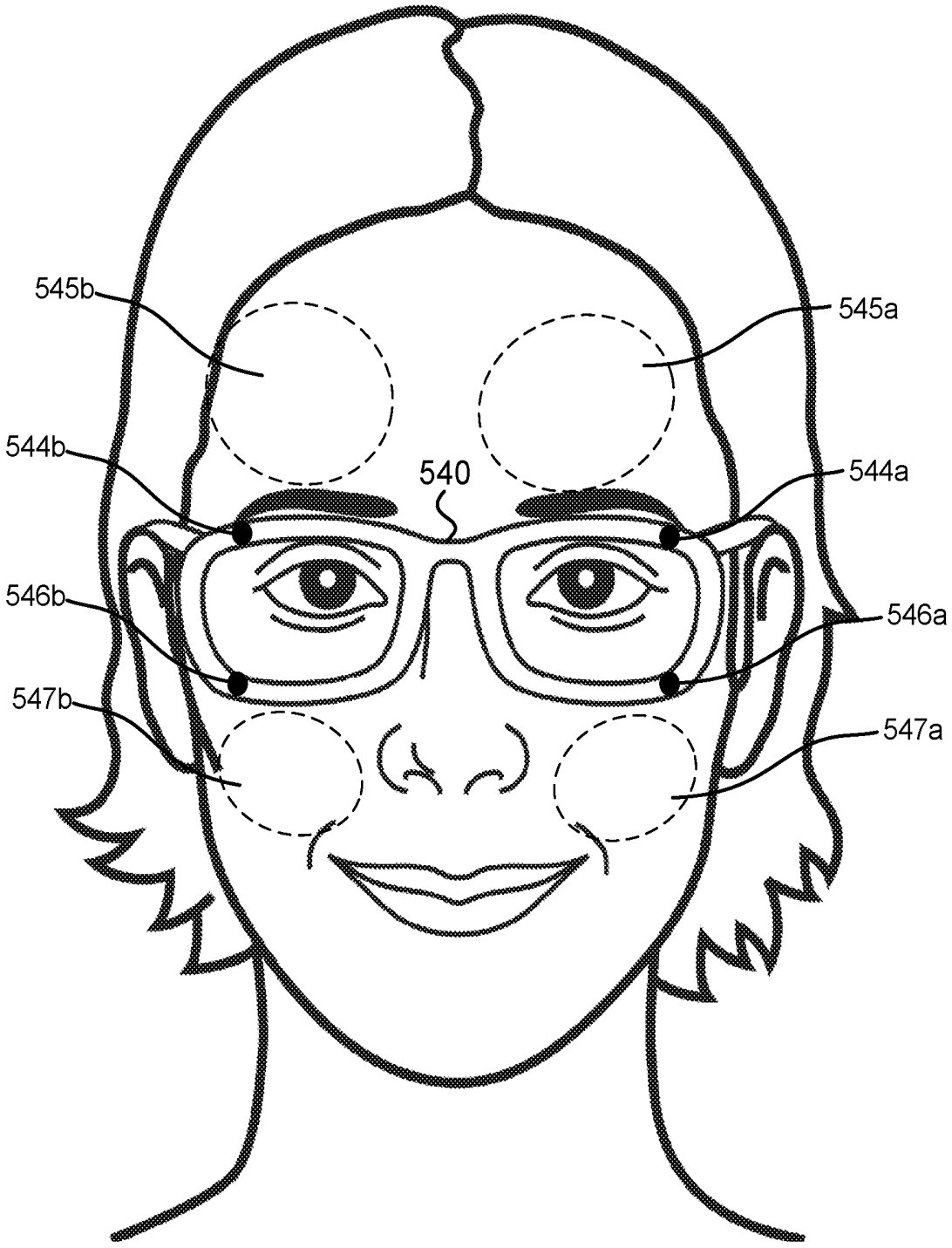

FIG. 2

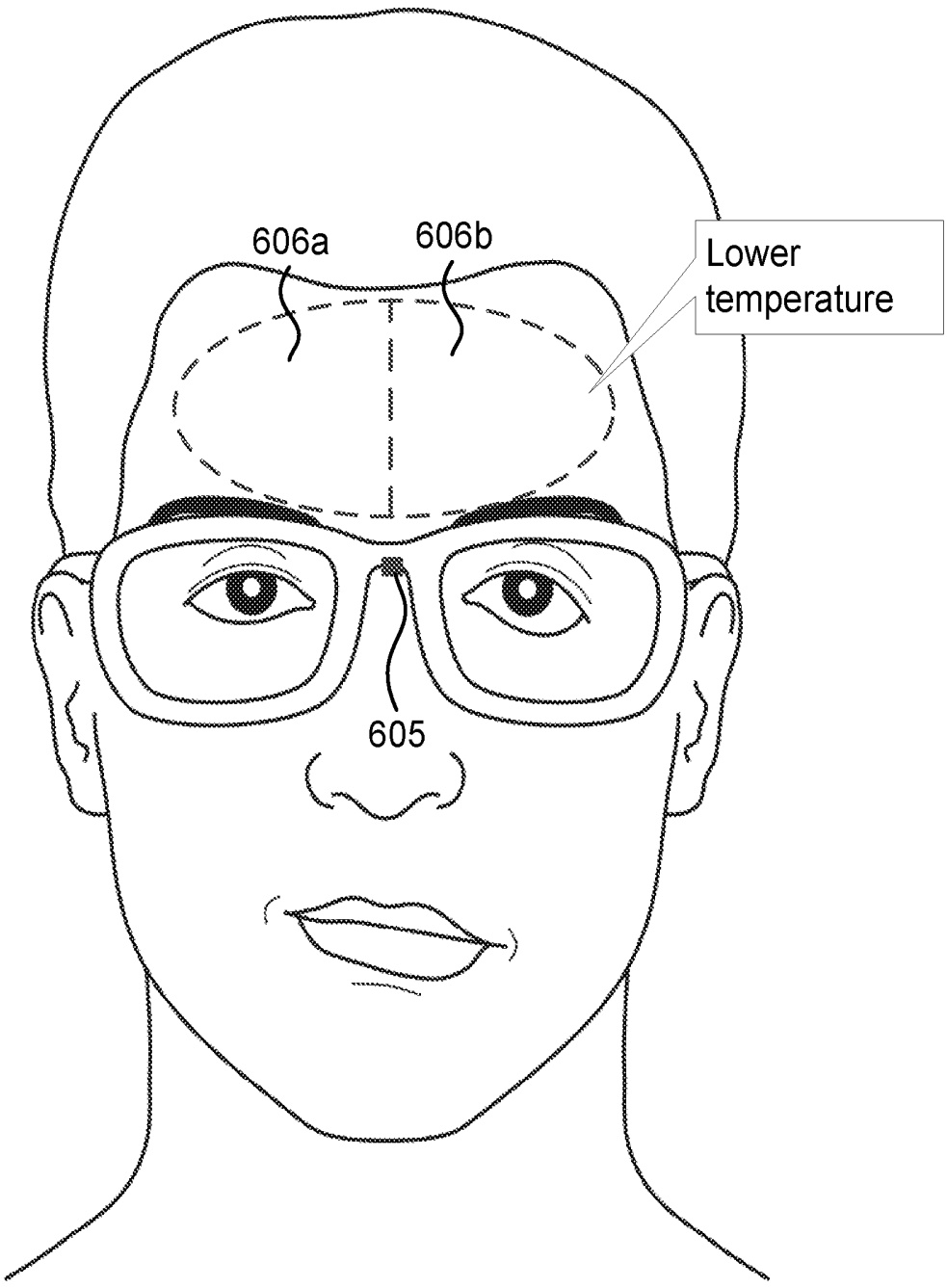

FIG. 3

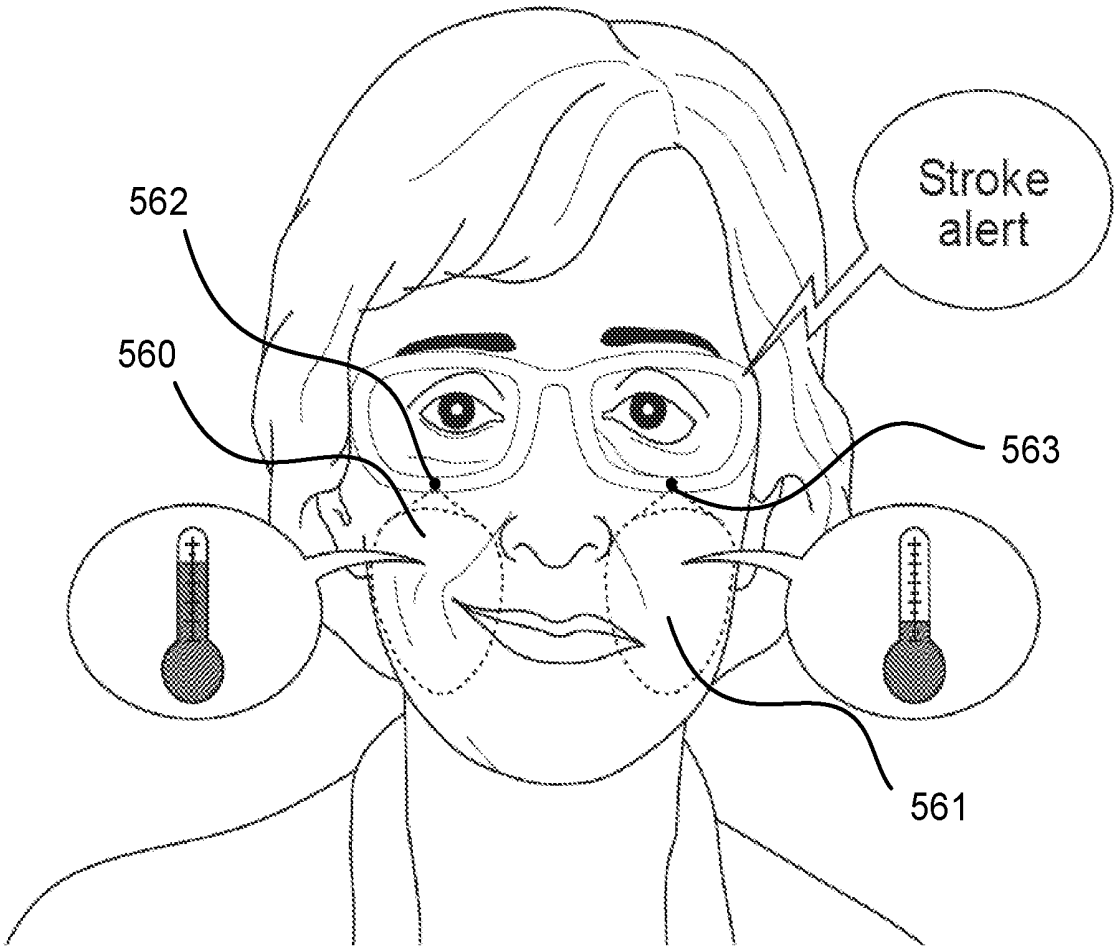

FIG. 4

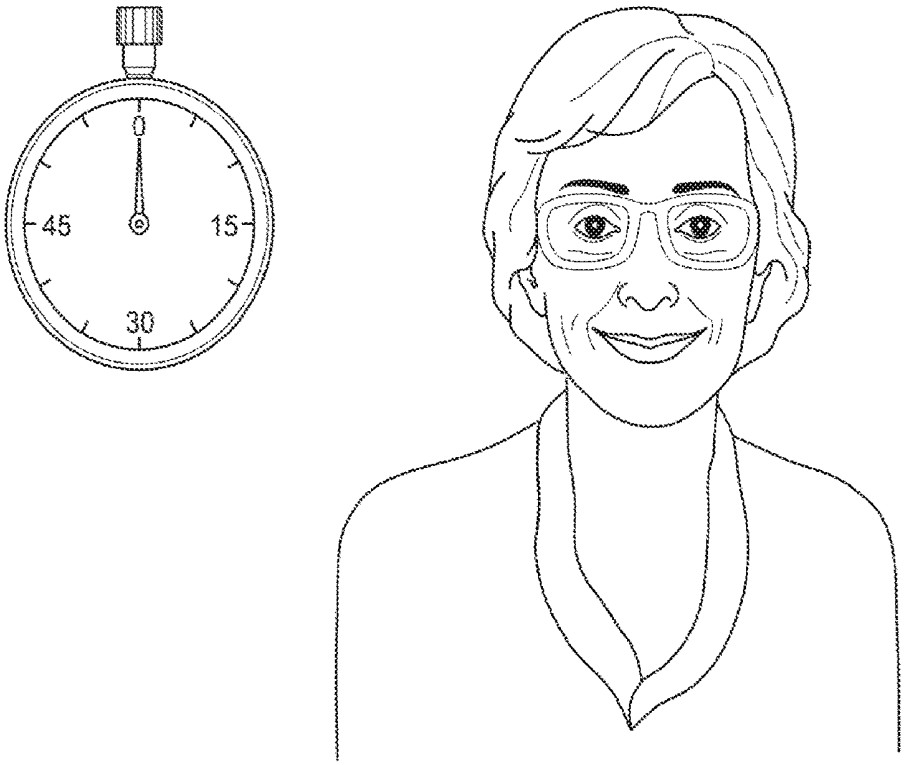

FIG. 5

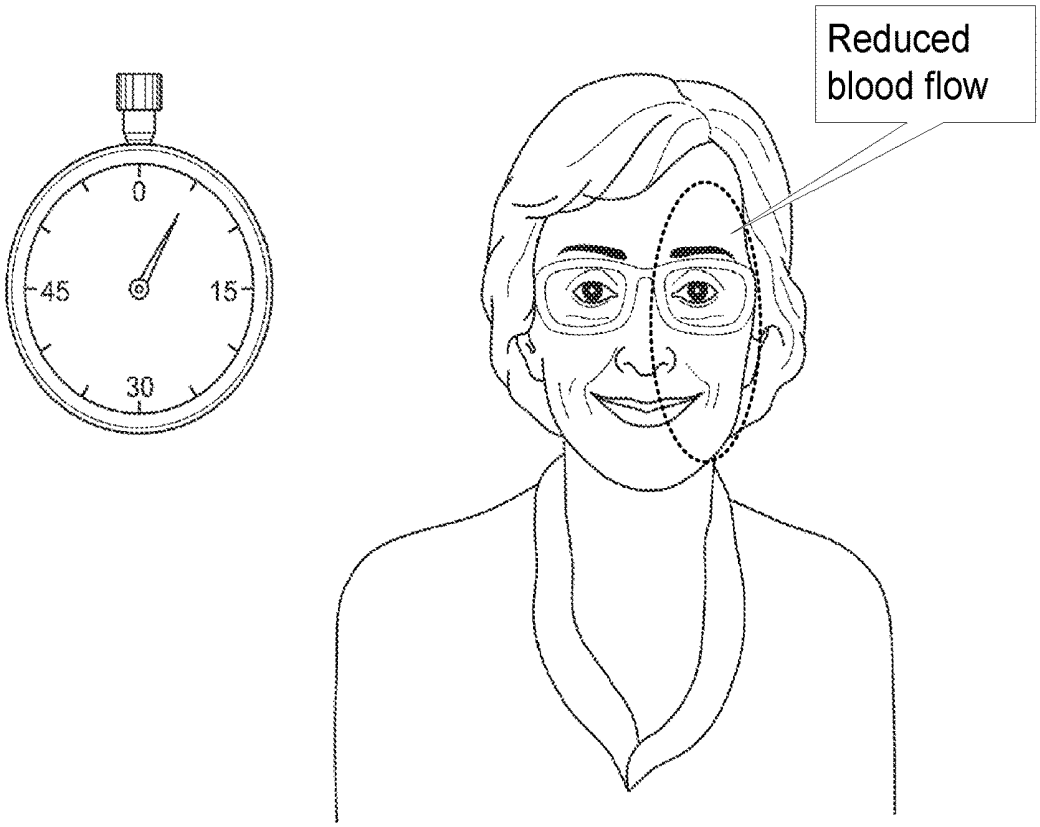

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

FIG. 11

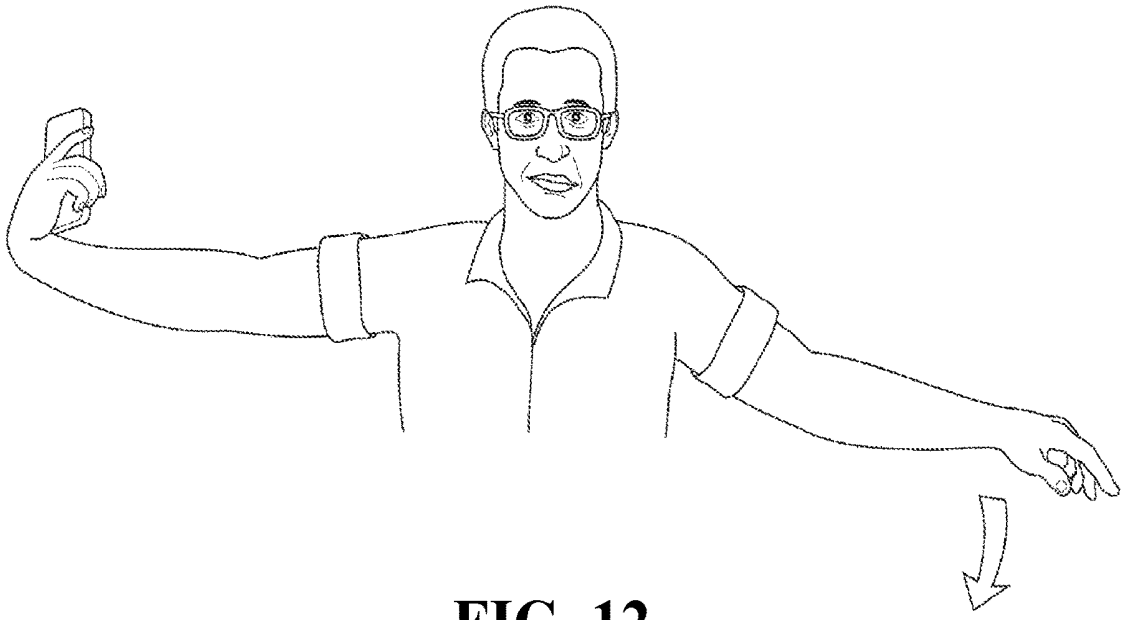

FIG. 12

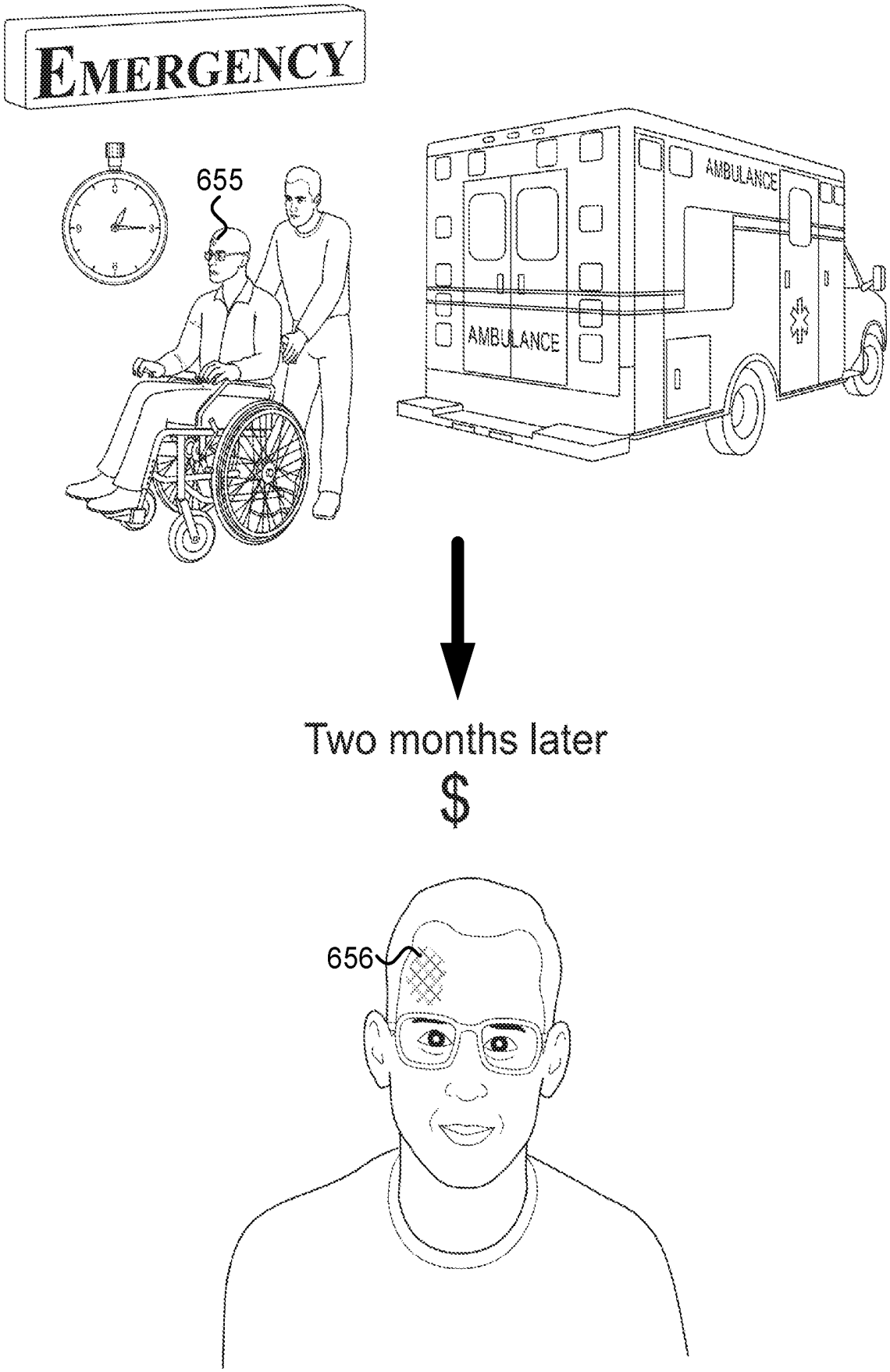

FIG. 13

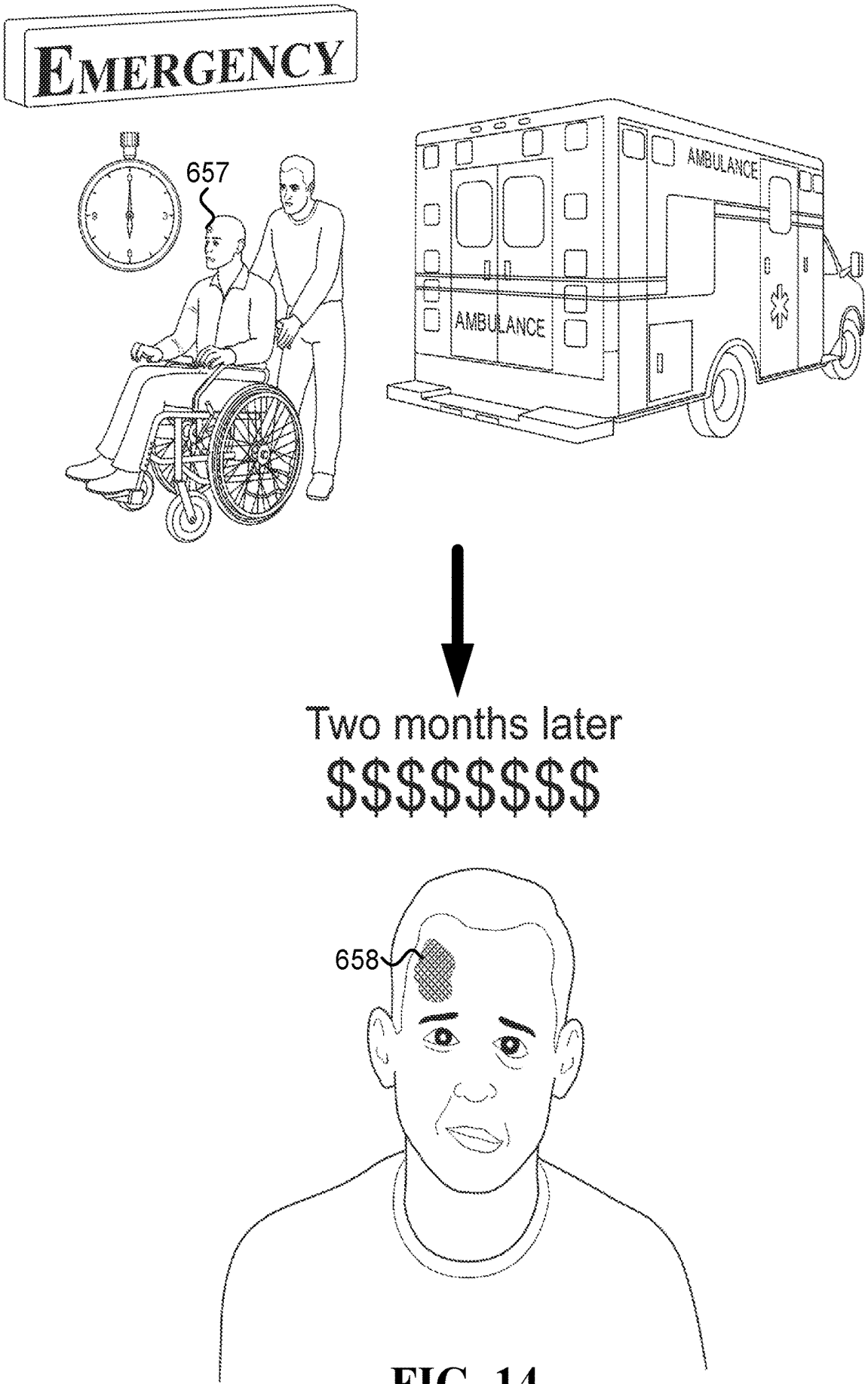

FIG. 14

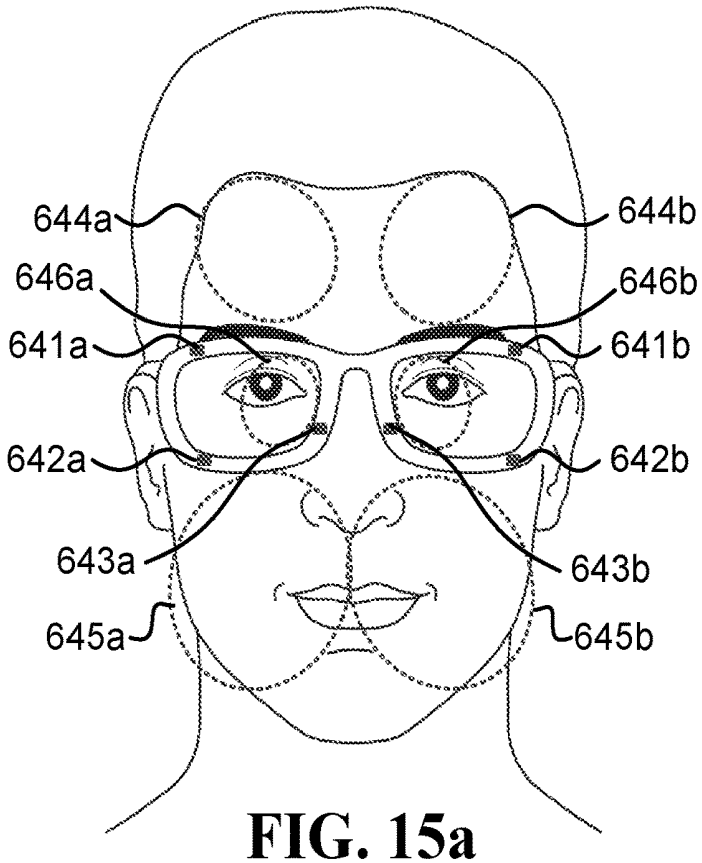

FIG. 15a

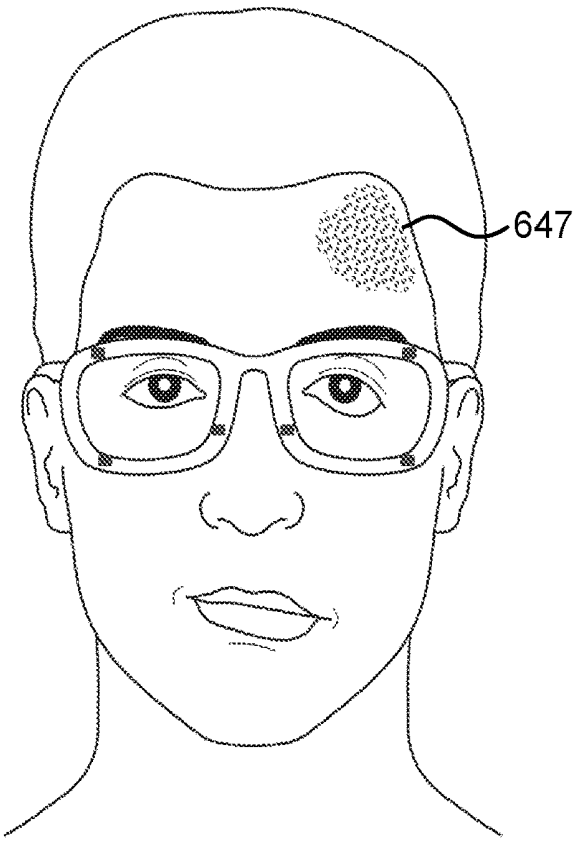

FIG. 15b

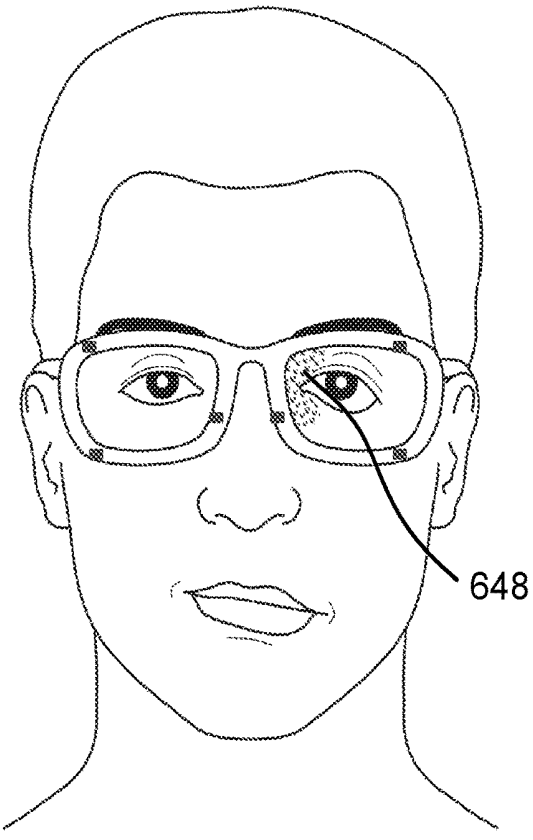

FIG. 15c

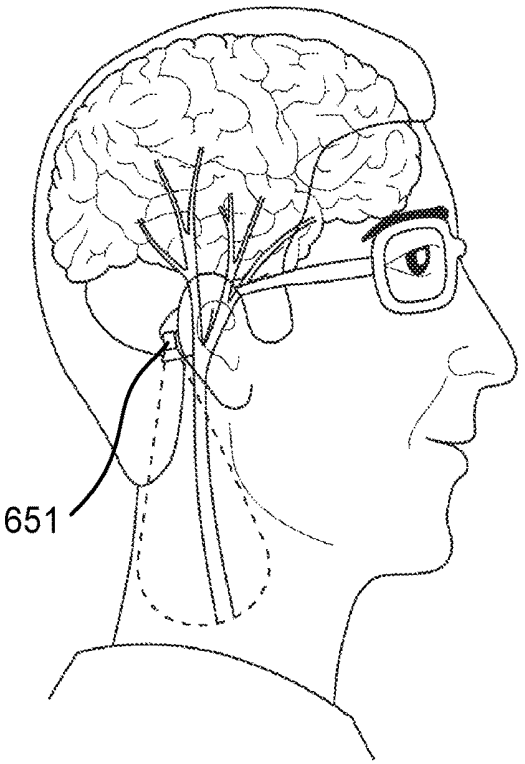

FIG. 16a

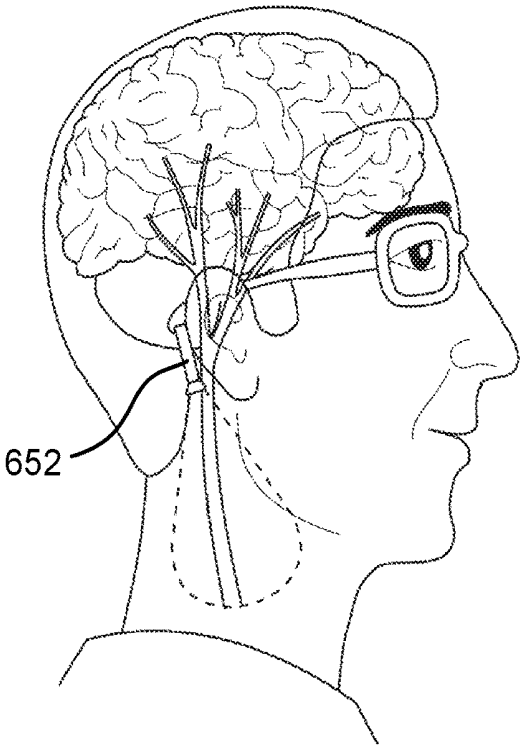

FIG. 16b

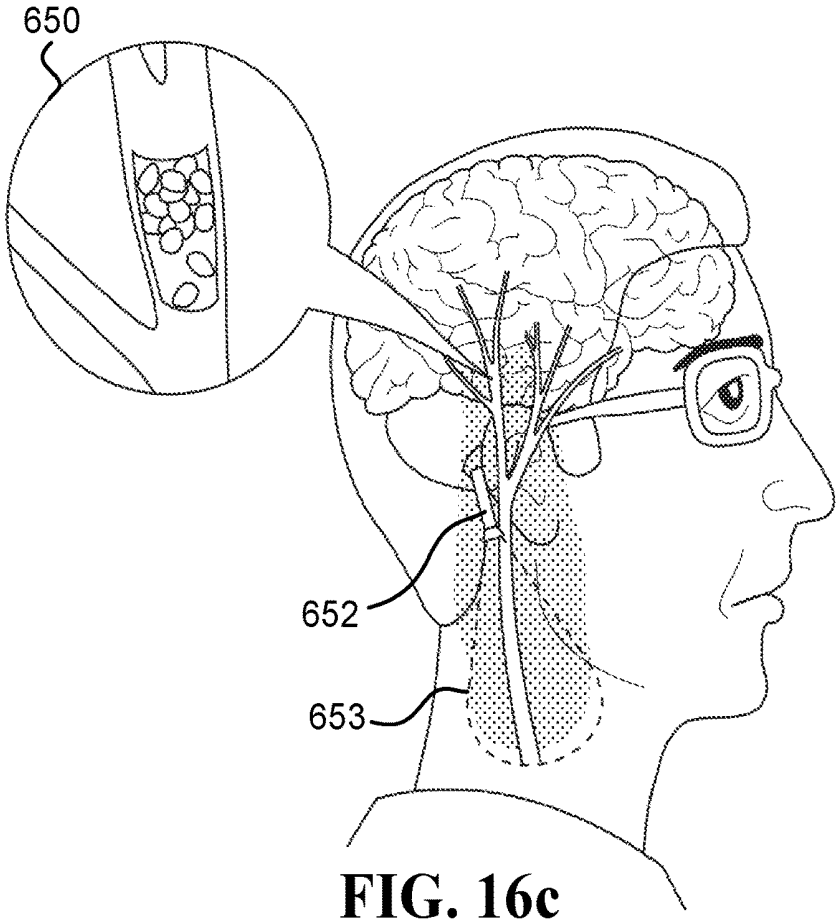

FIG. 16c

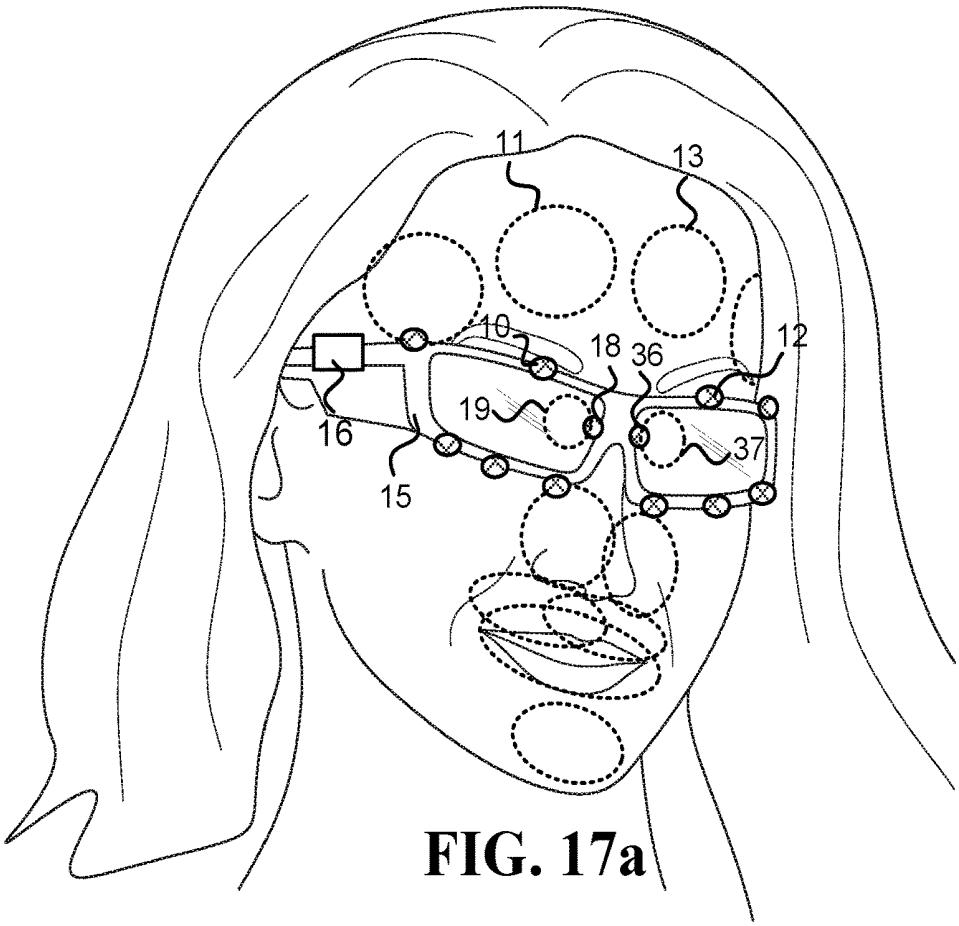

FIG. 17a

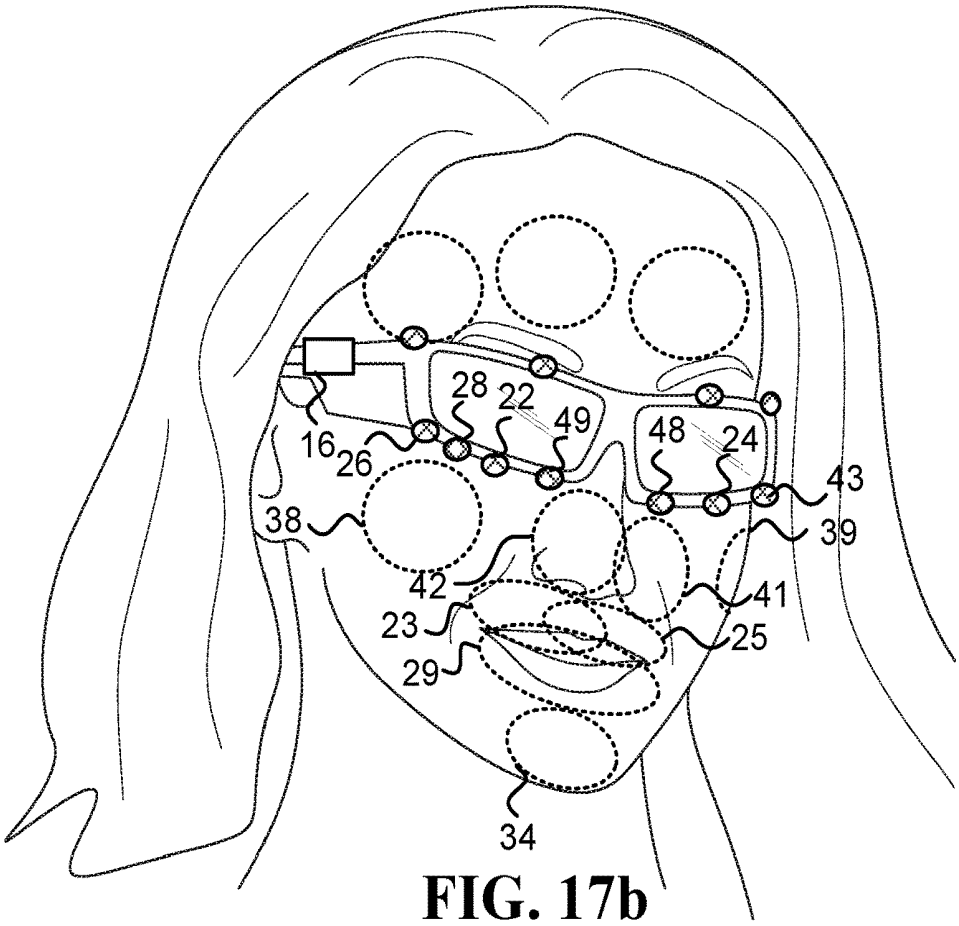

FIG. 17b

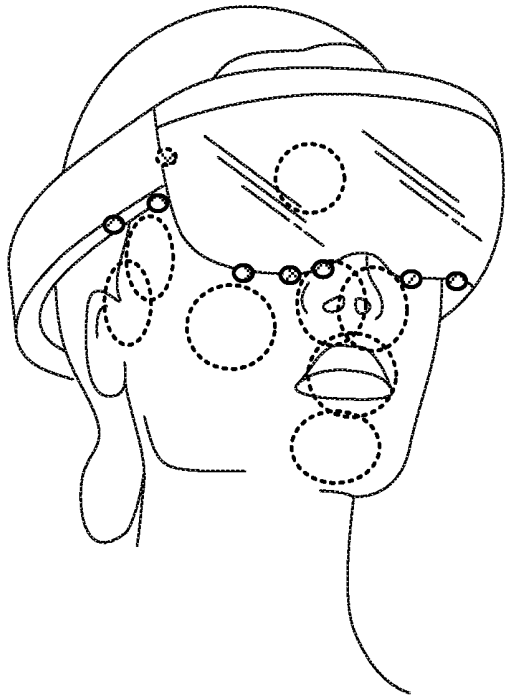

FIG. 18

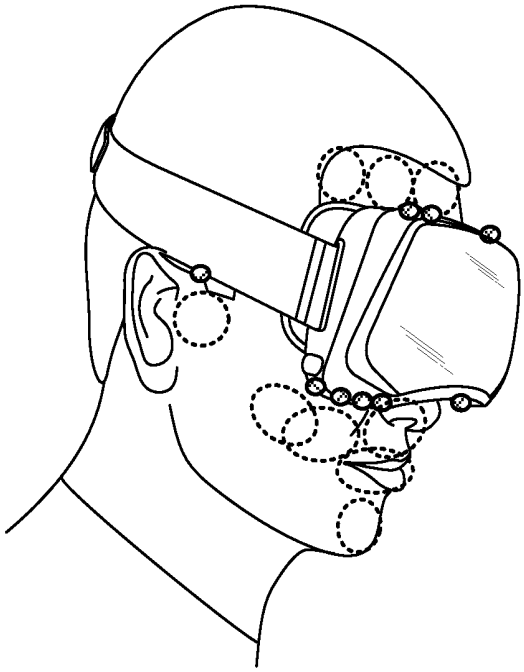

FIG. 19

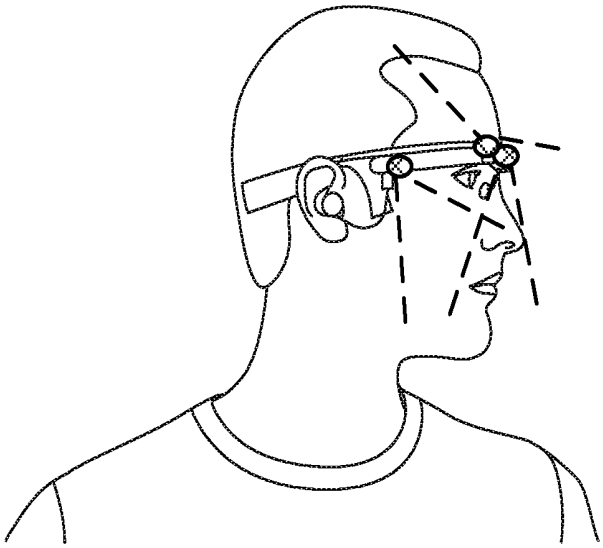

FIG. 20

FIG. 21

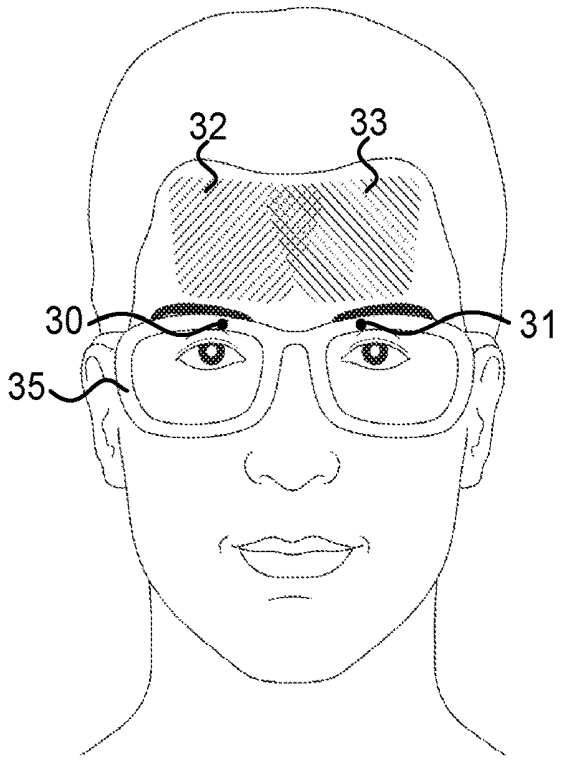

FIG. 22

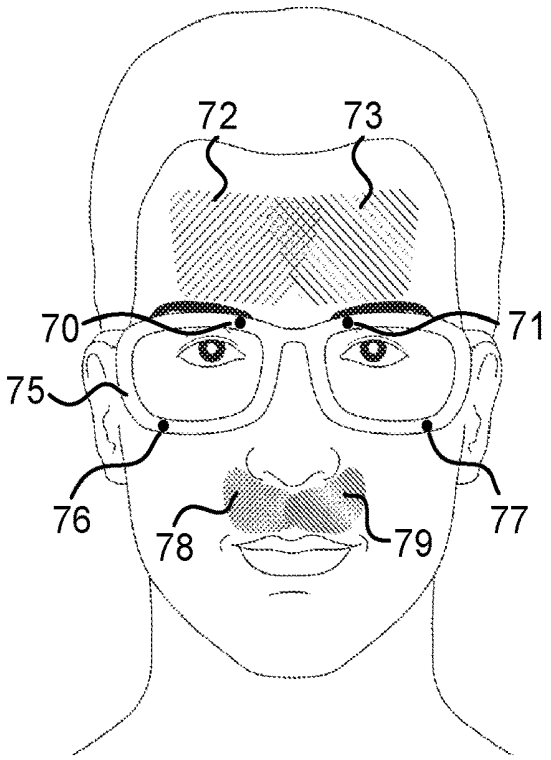

FIG. 23

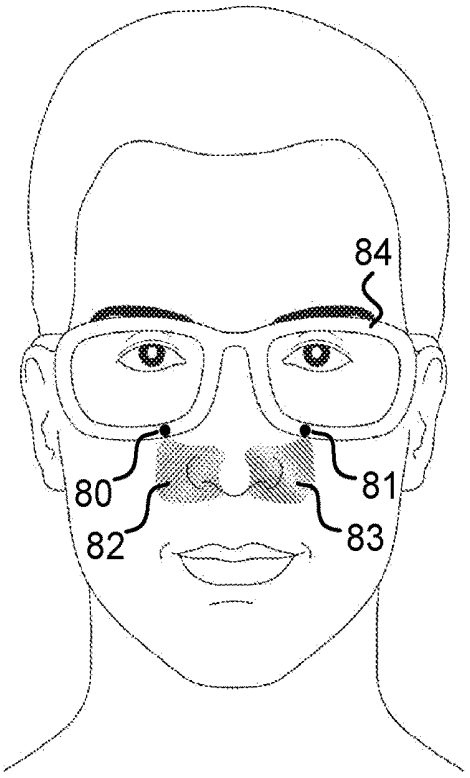

FIG. 24

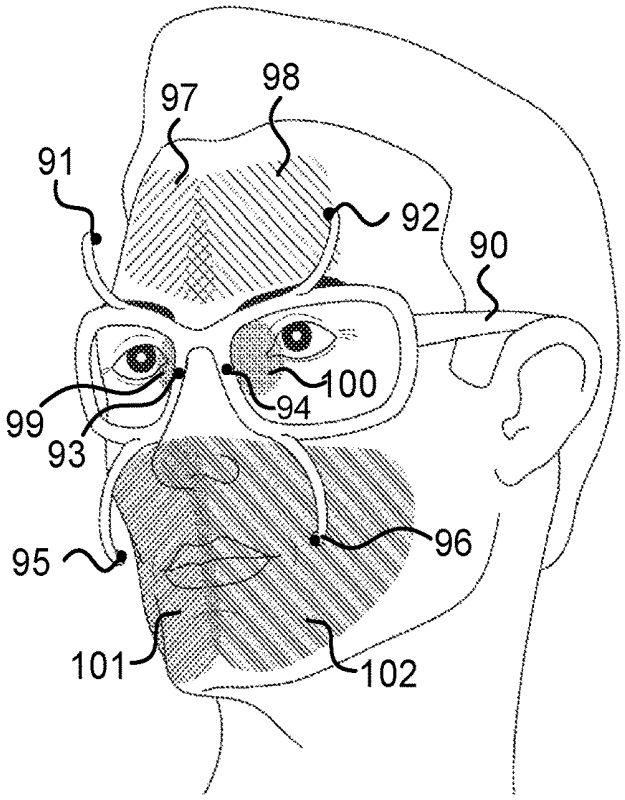

FIG. 25

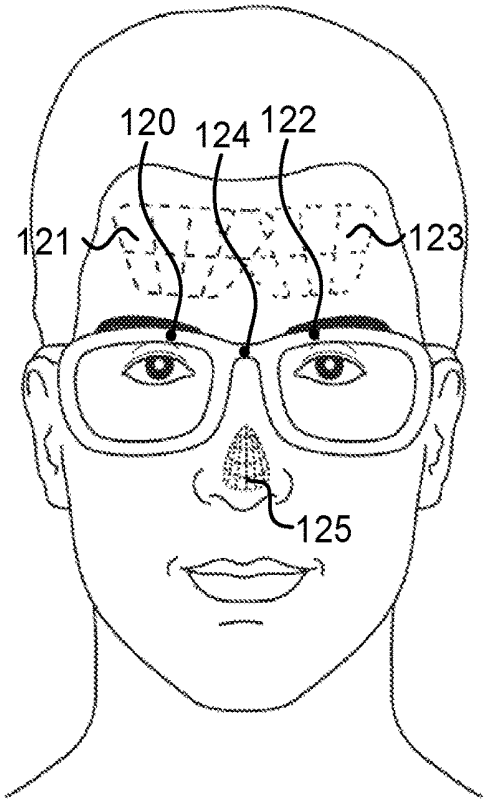

FIG. 26

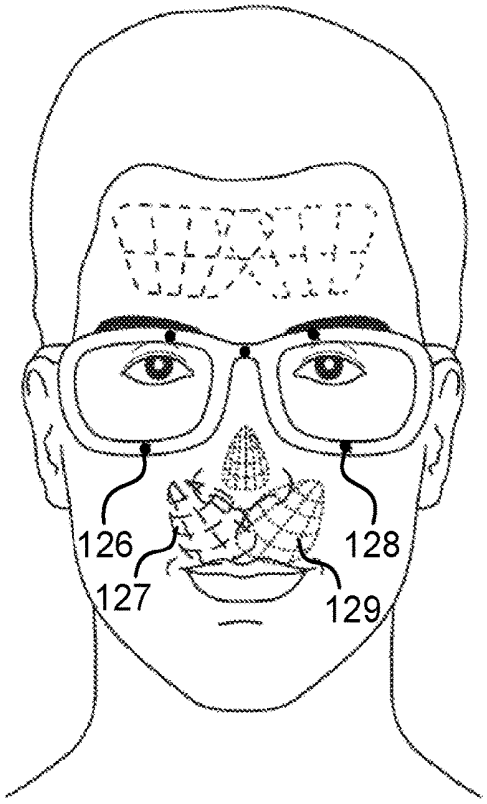

FIG. 27

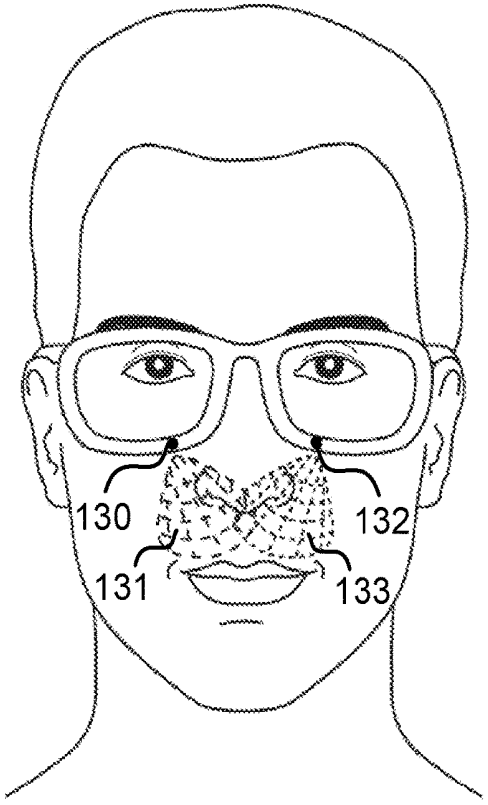

FIG. 28

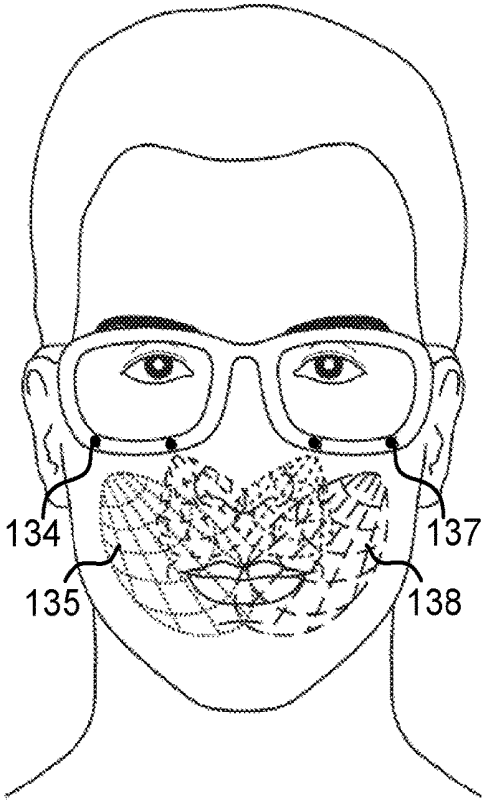

FIG. 29

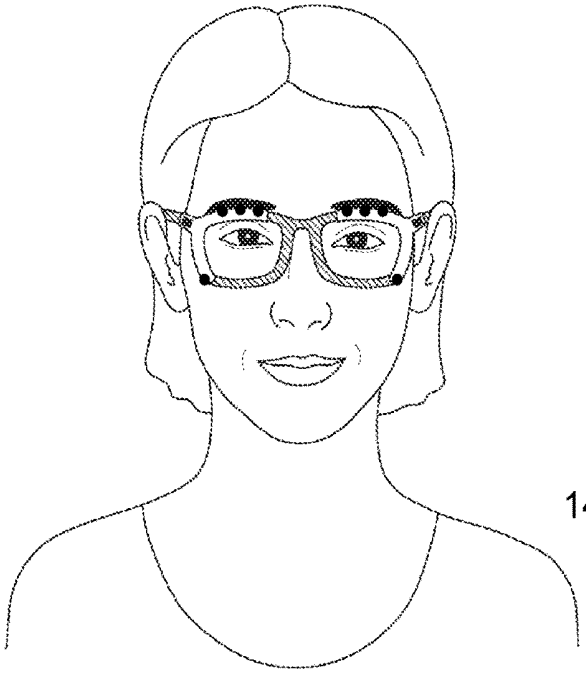

FIG. 30c

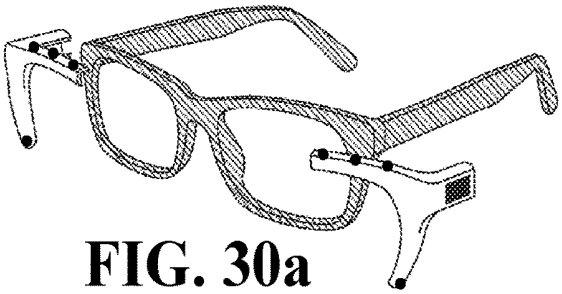

FIG. 30a

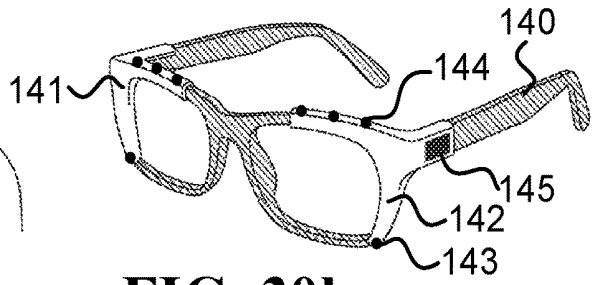

FIG. 30b

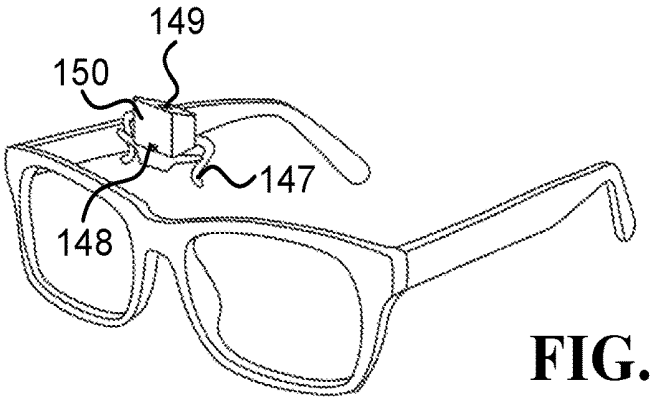

FIG. 31a

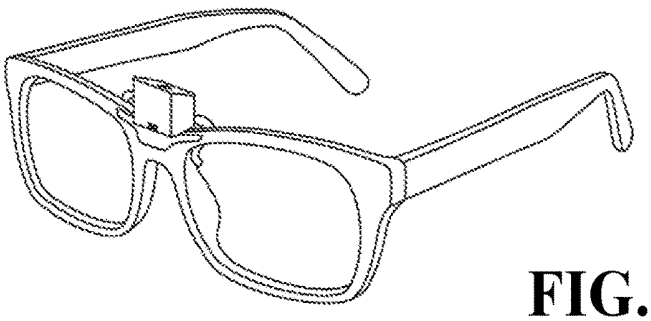

FIG. 31b

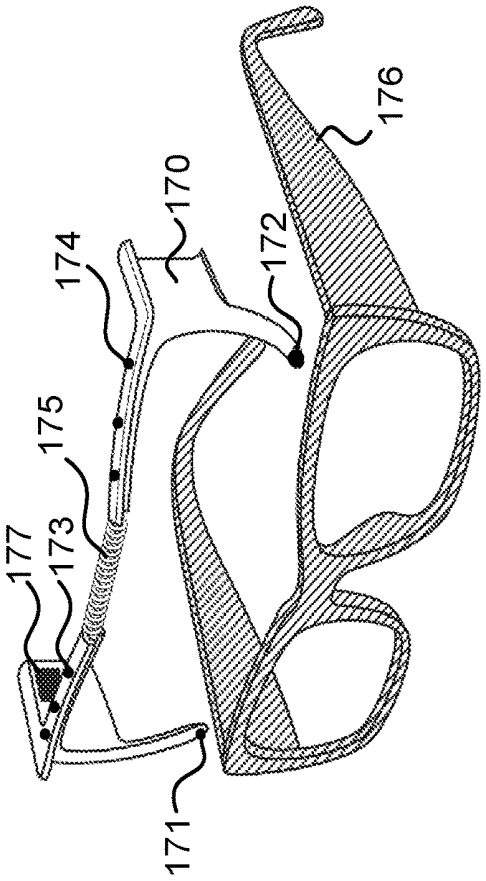

FIG. 32a

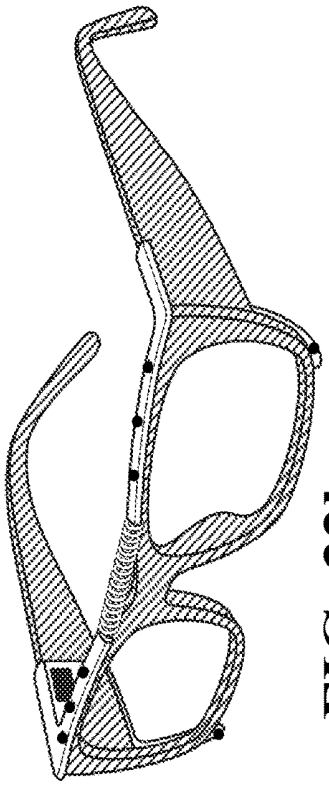

FIG. 32b

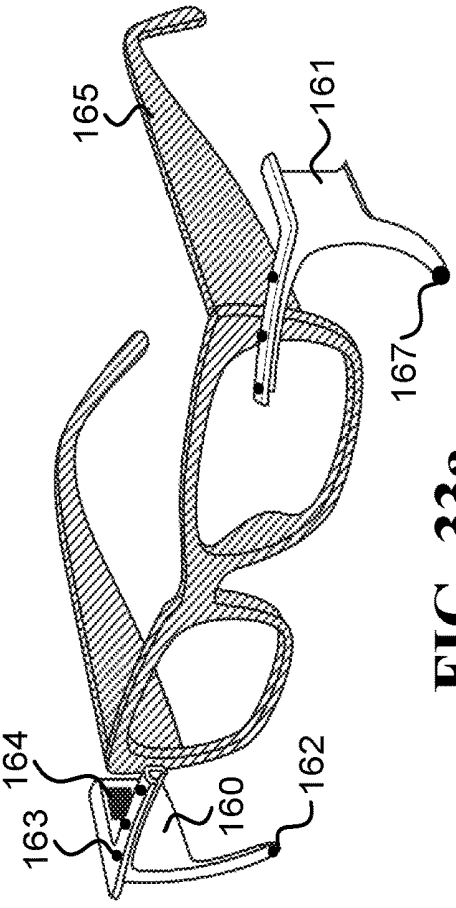

FIG. 33a

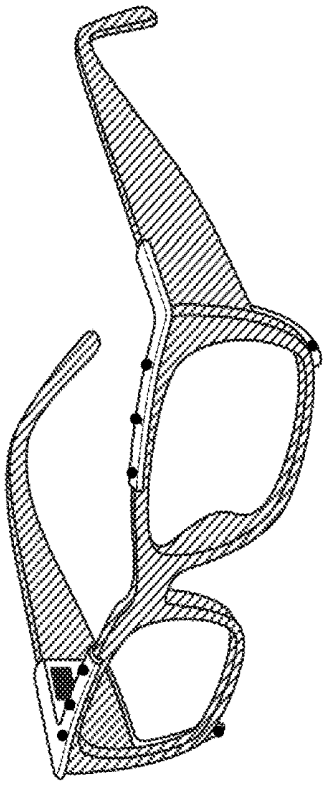

FIG. 33b

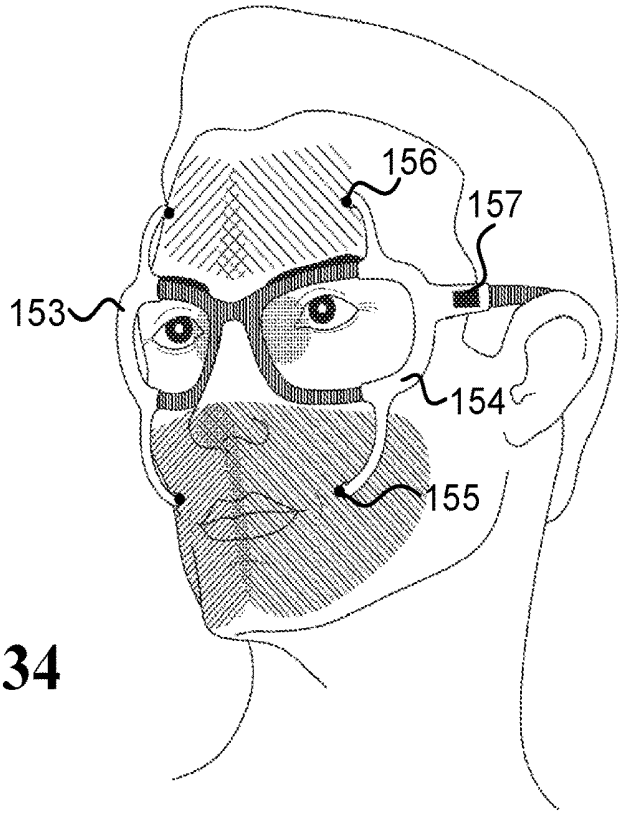

FIG. 34

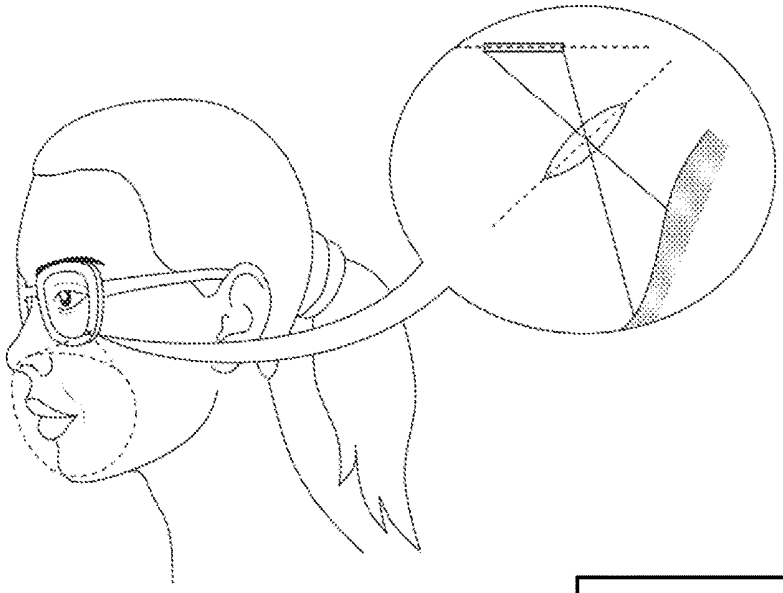

FIG. 35a

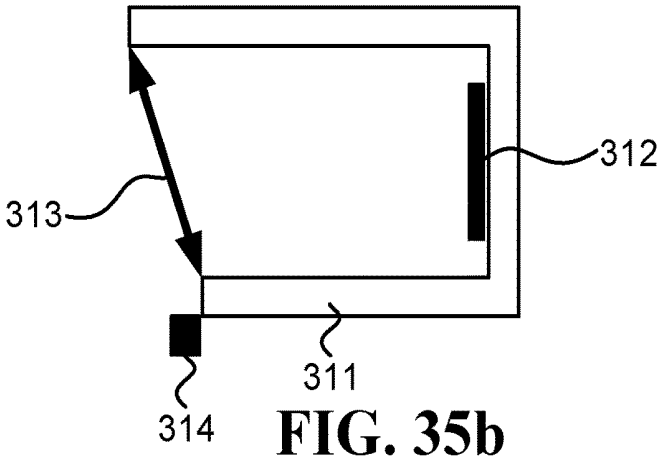

FIG. 35b

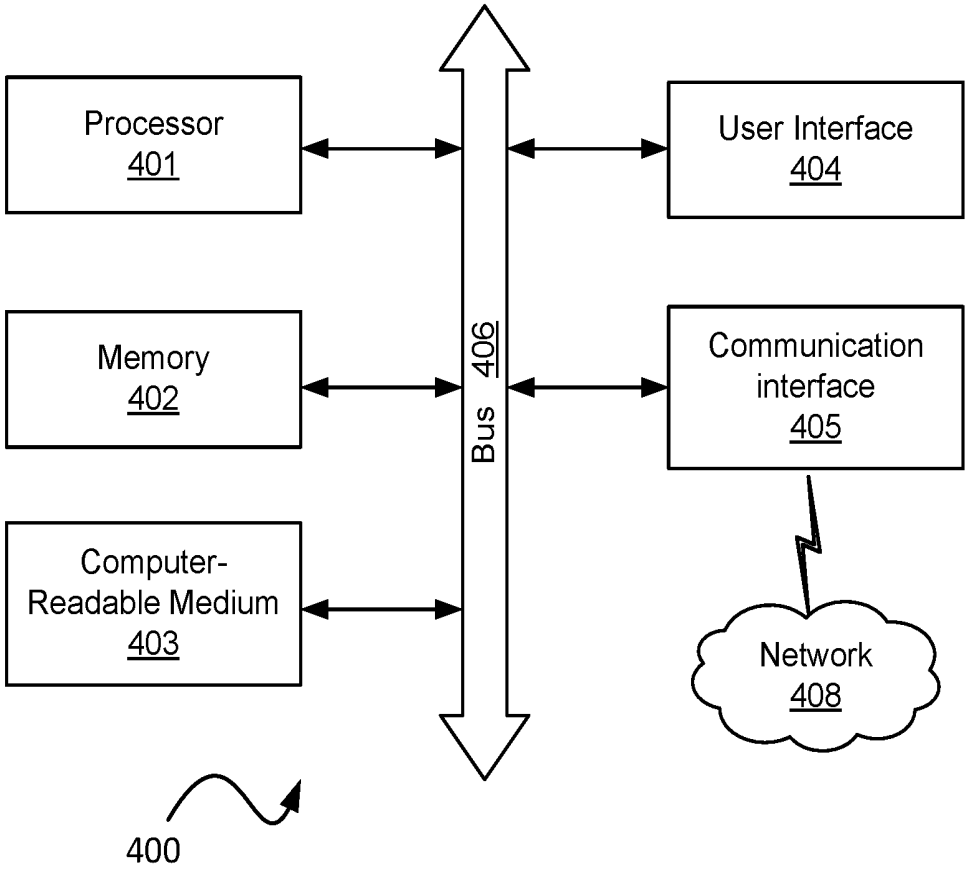

FIG. 36a

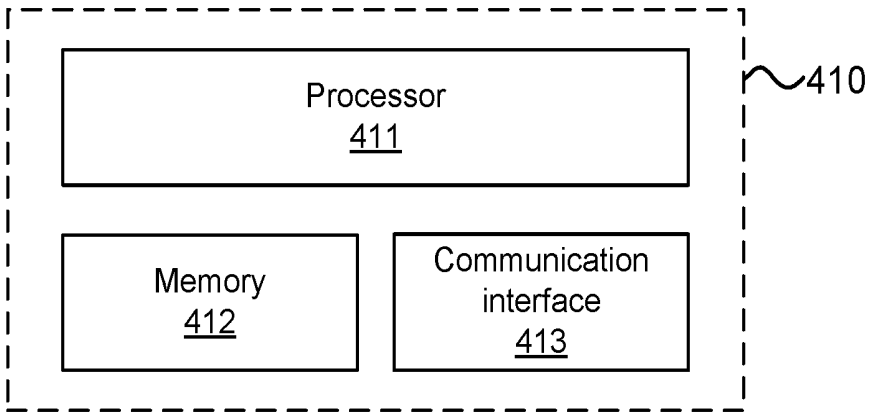

FIG. 36b

EYEGLASSES TO DETECT ABNORMAL MEDICAL EVENTS INCLUDING STROKE AND MIGRAINE

CROSS-REFERENCE TO RELATED APPLICATIONS

This Application claims priority to U.S. Provisional Patent Application No. 62/722,655, filed Aug. 24, 2018, and U.S. Provisional Patent Application No. 62/874,430, filed Jul. 15, 2019.

This Application is a Continuation-In-Part of U.S. application Ser. No. 16/453,993, filed Jun. 26, 2019. U.S. Ser. No. 16/453,993 is a Continuation-In-Part of U.S. application Ser. No. 16/375,841, filed Apr. 4, 2019. U.S. Ser. No. 16/375,841 is a Continuation-In-Part of U.S. application Ser. No. 16/156,493, filed Oct. 10, 2018. U.S. Ser. No. 16/156,493, is a Continuation-In-Part of U.S. application Ser. No. 15/635,178, filed Jun. 27, 2017, now U.S. Pat. No. 10,136,856, which claims priority to U.S. Provisional Patent Application No. 62/354,833, filed Jun. 27, 2016, and U.S. Provisional Patent Application No. 62/372,063, filed Aug. 8, 2016.

U.S. Ser. No. 16/156,493 is also a Continuation-In-Part of U.S. application Ser. No. 15/231,276, filed Aug. 8, 2016, which claims priority to U.S. Provisional Patent Application No. 62/202,808, filed Aug. 8, 2015, and U.S. Provisional Patent Application No. 62/236,868, filed Oct. 3, 2015.

U.S. Ser. No. 16/156,493 is also a Continuation-In-Part of U.S. application Ser. No. 15/832,855, filed Dec. 6, 2017, now U.S. Pat. No. 10,130,308, which claims priority to U.S. Provisional Patent Application No. 62/456,105, filed Feb. 7, 2017, and U.S. Provisional Patent Application No. 62/480,496, filed Apr. 2, 2017, and U.S. Provisional Patent Application No. 62/566,572, filed Oct. 2, 2017. U.S. Ser. No. 15/832,855 is a Continuation-In-Part of U.S. application Ser. No. 15/182,592, filed Jun. 14, 2016, now U.S. Pat. No. 10,165,949, a Continuation-In-Part of U.S. application Ser. No. 15/231,276, filed Aug. 8, 2016, a Continuation-In-Part of U.S. application Ser. No. 15/284,528, filed Oct. 3, 2016, now U.S. Pat. No. 10,113,913, a Continuation-In-Part of U.S. application Ser. No. 15/635,178, filed Jun. 27, 2017, now U.S. Pat. No. 10,136,856, and a Continuation-In-Part of U.S. application Ser. No. 15/722,434, filed Oct. 2, 2017.

U.S. Ser. No. 15/832,855 is a Continuation-In-Part of U.S. application Ser. No. 15/182,566, filed Jun. 14, 2016, now U.S. Pat. No. 9,867,546, which claims priority to U.S. Provisional Patent Application No. 62/175,319, filed Jun. 14, 2015, and U.S. Provisional Patent Application No. 62/202,808, filed Aug. 8, 2015.

U.S. Ser. No. 15/182,592 claims priority to U.S. Provisional Patent Application No. 62/175,319, filed Jun. 14, 2015, and U.S. Provisional Patent Application No. 62/202,808, filed Aug. 8, 2015.

U.S. Ser. No. 15/284,528 claims priority to U.S. Provisional Patent Application No. 62/236,868, filed Oct. 3, 2015, and U.S. Provisional Patent Application No. 62/354,833, filed Jun. 27, 2016, and U.S. Provisional Patent Application No. 62/372,063, filed Aug. 8, 2016.

U.S. Ser. No. 16/156,493 is also a Continuation-In-Part of U.S. application Ser. No. 15/833,115, filed Dec. 6, 2017, now U.S. Pat. No. 10,130,261. U.S. Ser. No. 15/833,115 is a Continuation-In-Part of U.S. application Ser. No. 15/182,592, a Continuation-In-Part of U.S. application Ser. No. 15/231,276, filed Aug. 8, 2016, a Continuation-In-Part of U.S. application Ser. No. 15/284,528, a Continuation-In-Part of U.S. application Ser. No. 15/635,178, and a Continuation-In-Part of U.S. application Ser. No. 15/722,434, filed Oct. 2, 2017.

U.S. Ser. No. 16/453,993 is also a Continuation-In-Part of U.S. application Ser. No. 16/147,695, filed Sep. 29, 2018. U.S. Ser. No. 16/147,695 is a Continuation of U.S. application Ser. No. 15/182,592, filed Jun. 14, 2016, which claims priority to U.S. Provisional Patent Application No. 62/175,319, filed Jun. 14, 2015, and U.S. Provisional Patent Application No. 62/202,808, filed Aug. 8, 2015.

ACKNOWLEDGMENTS

Gil Thieberger would like to thank his holy and beloved teacher, Lama Dvora-hla, for her extraordinary teachings and manifestation of wisdom, love, compassion and morality, and for her endless efforts, support, and skills in guiding him and others on their paths to freedom and ultimate happiness. Gil would also like to thank his beloved parents for raising him with love and care.

BACKGROUND

There are many medical illnesses that can benefit greatly from early intervention. For example in ischemic stroke, time reduction from onset of the initial event to administration of antithrombotic medication or interventional radiology can leave an individual with greatly enhanced neurologic function. Similarly, early treatment of migraine or infection can lead to reduced convalescence time, enhanced well-being and increased productivity.

The need for early intervention necessitates early diagnosis of the medical condition. Despite advances in wearables, currently the vast majority of individuals do not have access to technology that can measure significant physiologic changes in real time and help with diagnosis of migraine, headache, stroke, infection and other significant medical conditions. As a result, many people encounter delays in diagnosis and treatment, which results in increased morbidity and mortality. Existing wearables often offer limited sensors, poor signals, and suffer from significant artifacts.

SUMMARY

Some embodiments described herein utilize head-mounted sensors to obtain multiple photoplethysmogram signals at various regions on a user's head. A photoplethysmogram signal (PPG signal) is an optically obtained plethysmogram that is indicative of blood volume changes in the microvascular bed of tissue. A PPG signal is often obtained by using a pulse oximeter, which illuminates the skin and measures changes in light absorption. Another possibility for obtaining a PPG signal is using an imaging photoplethysmography (iPPG) device. As opposed to typical PPG devices, which usually come in contact with the skin, iPPG usually does not require contact with the skin and is obtained by a non-contact sensor, such as a video camera. Other terms that may be used to refer to iPPG include multi-site photoplethysmography (MPPG) or remote photoplethysmography (rPPG).

The multiple PPG signals can be indicative of blood flow and/or changes thereto, which may be indicative of an onset and/or occurrence of an abnormal medical event. Some examples of medical events that are considered an "abnormal medical event" herein include an Ischemic stroke, a

migraine, a headache, cellulitis (soft tissue infection), dermatitis (skin infection), and an ear infection.

One aspect of this disclosure includes a system configured to detect an abnormal medical event. The system includes at least one right-side head-mounted device configured to measure at least two signals indicative of photoplethysmographic signals (PPG_{SR1} and PPG_{SR2}, respectively) at first and second regions of interest (ROI_{R1} and ROI_{R2}, respectively) on the right side of a user's head, where ROI_{R1} and ROI_{R2} are located at least 2 cm apart. The system also includes at least one left-side head-mounted device configured to measure at least two signals indicative of photoplethysmographic signals (PPG_{SL1} and PPG_{SL2}, respectively) at first and second regions of interest (ROI_{L1} and ROI_{L2}, respectively) on the left side of the user's head, where ROI_{L1} and ROI_{L2} are located at least 2 cm apart. The system also includes a computer configured to detect the abnormal medical event based on an asymmetrical change to blood flow recognizable in PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}. Optionally, the asymmetrical change to the blood flow corresponds to a deviation of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} compared to a baseline that is based on previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, taken before the abnormal medical event. Optionally, the computer utilizes a machine learning based approach in which it is configured to generate feature values based on data that includes: (i) PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, and (ii) the previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user. The computer then utilizes a model to calculate, based on the feature values, a value indicative of whether the user is experiencing the abnormal medical event.

Having the computer base its detection of the abnormal medical event on multiple PPG signals (at least four in some embodiments described herein), may confer several advantages. In particular, having the PPG signals measured on different sides of the head can help identify cases in which changes in blood flow are localized to a certain body region (e.g., a certain side of the head). Identifying such occurrences is not possible with a single PPG signal, and/or with PPG signals that are measured on a single side of the head. Having a single PPG signal, or multiple PPG signals from the same side, does not provide comparative information that can help identify that the change to blood flow is asymmetrical (i.e., not the same on both sides of the head), since measurements from both sides of the head are needed to reach such a conclusion. Thus, systems that rely on a single PPG signal, or multiple PPG signals from the same side of the head, cannot provide the data required in order to detect abnormal medical event characterized by an asymmetrical change to blood flow, as embodiments described herein are capable of detecting.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments are herein described by way of example only, with reference to the following drawings:

FIG. **1***a* illustrates smartglasses which include contact photoplethysmographic devices;

FIG. **1***b* illustrates smartglasses that include first and second inward-facing cameras;

FIG. **2** illustrates smartglasses that include four inward-facing cameras;

FIG. **3** illustrates an embodiment of a system that includes a single head-mounted thermal camera that may be used to detect a stroke;

FIG. **4** illustrates a scenario in which an alert regarding a possible stroke is issued;

FIG. **5**, FIG. **6**, FIG. **7**, and FIG. **8** illustrate physiological and behavioral changes that may occur following a stroke;

FIG. **9**, FIG. **10**, FIG. **11**, and FIG. **12** illustrates various activities that a person may be requested to perform in order to determine whether the person has suffered from a stroke;

FIG. **13** and FIG. **14** illustrate the difference between a timely intervention in the event of a stroke and intervention that comes too late;

FIG. **15***a* illustrates one embodiment of a system that includes multiple pairs of right and left cameras and locations on the face that they may be used to measure;

FIG. **15***b* illustrates a stroke sign that involves decreased blood flow in the forehead;

FIG. **15***c* illustrates a stroke sign that involves decreased blood flow in a periorbital region;

FIG. **16***a* and FIG. **16***b* illustrate embodiments of a system with a head-mounted camera located behind the ear;

FIG. **16***c* illustrates an ischemic stroke that restricts the blood flow to the side of the head, which may be detected by embodiments described herein;

FIG. **17***a* and FIG. **17***b* illustrate various inward-facing head-mounted cameras coupled to an eyeglasses frame;

FIG. **18** illustrates inward-facing head-mounted cameras coupled to an augmented reality device;

FIG. **19** illustrates head-mounted cameras coupled to a virtual reality device;

FIG. **20** illustrates a side view of head-mounted cameras coupled to an augmented reality device;

FIG. **21** illustrates a side view of head-mounted cameras coupled to a sunglasses frame;

FIG. **22**, FIG. **23**, FIG. **24**, and FIG. **25** illustrate head-mounted systems (HMSs) configured to measure various ROIs relevant to some of the embodiments describes herein;

FIG. **26**, FIG. **27**, FIG. **28**, and FIG. **29** illustrate various embodiments of systems that include inward-facing head-mounted cameras having multi-pixel sensors (FPA sensors);

FIG. **30***a*, FIG. **30***b*, and FIG. **30***c* illustrate embodiments of two right and left clip-on devices that are configured to be attached/detached from an eyeglasses frame;

FIG. **31***a* and FIG. **31***b* illustrate an embodiment of a clip-on device that includes inward-facing head-mounted cameras pointed at the lower part of the face and the forehead;

FIG. **32***a* and FIG. **32***b* illustrate an embodiment of a single-unit clip-on device that is configured to be attached behind an eyeglasses frame;

FIG. **33***a* and FIG. **33***b* illustrate embodiments of right and left clip-on devices that are configured to be attached behind an eyeglasses frame;

FIG. **34** illustrates embodiments of right and left clip-on devices, which are configured to be attached/detached from an eyeglasses frame, and have protruding arms to hold inward-facing head-mounted cameras;

FIG. **35***a* is a schematic illustration of an inward-facing head-mounted camera embedded in an eyeglasses frame, which utilizes the Scheimpflug principle;

FIG. **35***b* is a schematic illustration of a camera that is able to change the relative tilt between its lens and sensor planes according to the Scheimpflug principle; and

FIG. **36***a* and FIG. **36***b* are schematic illustrations of possible embodiments for computers.

DETAILED DESCRIPTION

In some embodiments, a system configured to detect an abnormal medical event includes a computer and several

head-mounted devices that are used to measure photoplethysmographic signals (PPG signals) indicative of blood flow at various regions on a user's head. Optionally, the system may include additional components, such as additional sensors that may be used to measure the user and/or the environment. Additionally or alternatively, the system may include a frame configured to be worn on the user's head (e.g., a frame of eyeglasses or smartglasses) and to which at least some of the head-mounted devices and sensors are physically coupled. Having sensors, such as the devices that are used to measure photoplethysmographic signals, physically coupled to the frame may convey certain advantages, such as having the sensors remain at the same positions with respect to the head, even when the user's head makes angular movements. Some examples of abnormal medical events that may be detected by embodiments described herein include an ischemic stroke, a migraine, a headache, cellulitis (soft tissue infection), dermatitis (skin infection), and an ear infection.

In one embodiment, the system includes at least one right-side head-mounted device, configured to measure at least two signals indicative of photoplethysmographic signals (PPG_{SR1} and PPG_{SR2}, respectively) at first and second regions of interest (ROI_{R1} and ROI_{R2}, respectively) on the right side of a user's head. Optionally, ROI_{R1} and ROI_{R2} are located at least 2 cm apart (where cm denotes centimeters). Optionally, each device, from among the at least one right-side head-mounted device(s), is located to the right of the vertical symmetry axis that divides the user's face.

Additionally, the system includes at least one left-side head-mounted device configured to measure at least two signals indicative of photoplethysmographic signals (PPG_{SL1} and PPG_{SL2}, respectively) at first and second regions of interest (ROI_{L1} and ROI_{L2}, respectively) on the left side of the user's head. Optionally, each device, from among the at least one right-side head-mounted device(s), is located to the left of the vertical symmetry axis that divides the user's face.

In some embodiments, ROI_{R1} and ROI_{L1} may be symmetrical regions on the right and left sides of the head, respectively (with respect to a symmetry axis that splits the face to right and left sides). Additionally or alternatively, ROI_{R2} and ROI_{L2} may be symmetrical regions on the right and left sides of the head, respectively. In other embodiments, ROI_{R1} and ROI_{L1} may not be symmetrical regions on the right and left side of the head, and/or ROI_{R2} and ROI_{L2} may not be symmetrical regions on the right and left side of the head. Optionally, two regions are considered to be in symmetrical locations if one region is within 1 cm of the symmetrical region on the head.

Various types of devices may be utilized in order to obtain PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and/or PPG_{SL2}. In one embodiment, the at least one right-side head-mounted device includes first and second contact photoplethysmographic devices (PPG_1, PPG_2, respectively). Additionally or alternatively, the at least one left-side head-mounted device may include third and fourth contact photoplethysmographic devices (PPG_3, PPG_4, respectively). Herein, a "contact photoplethysmographic device" is a photoplethysmographic device that comes in contact with the user's skin, and typically occludes the area being measured. An example of a contact photoplethysmographic device is the well-known pulse oximeter.

In one example, PPG_1, PPG_2, PPG_3, and PPG_4 are physically coupled to an eyeglasses frame, PPG_1 and PPG_3 are in contact with the nose, and PPG_2 and PPG_4 are in contact with regions in the vicinities of the ears (e.g., within a distance of less than 5 cm from the center of the concha), respectively.

FIG. **1***a* illustrates smartglasses that include contact photoplethysmographic devices that may be used to obtain PPG signals, as described above. The contact PPG devices are coupled to a frame **674**. The contact PPG devices may be coupled at various locations on the frame **674** and thus may come in contact with various regions on the user's head. For example, contact PPG device **671***a* is located on the right temple tip, which brings it to contact with a region behind the user's ear (when the user wears the smartglasses). Contact PPG device **671***b* is located on the right temple of the frame **674**, which puts it in contact with a region on the user's right temple (when wearing the smartglasses). It is to be noted that in some embodiments, in order to bring the contact PPG device close such that it touches the skin, various apparatuses may be utilized, such as spacers (e.g., made from rubber or plastic), and/or adjustable inserts that can help bridge a possible gap between a frame's temple and the user's face. Such an apparatus is spacer **672** which brings contact PPG device **671***b* in contact with the user's temple when the user wears the smartglasses.

Another possible location for a contact PPG device is the nose bridge, as contact PPG device **671***c* is illustrated in the figure. It is to be noted the contact PPG device **671***c* may be embedded in the nose bridge (or one of its components), and/or physically coupled to a part of the nose bridge. The figure also illustrates computer **673**, which may be utilized in some embodiments, to perform processing of PPG signals and/or detection of the abnormal medical event, as described further below.

It is to be noted that FIG. **1***a* illustrates but a few of the possible locations for contact PPG devices on a frame. Any pair of contact PPG devices **671***a*, **671***b*, and **671***c* may be the aforementioned PPG_1 and PPG_2. Additionally, some embodiments may include additional contact PPG devices on each side of the frames. Furthermore, it is to be noted that while contact PPG devices on the left side were not illustrated in the figure, additional PPG devices may be located in similar locations to the ones of PPG devices **671***a* to **671***c* are located, but on the left side of the frame.

In another embodiment, one or more video cameras may be utilized to obtain PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and/or PPG_{SL2} utilizing imaging photoplethysmography. Using video cameras can be advantageous in some scenarios, such as stroke, where it is unknown in advanced where the physiological response associated with the abnormal medical event will appear on the user's head. Thus, in some embodiments involving these scenarios, using video cameras may provide a great advantage over contact PPG devices, because the video cameras cover larger areas, which increase the chance to capture on time the physiological response associated with the abnormal medical event.

In one embodiment, the at least one right-side head-mounted device includes a first inward-facing camera located more than 0.5 cm away from ROI_{R1} and ROI_{R2}, and PPG_{SR1} and PPG_{SR2} are recognizable from color changes in regions in images taken by the first camera. Additionally or alternatively, the at least one left-side head-mounted device may include a second inward-facing camera located more than 0.5 cm away from ROI_{L1} and ROI_{L2}, and PPG_{SL} and PPG_{SL2} are recognizable from color changes in regions in images taken by the second camera. In one embodiment, the system includes both at least one contact PPG device and at least one video camera.

In one embodiment, each of the first and second inward-facing cameras utilizes a sensor having more than 30 pixels, and each of ROI_{R1} and ROI_{L1} covers a skin area greater than 6 cm^2, which is illuminated by ambient light. In another embodiment, each of the first and second inward-facing cameras utilizes a sensor having more than 20 pixels, and each of ROI_{R1} and ROI_{L1} covers a skin area greater than 2 cm^2, which is illuminated by ambient light. In still another embodiment, each of the first and second inward-facing cameras utilizes a sensor comprising at least 3×3 pixels configured to detect electromagnetic radiation having wavelengths in at least a portion of the range of 200 nm to 1200 nm. Optionally, the system includes first and second active light sources configured to illuminate portions of the right side of the face (which include ROI_{R1} and ROI_{R2}) and portions of the left side of the face (which include ROI_{L1} and ROI_{L2}), respectively. In one example, the first and second active light sources are head-mounted light sources configured to illuminate their respective portions of the face with electromagnetic radiation having wavelengths in at least a portion of the range of 750 nm to 1200 nm.

In one embodiment, due to the angle between the optical axis of a certain inward-facing camera (from among the first and second inward-facing cameras) and its ROI, the Scheimpflug principle may be employed in order to capture sharper images with the certain inward-facing camera. For example, when the user wears a frame to which the certain inward-facing camera is coupled, the certain inward-facing camera may have a certain tilt greater than 20 between its sensor and lens planes, in order to capture the sharper images.

FIG. **1***b* illustrates smartglasses that include first and second inward-facing cameras, such as the ones described above. The figure illustrates a frame **677** to which a first inward-facing camera **675***a* is coupled above the lens that is in front of the right eye, and a second inward-facing camera **675***b* that is coupled to the frame **677** above the lens that is in front of the left eye. The figure also illustrates a computer **676** that is coupled to the frame **677**, and may be utilized to process images obtained by the first inward-facing camera **675***a* and/or the second inward-facing camera **675***b*, and/or perform the detection of the abnormal medical event based on PPG signals recognizable in images captured by those cameras.

Various regions on the face may be measured in embodiments that utilize imaging photoplethysmography. In one example, ROI_{R1} and ROI_{L1} are located on the user's right and left cheeks, respectively. In another example, ROI_{R2} and ROI_{L2} are located on the right and left sides of the user's nose, respectively. In yet another example, ROI_{R1} and ROI_{L1} are located on the right and left sides of the user's forehead, respectively. In still another example, ROI_{R2} and ROI_{L2} are located on the user's right and left temples, respectively.

A configuration consistent with some of the examples described above is illustrated in FIG. **2**. In this figure, four inward-facing cameras are coupled to a frame **540** worn on a user's head: (i) Inward-facing camera **544***a* is coupled to the top-left side of the frame and captures images of ROI **545***a*, which is on the left side of the user's forehead; (ii) Inward-facing camera **544***b* is coupled to the top-right side of the frame and captures images of ROI **545***b*, which is on the right side of the user's forehead; (iii) Inward-facing camera **546***a* is coupled to the bottom-left side of the frame and captures images of ROI **547***a*, which is on the user's left cheek; And (iv) Inward-facing camera **546***b* is coupled to the bottom-right side of the frame and captures images of ROI **547***b*, which is on the user's right cheek.

Herein, sentences of the form "a PPG signal is recognizable from color changes in a region in images" refer to effects of blood volume changes due to pulse waves that may be extracted from a series of images of the region. These changes may be identified and/or utilized by a computer (e.g., in order to generate a signal indicative of the blood volume at the region), but need not necessarily be recognizable to the naked eye (e.g., because of their subtlety, the short duration in which they occur, or involvement of light outside of the visible spectrum). For example, blood flow may cause facial skin color changes (FSCC) that corresponds to different concentrations of oxidized hemoglobin due to varying volume of blood at a certain region due to different stages of a cardiac pulse, and/or the different magnitudes of cardiac output. Similar blood flow dependent effects may be viewed with other types of signals (e.g., slight changes in cutaneous temperatures due to the flow of blood).

In some embodiments, the system configured to detect the abnormal medical event may further include first and second outward-facing head-mounted cameras for taking images of the environment to the right and to the left of the user's head, respectively. Images taken by these cameras, which are indicative of illumination towards the face, may be utilized to improve the accuracy of detecting the abnormal medical event.

In one example, the first and second outward-facing head-mounted cameras may be thermal cameras that take thermal measurements of the environment. Heat from the environment may affect the surface blood flow, and thus reduce the accuracy of detecting the abnormal medical event. By taking the thermal measurements of the environment into account, the computer is able to detect, and maybe even compensate, for temperature interferences from the environment. Examples of outward-facing head-mounted thermal cameras include thermopile-based and/or microbolometer-based cameras having one or more pixels.

In another example, the first and second outward-facing head-mounted cameras may be visible-light cameras (such as CMOS cameras), and/or light intensity sensors (such as photodiodes, photoresistors, and/or phototransistor). Illumination from the environment may affect the surface blood flow (especially when heating the skin), and/or interfere with the photoplethysmographic signals to be measured, and thus reduce the accuracy of detecting the abnormal medical event. By taking the illumination from the environment into account, the computer is able to detect, and maybe even compensate, for the interferences from the environment.

In one embodiment, the at least one right-side head-mounted device and/or the at least one left-side head-mounted device are coupled to a clip-on, and the clip-on comprises a body configured to be attached and detached, multiple times, from a frame configured to be worn on the user's head. FIG. **30***a* to FIG. **34** illustrate various examples of embodiments of systems that include a clip-on which may have the aforementioned head-mounted devices coupled thereto.

Various embodiments described herein include a computer configured to detect the abnormal medical event based on an asymmetrical change to blood flow recognizable in at least PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}. Optionally, the asymmetrical change to the blood flow corresponds to a deviation of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} compared to a baseline based on previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, taken before the abnormal medical event (e.g., minutes, hours, and even days before the abnormal medical event). In one example, "a baseline based on the previous measurements"

is one or more values that are calculated based on the previous measurements (e.g., one or more values representing a normal, baseline blood flow of the user). In another example, "a baseline based on the previous measurements" may be some, or even all, the previous measurements themselves, which may be provided as an input used in calculations involved in the detection of the abnormal medical event (without necessarily calculating an explicit value that is considered a "baseline" value of the user's blood flow).

Examples of computers that may be utilized to perform calculations involved in the detection of the abnormal medical event are computers modeled according to computer **400** or computer **410** illustrated in FIG. **36***a* and FIG. **36***b*, respectively. Additional examples are the computers **673** and **676** illustrated in FIG. **1***a* and FIG. **1***b*, respectively. It is to be noted that the use of the singular term "computer" is intended to imply one or more computers, which jointly perform the functions attributed to "the computer" herein. In particular, in some embodiments, some functions attributed to the computer, such as preprocessing PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}, may be performed by a processor on a wearable device (e.g., smartglasses) and/or a computing device of the user (e.g., smartphone), while other functions, such as the analysis of sensor data and determining whether the user is experiencing the abnormal medical event, may be performed on a remote processor, such as a cloud-based server. In other embodiments, essentially all functions attributed to the computer herein may be performed by a processor on a wearable device (e.g., smartglasses to which the head-mounted devices are coupled) and/or some other device carried by the user, such as a smartwatch or smartphone.

Herein, detecting the abnormal medical event may mean detecting that the user is suffering from the abnormal medical event, and/or that there is an onset of the abnormal medical event. Additionally, an "abnormal" medical event may be a medical event that the user has yet to experience, or does not experience most of the time.

In some embodiments, detecting the abnormal medical event may involve calculating one or more of the following values: an indication of whether or not the user is experiencing the abnormal medical event, a value indicative of an extent to which the user is experiencing the abnormal medical event, a duration since the onset of the abnormal medical event, and a duration until an onset of the abnormal medical event.

When the blood flow on both sides of the head and/or body are monitored, asymmetric changes may be recognized. These changes are typically different from symmetric changes that can be caused by factors such as physical activity (which typically affects the blood flow on both sides in the same way). An asymmetric change to the blood flow can mean that one side has been affected by an event, such as a stroke, which does not influence the other side. In one example, the asymmetric change to blood flow involves a change in blood flow velocity on left side of the head that is at least 10% greater or 10% lower than a change in blood flow velocity on one right side of the head. In another example, the asymmetric change to blood flow involves a change in the volume of blood the flows during a certain period in the left side of the head that is at least 10% greater or 10% lower than the volume of blood that flows during the certain period in the right side of the head. In yet another example, the asymmetric change to blood flow involves a change in the direction of the blood flow on one side of the head (e.g., as a result of a stroke), which is not necessarily observed at the symmetric location on the other side of the head.

Referring to an asymmetrical change to blood flow as being "recognizable in PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}" means that values extracted from PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} provide an indication that an asymmetric change to the blood flow has occurred. That is, a difference that has emerged in the PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} may reflect a change in blood flow velocity on one side of the head, a change in blood flow volume, and/or a change in blood flow direction, as described in the examples above. It is to be noted, that the change in blood flow does not need to be directly quantified from the values PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} in order for it to be "recognizable in PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}". Rather, in some embodiments, feature values generated based on PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} may be used by a machine learning-based predictor to detect a phenomenon, such as the abnormal medical event, which is associated with the asymmetrical change in blood flow.

Having multiple PPG signals, measured at different sides of the head, can assist in detecting an asymmetric change to blood flow in different ways. In one example, an asymmetric change in blood flow may be characterized in an increase in volume at a certain region and/or side of the head, compared to other regions and/or the other side of the head. In this example, the amplitude of the PPG signal at the certain region may show a greater increase compared to increases observed with PPG signals at other regions and/or on the other side of the head. In another example, an asymmetric change in blood flow may be characterized by a decrease in blood velocity at a certain region and/or side of the head, compared to other regions and/or the other side of the head. In this example, a pulse arrival time (PAT) at the certain region may exhibit a larger delay compared to the delay of PATs at other regions and/or at the other side of the head. In still another example, an asymmetric change in blood flow may be characterized by a change in a direction of blood flow at a certain region, compared to other regions and/or the symmetric region on the other side of the head. In this example, an order at which pulse waves arrive at different regions (as evident by PPG signals at the different regions) may be indicative of the direction of blood flow. Thus, a change in the arrival order of pulse waves on one side of the head, which does not occur at regions on the other side of the head, may indicate an asymmetrical change of a direction of blood flow.

In some embodiments, the computer detects the abnormal medical event by utilizing previously taken PPG signals of the user (i.e., previously taken PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}), from a period that precedes the current abnormal medical event being detected at that time. This enables an asymmetrical change to be observed, since it provides a baseline according to which it is possible to compare current PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}, such that it may be determined that a change to blood flow on one side of the head is not the same as a change on the other side of the head. In some embodiments, previously taken PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} are utilized to calculate a baseline blood flow, such as values representing the extent of blood flow at the different sides of the head, and/or at different regions (e.g., ROI_{R1}, ROI_{R2}, ROI_{L1} and ROI_{L2}). Optionally, calculating the baseline blood flow may be done based on previously taken PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} that were measured at least an hour before the abnormal medical event is detected. Optionally, the previ-

ously taken PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} include PPG signals measured at least a day before the abnormal medical event is detected. Optionally, the previously taken PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} include PPG signals measured more than a week before the abnormal medical event is detected.

A baseline for the blood flow may be calculated in various ways. In a first example, the baseline is a function of the average measurements of the user (which include previously taken PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}), which were taken before the occurrence of the abnormal medical event. In a second example, the baseline may be a function of the situation the user is in, such that previous measurements taken during similar situations are weighted higher than previous measurements taken during less similar situations. A PPG signal may show different characteristics in different situations because of the different mental and/or physiological states of the user in the different situations. As a result, a situation-dependent baseline can improve the accuracy of detecting the abnormal medical event. In a third example, the baseline may be a function of an intake of some substance, such that previous measurements taken after consuming similar substances are weighted higher than previous measurements taken after not consuming the similar substances and/or after consuming less similar substances. A PPG signal may show different characteristics after the user consumes different substances because of the different mental and/or physiological states the user may be in after consuming the substances, especially when the substances include things such as medications, drugs, alcohol, and/or certain types of food. As a result, a substance-dependent baseline can improve the accuracy of detecting the abnormal medical event.

There are various types of abnormal medical events that may be detected based on PPG signals that reflect an asymmetrical change to blood flow, which is recognizable in PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user.

In some embodiments, the abnormal medical event may involve the user having a cerebrovascular accident, which is also known as having a stroke. An occurrence of a stroke often has the following effect on a person. A blood clot (in the case of ischemic stroke) or the raptured artery (in the case of a hemorrhagic stroke) changes the blood flow to certain regions of the brain. One or more of several mechanisms may be the cause of changes to blood flow that are observed following an onset of a stroke. Blood flow may change due to a stroke because of flaccid muscles (on one side of the face) that use less oxygen and demand less blood. In such an event, local regulation mechanisms may generate signals to the smooth muscles that decrease the diameter of the arteries (which can reduce blood flow). Additionally or alternatively, blood flow may change due to a stroke because of nerve control changes that occur due to reduced blood flow to the brain (a neurogenic mechanism); the same nerves that control the muscles can also be involved in the control of the constriction/dilation of blood vessels. Another possible cause of changes to blood flow involves obstruction-related passive changes. Blood that flows through the major vessels (in the base of the brain it is either the carotid (front) or vertebral (back) arteries, must flow out through one of the branches. When one pathway is blocked or restricted (due to the stroke), more blood has to go through collateral pathways (which may change the blood flow). Thus, changes to the blood flow in the face (and other areas of the head), especially if they are asymmetric, can be early indicators of a stroke. An event of a stroke may be detected in various ways, some which are described in the following examples.

In one embodiment, the abnormal medical event is an ischemic stroke, and the deviation (of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} compared to a baseline based on the previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user) involves an increase in asymmetry between blood flow on the left side of the head and blood flow on the right side of the head, with respect to a baseline asymmetry level between blood flow on the left side of the head and blood flow on the right side of the head (as determined based on the previous measurements). In some embodiments, the term "ischemic stroke" may also include Transient Ischemic Attack (TIA), known as "mini stroke".

In another embodiment, the abnormal medical event is an ischemic stroke, and the deviation (of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} compared to a baseline based on the previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user) involves a monotonic increase in asymmetry between blood flow at ROI_{R1} and ROI_{R2}, with respect to a baseline asymmetry of the user (between blood flow at ROI_{R1} and ROI_{R2}) during a period longer than 10 minutes. Optionally, ROI_{R1} is located in proximity of the mastoid process behind the right ear, and ROI_{R2} is located before of the right ear.

In yet another embodiment, the abnormal medical event is an ischemic stroke, and the deviation involves an increase in variation between blood flow at ROI_{R1} and ROI_{R2}, with respect to a baseline variation of the user between blood flow at ROI_{R1} and ROI_{R2}. Optionally, the computer suggests the user to take images of at least one of the retinas, responsive to detecting the increase in variation. The computer may then compare the images of the retinas with previously taken images of the user's retinas, and utilize such a comparison to improve the accuracy of detecting whether the user has suffered the ischemic stroke. Optionally, the comparison of the images of the retinas may take into account parameters such as the diameter of retinal arteries, swelling of the boundaries of the optic disk, and/or blurring of the boundaries of the optic disk. The images of the retinas may be taken by any known and/or to be invented appropriate device.

In some embodiments, the abnormal medical event may involve the user having a migraine or another form of headache. With migraines and other headaches, vasoconstriction of facial or cranial blood vessels may lead to asymmetric changes in blood flow between the left and right sides of the head. Compensatory mechanisms may change smooth muscle constriction around blood vessels, further exacerbating this asymmetry. This vasoconstriction can lead to differential surface blood flow, muscle contraction, and facial temperature changes, leading to asymmetric blood flow. As each individual's particular patterns of vasoconstriction would be unique to the individual, the asymmetric phenomena may be different for different users. Thus, measuring deviation from the user's baseline blood flow patterns may increase the accuracy of detecting these asymmetric phenomena, in some embodiments. Additionally, the time course of migraine or headache usually involves an occurrence over the course of minutes to hours (from the onset of changes to blood flow), and usually occurs with a characteristic pattern, allowing it to be differentiated from signs of other medical, artificial or external causes, which manifest different patterns of blood flow and/or time courses.

In one embodiment, the abnormal medical event is a migraine attack, and the deviation (of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} compared to a baseline based on the previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user) is indicative of a pattern of a certain

change to facial blood flow, which is associated with a pattern of a change to facial blood flow of at least one previous migraine attack, determined based on data comprising previous PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}, which were measured starting from at least 5 minutes before the previous migraine attack. In this embodiment, the time of the beginning of the previous migraine attack corresponds to the time at which the user became aware of the migraine attack.

In another embodiment, the abnormal medical event is headache, and the deviation is indicative of at least one of: a change in directionality of facial blood flow, and an asymmetrical reduction in blood flow to one side of the face (for a period lasting more than one minute). For some people, a migraine attack and/or a headache may cause a change in directionality of facial blood flow because the pulse propagation across the face arrives at one side before it arrives to the other side. In one example, the changes in directionality of facial blood flow are calculated from phase variations between PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} relative to a baseline for the user. For some people, vasoconstriction caused by a migraine attack and/or a headache may affect the amplitude of the PPG signals, such as decreasing of amplitudes of the PPG signals in a certain region. In one example, the reduction in blood flow to one side of the face is calculated from changes between amplitudes of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} relative to the baseline.

In some embodiments, the abnormal medical event may involve the user suffering from an infection. Inflammatory conditions, such as cellulitis, dermatitis and ear infection, originate in infection or inflammation in one particular region of the face, causing vasodilation leading to a facial asymmetry originating from phenomena such as increase in swelling, redness and warmth, which are detectable only in the vicinity of the infection. As each individual's baseline facial blood flow and coloration is different, comparing current measurements with the baseline may allow accurate identification of vasodilation resulting from an inflammatory condition. The time course of such inflammatory conditions would usually occur over the course of hours to days, allowing it to be differentiated from other medical or artificial phenomena, which may have similar signs but over a different time course.

Since inflammation often causes temperatures at the infected region to rise, accuracy of detection of some abnormal medical events may increase by measuring the temperature at different regions on the head. In one embodiment, the system configured to detect an abnormal medical event includes right and left head-mounted thermometers, located at least 2 cm to the right and to the left of a vertical symmetry axis that divides the face, respectively. The head-mounted thermometers may be contact thermometers, such as thermistors, and/or non-contact thermal cameras. Optionally, the head-mounted thermometers measure ROIs on one or more of the following regions: the forehead, the temples, behind the ear, the cheeks, the nose, and the mouth. The right and left head-mounted thermometers take right and left temperature measurements, respectively. Optionally, the computer detects the abnormal medical event also based on a deviation of the right and left temperature measurements from a baseline temperature for the user, where the baseline temperature for the user is calculated based on data comprising previous right and left temperature measurements of the user, taken more than a day before the abnormal medical event. Optionally, the abnormal medical event detected in this embodiment is selected from a set comprising cellulitis and dermatitis.

In one embodiments, the system configured to detect an abnormal medical event may optionally include right and left head-mounted thermometers, located less than 4 cm from the right and left earlobes, respectively, which provide right and left temperature measurements, respectively. Optionally, the computer detects the abnormal medical event also based on a deviation of the right and left temperature measurements from a baseline temperature for the user, where the baseline temperature for the user is calculated based on data comprising previous right and left temperature measurements of the user, taken more than a day before the abnormal medical event. In one example, the abnormal medical event is ear infection. In another example, the abnormal medical event is cerebrovascular accident. In still another example, the abnormal medical event is mastoiditis.

Obtaining the PPG signals PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} from measurements taken by the at least one right-side head-mounted device and the at least one left-side head-mounted device may involve, in some embodiments, performing various preprocessing operations in order to assist in calculations and/or in extraction of the PPG signals. Optionally, the measurements may undergo various preprocessing steps prior to being used by the computer to detect the abnormal medical event, and/or as part of the process of the detection of the abnormal medical event. Some non-limiting examples of the preprocessing include: normalization of pixel intensities (e.g., to obtain a zero-mean unit variance time series signal), and conditioning a time series signal by constructing a square wave, a sine wave, or a user defined shape, such as that obtained from an ECG signal or a PPG signal as described in U.S. Pat. No. 8,617,081.

In some embodiments, in which the at least one right-side head-mounted device and/or at least one left-side head-mounted device are cameras, images taken by the cameras may undergo various preprocessing to improve the signal, such as color space transformation (e.g., transforming RGB images into a monochromatic color or images in a different color space), blind source separation using algorithms such as independent component analysis (ICA) or principal component analysis (PCA), and various filtering techniques, such as detrending, bandpass filtering, and/or continuous wavelet transform (CWT). Various preprocessing techniques known in the art that may assist in extracting an PPG signals from images are discussed in Zaunseder et al. (2018), "Cardiovascular assessment by imaging photoplethysmography-a review", Biomedical Engineering 63(5), 617-634. An example of preprocessing that may be used in some embodiments is given in U.S. Pat. No. 9,020,185, titled "Systems and methods for non-contact heart rate sensing", which describes how a times-series signals obtained from video of a user can be filtered and processed to separate an underlying pulsing signal by, for example, using an ICA algorithm.

In some embodiments, detection of the abnormal medical event may involve calculation of pulse arrival times (PATs) at one or more of the regions ROI_{R1}, ROI_{R2}, ROI_{L1} and ROI_{L2}. Optionally, a PAT calculated from an PPG signal represents a time at which the value representing blood volume (in the waveform represented in the PPG) begins to rise (signaling the arrival of the pulse). Alternatively, the PAT may be calculated as a different time, with respect to the pulse waveform, such as the time at which a value representing blood volume reaches a maximum or a certain threshold, or the PAT may be the average of the time the

blood volume is above a certain threshold. Another approach that may be utilized to calculate a PAT from an iPPG signal is described in Sola et al. "Parametric estimation of pulse arrival time: a robust approach to pulse wave velocity", Physiological measurement 30.7 (2009): 603, which describe a family of PAT estimators based on the parametric modeling of the anacrotic phase of a pressure pulse.

Detection of the abnormal medical event may involve the computer utilizing an approach that may be characterized as involving machine learning. In some embodiments, such a detection approach may involve the computer generating feature values based on data that includes PPG signals (i.e., PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user) and optionally other data, and then utilizing a previously trained model to calculate one or more values indicative of whether the user is experiencing the abnormal medical event (which may be any one of the examples of values mentioned further above as being calculated by the computer for this purpose). It is to be noted that when the computer calculates a value that is indicative of the user having the abnormal medical event, at least some of the feature values may reflect the fact that an asymmetrical change to blood flow had occurred. Optionally, the additional data used to generate at least some of the feature values includes previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, and/or measurements from additional sensors and/or data sources as discussed below.

Feature values generated based on PPG signals may include various types of values, which may be indicative of dynamics of the blood flow at the respective regions to which the PPG signals correspond. Optionally, these feature values may relate to properties of a pulse waveform, which may be a specific pulse waveform (which corresponds to a certain beat of the heart), or a window of pulse waveforms (e.g., an average property of pulse waveforms in a certain window of time). Some examples of feature values that may be generated based on a pulse waveform include: the area under the pulse waveform, the amplitude of the pulse waveform, a derivative and/or second derivative of the pulse waveform, a pulse waveform shape, pulse waveform energy, and pulse transit time (to the respective ROI). Some additional examples of features may be indicative one or more of the following: a magnitude of a systolic peak, a magnitude of a diastolic peak, duration of the systolic phase, and duration of the diastolic phase. Additional examples of feature values may include properties of the cardiac activity, such as the heart rate and heart rate variability (as determined from the PPG signal). Additionally, some feature values may include values of other physiological signals that may be calculated based on PPG signals, such as blood pressure and cardiac output.

It is to be noted that the aforementioned feature values may be calculated in various ways. In one example, some feature values are calculated for each PPG signal individually. In another example, some feature values are calculated after normalizing a PPG signal with respect to previous measurements from the corresponding PPG device used to measure the PPG signal. In other examples, at least some of the feature values may be calculated based on an aggregation of multiple PPG signals (e.g., different pixels/regions in images captured by an iPPG device), or by aggregating values from multiple contact PPG devices.

In some embodiments, at least some of the feature values may represent comparative values, which provide an indication of the difference in blood flow, and/or in some other property that may be derived from a PPG signal, between various regions on the head. Optionally, such feature values may assist in detecting asymmetrical blood flow (and/or changes thereto). In one example, the feature values include a certain feature value indicative of a difference in maximal amplitudes of one or more of the following pairs of PPG signals: (i) PPG_{SR1} and PPG_{SR2}, (ii) PPG_{SR1} and PPG_{SL1}, and (iii) PPG_{SR1} and PPG_{SL2}. In another example, the feature values include a certain feature value indicative of a difference in a pulse arrival time between the following pairs of regions of interest: (i) ROI_{R1} and ROI_{R2}, (ii) ROI_{R1} and ROI_{L1}, and (iii) ROI_{R1} and ROI_{L2}.

In some embodiments, at least some of the feature values describe properties of pulse waveforms (e.g., various types of feature values mentioned above), which are derived from the previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user. Optionally, these feature values may include various blood flow baselines for the user, which correspond to a certain situation the user was in when the previous measurements were taken.

In some embodiments, at least some of the feature values may be "raw" or minimally processed measurements of the at least one right-side head-mounted device and/or at least one left-side head-mounted device. In one example, at least some of the feature values may be values obtained from contact PPG devices. In another example, at least some of the feature values may be pixel values obtained by inward-facing head-mounted cameras. Optionally, the pixel values may be provided as input to functions in order to generate at feature values that are low-level image-based features. Some examples of low-level features, which may be derived from images, include feature generated using Gabor filters, local binary patterns (LBP) and their derivatives, algorithms such as SIFT and/or SURF (and their derivatives), image key-points, histograms of oriented gradients (HOG) descriptors, and products of statistical procedures such independent component analysis (ICA), principal component analysis (PCA), or linear discriminant analysis (LDA). Optionally, one or more of the feature values may be derived from multiple images taken at different times, such as volume local binary patterns (VLBP), cuboids, and/or optical strain-based features. In one example, one or more of the feature values may represent a difference between values of pixels at one time t and values of other pixels at a different region at some other time t+x (which, for example, can help detect different arrival times of a pulse wave).

In some embodiments, at least some feature values may be generated based on other data sources (in addition to PPG signals). In some examples, at least some feature values may be generated based on other sensors, such as movement sensors (which may be head-mounted, wrist-worn, or carried by the user some other way), head-mounted thermal cameras (e.g., as mentioned above), or other sensors used to measure the user. In other examples, at least some feature values may be indicative of environmental conditions, such as the temperature, humidity, and/or extent of illumination (e.g., as obtained utilizing an outward-facing head-mounted camera). Additionally, some feature values may be indicative of physical characteristics of the user, such as age, sex, weight, Body Mass Index (BMI), skin tone, and other characteristics and/or situations the user may be in (e.g., level of tiredness, consumptions of various substances, etc.)

Stress is a factor that can influence the diameter of the arteries, and thus influence calculated values that relate to the PPG signals and/or blood flow. In one embodiment, the computer receives a value indicative of a stress level of the user, and generates at least one of the feature values based on the received value. Optionally, the value indicative of the stress level is obtained using a thermal camera. In one

example, the system may include an inward-facing head-mounted thermal camera that takes measurements of a periorbital region of the user, where the measurements of a periorbital region of the user are indicative of the stress level of the user. In another example, the system includes an inward-facing head-mounted thermal camera that takes measurements of a region on the forehead of the user, where the measurements of the region on the forehead of the user are indicative of the stress level of the user. In still another example, the system includes an inward-facing head-mounted thermal camera that takes measurements of a region on the nose of the user, where the measurements of the region on the nose of the user are indicative of the stress level of the user.

Hydration is a factor that affects blood viscosity, which can affect the speed at which the blood flows in the body. In one embodiment, the computer receives a value indicative of a hydration level of the user, and generates at least one of the feature values based on the received value. Optionally, the system includes an additional camera that detects intensity of radiation that is reflected from a region of exposed skin of the user, where the radiation is in spectral wavelengths chosen to be preferentially absorbed by tissue water. In one example, said wavelengths are chosen from three primary bands of wavelengths of approximately 1100-1350 nm, approximately 1500-1800 nm, and approximately 2000-2300 nm. Optionally, measurements of the additional camera are utilized by the computer as values indicative of the hydration level of the user.

The following are examples of embodiments that utilize additional inputs to generate feature values used to detect the abnormal medical event. In one embodiment, the computer receives a value indicative of a temperature of the user's body, and generates at least one of the feature values based on the received value. In another embodiment, the computer receives a value indicative of a movement of the user's body, and generates at least one of the feature values based on the received value. For example, the computer may receive the input form a head-mounted Inertial Measurement Unit (IMU) that includes a combination of accelerometers, gyroscopes, and optionally magnetometers, and/or an IMU in a mobile device carried by the user. In yet another embodiment, the computer receives a value indicative of an orientation of the user's head, and generates at least one of the feature values based on the received value. For example, the computer may receive the values indicative of the head's orientation from an outward-facing head-mounted camera, and/or from a nearby non-wearable video camera. In still another embodiment, the computer receives a value indicative of consumption of a substance by the user, and generates at least one of the feature values based on the received value. Optionally, the substance comprises a vasodilator and/or a vasoconstrictor.

The model utilized to detect the abnormal medical event may be generated, in some embodiments, based on data obtained from one or more users, corresponding to times in which the one or more users were not affected by the abnormal medical event, and additional data obtained while the abnormal medical event occurred and/or following that time. Thus, this training data may reflect PPG signals and/or blood flow both at normal times, and changes to PPG signals and/or blood flow that may ensue due to the abnormal medical event. This data may be used to generate samples, each sample including feature values generated based on PPG signals of a user and optionally additional data (as described above), and a label. The PPG signals include PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user at a certain time, and optionally previous PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, taken before the certain time. The label is a value related to the status of the abnormal medical event. For example, the label may be indicative of whether the user, at the certain time, experienced the abnormal medical event. In another example, the label may be indicative of the extent or severity of the abnormal medical event at the certain time. In yet another example, the label may be indicative of the duration until an onset of the abnormal medical event. In still another example, the label may be indicative of the duration that has elapsed since the onset of the abnormal medical event.

In some embodiments, the model used by the computer to detect the abnormal medical event from measurements of a certain user may be generated, at least in part, based on data that includes previous measurements of the certain user (and as such, may be considered personalized to some extent for the certain user). Additionally or alternatively, in some embodiments, the model may be generated based on data of other users. Optionally, the data used to train the model may include data obtained from a diverse set of users (e.g., users of different ages, weights, sexes, preexisting medical conditions, etc.). Optionally, the data used to train the model which is used to detect the abnormal medical event with a certain user includes data of other users with similar characteristics to the certain user (e.g., similar weight, age, sex, height, and/or preexisting condition).

In order to achieve a robust model, which may be useful for detecting the abnormal medical event for a diverse set of conditions, in some embodiments, the samples used for the training of the model may include samples based on data collected when users were in different conditions. Optionally, the samples are generated based on data collected on different days, while indoors and outdoors, and while different environmental conditions persisted. In one example, the model is trained on samples generated from a first set of training data taken during daytime, and is also trained on other samples generated from a second set of training data taken during nighttime. In a second example, the model is trained on samples generated from a first set of training data taken while users were exercising and moving, and is also trained on other samples generated from a second set of data taken while users were sitting and not exercising.

Utilizing the model to detect the abnormal medical event may involve the computer performing various operations, depending on the type of model. The following are some examples of various possibilities for the model and the type of calculations that may be accordingly performed by the computer, in some embodiments, in order to calculate a value indicative of whether the user was experiencing the abnormal medical event: (a) the model comprises parameters of a decision tree. Optionally, the computer simulates a traversal along a path in the decision tree, determining which branches to take based on the feature values. A value indicative of whether the user was experiencing the abnormal medical event may be obtained at the leaf node and/or based on calculations involving values on nodes and/or edges along the path; (b) the model comprises parameters of a regression model (e.g., regression coefficients in a linear regression model or a logistic regression model). Optionally, the computer multiplies the feature values (which may be considered a regressor) with the parameters of the regression model in order to obtain the value indicative of whether the user was experiencing the abnormal medical event; and/or (c) the model comprises parameters of a neural network. For example, the parameters may include values defining at least the following: (i) an interconnection pattern between differ-

ent layers of neurons, (ii) weights of the interconnections, and (iii) activation functions that convert each neuron's weighted input to its output activation. Optionally, the computer provides the feature values as inputs to the neural network, computes the values of the various activation functions and propagates values between layers, and obtains an output from the network, which is the value indicative of whether the user was experiencing the abnormal medical event.

In some embodiments, a machine learning approach that may be applied to calculating a value indicative of whether the user is experiencing an abnormal medical event may be characterized as "deep learning". In one embodiment, the model may include parameters describing multiple hidden layers of a neural network. Optionally, the model may include a convolution neural network (CNN). In one example, the CNN may be utilized to identify certain patterns in video images, such as the patterns of corresponding to blood volume effects and ballistocardiographic effects of the cardiac pulse. Due to the fact that calculating a value indicative of whether the user is experiencing the abnormal medical event may be based on multiple, possibly successive, images that display a certain pattern of change over time (i.e., across multiple frames), these calculations may involve retaining state information that is based on previous images. Optionally, the model may include parameters that describe an architecture that supports such a capability. In one example, the model may include parameters of a recurrent neural network (RNN), which is a connectionist model that captures the dynamics of sequences of samples via cycles in the network's nodes. This enables RNNs to retain a state that can represent information from an arbitrarily long context window. In one example, the RNN may be implemented using a long short-term memory (LSTM) architecture. In another example, the RNN may be implemented using a bidirectional recurrent neural network architecture (BRNN).

The following method for detecting an abnormal medical event may be used by systems modeled according to FIG. **1***a* or FIG. **1***b*. The steps described below may be performed by running a computer program having instructions for implementing the method. Optionally, the instructions may be stored on a computer-readable medium, which may optionally be a non-transitory computer-readable medium. In response to execution by a system including a processor and memory, the instructions cause the system to perform the following steps:

In Step 1, measuring, utilizing at least one right-side head-mounted device, at least two signals indicative of photoplethysmographic signals (PPG_{SR1} and PPG_{SR2}, respectively) at first and second regions of interest (ROI_{R1} and ROI_{R2}, respectively) on the right side of a user's head. ROI_{R1} and ROI_{R2} are located at least 2 cm apart.

In Step 2, measuring, utilizing at least one left-side head-mounted device, at least two signals indicative of photoplethysmographic signals (PPG_{SL1} and PPG_{SL2}, respectively) at first and second regions of interest (ROI_{L1} and ROI_{L2}, respectively) on the left side of the user's head. ROI_{L1} and ROI_{L2} are located at least 2 cm apart.

And in Step 3, detecting the abnormal medical event based on an asymmetrical change to blood flow recognizable in PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}, relative to a baseline based on previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, taken before the abnormal medical event.

In some embodiments, detecting the abnormal medical event is done utilizing a machine learning-based approach. Optionally, the method includes the following steps: generating feature values based on data comprising: (i) PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, and (ii) the previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user; and utilizing a model to calculate, based on the feature values, a value indicative of whether the user is experiencing the abnormal medical event.

The following is description of additional aspects of embodiments of systems configured to detect an abnormal medical event, as well as additional embodiments for various systems that may detect physiological responses based on thermal measurements and/or other sources of data.

"Visible-light camera" refers to a non-contact device designed to detect at least some of the visible spectrum, such as a video camera with optical lenses and CMOS or CCD sensor. A "thermal camera" refers herein to a non-contact device that measures electromagnetic radiation having wavelengths longer than 2500 nanometer (nm) and does not touch its region of interest (ROI). A thermal camera may include one sensing element (pixel), or multiple sensing elements that are also referred to herein as "sensing pixels", "pixels", and/or focal-plane array (FPA). A thermal camera may be based on an uncooled thermal sensor, such as a thermopile sensor, a microbolometer sensor (where microbolometer refers to any type of a bolometer sensor and its equivalents), a pyroelectric sensor, or a ferroelectric sensor.

A reference to a "camera" herein may relate to various types of devices. In one example, a camera may be a visible-light camera. In another example, a camera may capture light in the ultra-violet range. In another example, a camera may capture near infrared radiation (e.g., wavelengths between 750 and 2000 nm). And in still another example, a camera may be a thermal camera.

In some embodiments, a device, such as a camera, may be positioned such that it occludes an ROI on the user's face, while in other embodiments, the device may be positioned such that it does not occlude the ROI. Sentences in the form of "the system/camera does not occlude the ROI" indicate that the ROI can be observed by a third person located in front of the user and looking at the ROI, such as illustrated by all the ROIs in FIG. **23** and FIG. **27**. Sentences in the form of "the system/camera occludes the ROI" indicate that some of the ROIs cannot be observed directly by that third person, such as ROIs **19** and **37** that are occluded by the lenses in FIG. **17***a*, and ROIs **97** and **102** that are occluded by cameras **91** and **96**, respectively, in FIG. **25**. Additionally, when the context is clear, an ROI (region of interest) may be referred to as a "region" (which is on the body or face of the user).

Although many of the disclosed embodiments can use occluding cameras (with or without a light source) successfully, in certain scenarios, such as when using an HMS on a daily basis and/or in a normal day-to-day setting, using cameras that do not occlude their ROIs on the face may provide one or more advantages to the user, to the HMS, and/or to the cameras, which may relate to one or more of the following: esthetics, better ventilation of the face, reduced weight, simplicity to wear, and reduced likelihood to being tarnished.

The term "inward-facing head-mounted camera" refers to a camera configured to be worn on a user's head and to remain pointed at its ROI, which is on the user's face, also when the user's head makes angular and lateral movements (such as movements with an angular velocity above 0.1 rad/sec, above 0.5 rad/sec, and/or above 1 rad/sec). A head-mounted camera (which may be inward-facing and/or

outward-facing) may be physically coupled to a frame worn on the user's head, may be attached to eyeglass using a clip-on mechanism (configured to be attached to and detached from the eyeglasses), may be physically coupled to a hat or a helmet, or may be mounted to the user's head using any other known device that keeps the camera in a fixed position relative to the user's head also when the head moves. Sentences in the form of "camera physically coupled to the frame" mean that the camera moves with the frame, such as when the camera is fixed to (or integrated into) the frame, or when the camera is fixed to (or integrated into) an element that is physically coupled to the frame.

Sentences in the form of "a frame configured to be worn on a user's head" or "a frame worn on a user's head" refer to a mechanical structure that loads more than 50% of its weight on the user's head. For example, an eyeglasses frame may include two temples connected to two rims connected by a bridge; the frame in Oculus Rift™ includes the foam placed on the user's face and the straps; and the frames in Google Glass™ and Spectacles by Snap Inc. are similar to eyeglasses frames. Additionally or alternatively, the frame may connect to, be affixed within, and/or be integrated with, a helmet (e.g., sports, motorcycle, bicycle, and/or combat helmets) and/or a brainwave-measuring headset.

When a camera is inward-facing and head-mounted, challenges faced by systems known in the art that are used to acquire images, which include non-head-mounted cameras, may be simplified and even eliminated with some of the embodiments described herein. Some of these challenges may involve dealing with complications caused by movements of the user, image registration, ROI alignment, tracking based on hot spots or markers, and motion compensation.

In various embodiments, cameras are located close to a user's face, such as at most 2 cm, 5 cm, 10 cm, 15 cm, or 20 cm from the face. The distance from the face/head in sentences such as "a camera located less than 10 cm from the face/head" refers to the shortest possible distance between the camera and the face/head. The head-mounted cameras used in various embodiments may be lightweight, such that each camera weighs below 10 g, 5 g, 1 g, and/or 0.5 g.

The following figures show various examples of HMSs equipped with head-mounted cameras. FIG. **17***a* illustrates various inward-facing head-mounted cameras coupled to an eyeglasses frame **15**. Cameras **10** and **12** capture regions **11** and **13** on the forehead, respectively. Cameras **18** and **36** capture regions on the periorbital areas **19** and **37**, respectively. The HMS further includes an optional computer **16**, which may include a processor, memory, a battery and/or a communication module. FIG. **17***b* illustrates a similar HMS in which inward-facing head-mounted cameras **48** and **49** capture regions **41** and **41**, respectively. Cameras **22** and **24** capture regions **23** and **25**, respectively. Camera **28** captures region **29**. And cameras **26** and **43** capture regions **38** and **39**, respectively.

FIG. **18** illustrates inward-facing head-mounted cameras coupled to an augmented reality device such as Microsoft HoloLens™. FIG. **19** illustrates head-mounted cameras coupled to a virtual reality device such as Facebook's Oculus Rift™. FIG. **20** is a side view illustration of head-mounted cameras coupled to an augmented reality device such as Google Glass™. FIG. **21** is another side view illustration of head-mounted cameras coupled to a sunglasses frame.

FIG. **22** to FIG. **25** illustrate HMSs configured to capture various ROIs relevant to some of the embodiments describes herein. FIG. **22** illustrates a frame **35** that mounts inward-facing head-mounted cameras **30** and **31** that capture regions **32** and **33** on the forehead, respectively. FIG. **23** illustrates a frame **75** that mounts inward-facing head-mounted cameras **70** and **71** that capture regions **72** and **73** on the forehead, respectively, and inward-facing head-mounted cameras **76** and **77** that capture regions **78** and **79** on the upper lip, respectively. FIG. **24** illustrates a frame **84** that mounts inward-facing head-mounted cameras **80** and **81** that capture regions **82** and **83** on the sides of the nose, respectively. And FIG. **25** illustrates a frame **90** that includes (i) inward-facing head-mounted cameras **91** and **92** that are mounted to protruding arms, and capture regions **97** and **98** on the forehead, respectively, (ii) inward-facing head-mounted cameras **95** and **96**, which are also mounted to protruding arms, which capture regions **101** and **102** on the lower part of the face, respectively, and (iii) head-mounted cameras **93** and **94** that capture regions on the periorbital areas **99** and **100**, respectively.

FIG. **26** to FIG. **29** illustrate various inward-facing head-mounted cameras having multi-pixel sensors (FPA sensors), configured to capture various ROIs relevant to some of the embodiments describes herein. FIG. **26** illustrates head-mounted cameras **120** and **122** that capture regions **121** and **123** on the forehead, respectively, and head-mounted camera **124** that captures region **125** on the nose. FIG. **27** illustrates head-mounted cameras **126** and **128** that capture regions **127** and **129** on the upper lip, respectively, in addition to the head-mounted cameras already described in FIG. **26**. FIG. **28** illustrates head-mounted cameras **130** and **132** that capture larger regions **131** and **133** on the upper lip and the sides of the nose, respectively. And FIG. **29** illustrates head-mounted cameras **134** and **137** that capture regions **135** and **138** on the right and left cheeks and right and left sides of the mouth, respectively, in addition to the head-mounted cameras already described in FIG. **28**.

In some embodiments, the head-mounted cameras may be physically coupled to the frame using a clip-on device configured to be attached/detached from a pair of eyeglasses in order to secure/release the device to/from the eyeglasses, multiple times. The clip-on device holds at least an inward-facing camera, a processor, a battery, and a wireless communication module. Most of the clip-on device may be located in front of the frame (as illustrated in FIG. **30***b*, FIG. **31***b*, and FIG. **34**), or alternatively, most of the clip-on device may be located behind the frame, as illustrated in FIG. **33***b* and FIG. **32***b*.

FIG. **30***a*, FIG. **30***b*, and FIG. **30***c* illustrate two right and left clip-on devices **141** and **142**, respectively, configured to attached/detached from an eyeglasses frame **140**. The clip-on device **142** includes an inward-facing head-mounted camera **143** pointed at a region on the lower part of the face (such as the upper lip, mouth, nose, and/or cheek), an inward-facing head-mounted camera **144** pointed at the forehead, and other electronics **145** (such as a processor, a battery, and/or a wireless communication module). The clip-on devices **141** and **142** may include additional cameras illustrated in the drawings as black circles.

FIG. **31***a* and FIG. **31***b* illustrate a clip-on device **147** that includes an inward-facing head-mounted camera **148** pointed at a region on the lower part of the face (such as the nose), and an inward-facing head-mounted camera **149** pointed at the forehead. The other electronics (such as a processor, a battery, and/or a wireless communication module) is located inside the box **150**, which also holds the cameras **148** and **149**.

FIG. **33***a* and FIG. **33***b* illustrate two right and left clip-on devices **160** and **161**, respectively, configured to be attached

behind an eyeglasses frame **165**. The clip-on device **160** includes an inward-facing head-mounted camera **162** pointed at a region on the lower part of the face (such as the upper lip, mouth, nose, and/or cheek), an inward-facing head-mounted camera **163** pointed at the forehead, and other electronics **164** (such as a processor, a battery, and/or a wireless communication module). The clip-on devices **160** and **161** may include additional cameras illustrated in the drawings as black circles.

FIG. **32***a* and FIG. **32***b* illustrate a single-unit clip-on device **170**, configured to be attached behind an eyeglasses frame **176**. The single-unit clip-on device **170** includes inward-facing head-mounted cameras **171** and **172** pointed at regions on the lower part of the face (such as the upper lip, mouth, nose, and/or cheek), inward-facing head-mounted cameras **173** and **174** pointed at the forehead, a spring **175** configured to apply force that holds the clip-on device **170** to the frame **176**, and other electronics **177** (such as a processor, a battery, and/or a wireless communication module). The clip-on device **170** may include additional cameras illustrated in the drawings as black circles.

FIG. **34** illustrates two right and left clip-on devices **153** and **154**, respectively, configured to attached/detached from an eyeglasses frame, and having protruding arms to hold the inward-facing head-mounted cameras. Head-mounted camera **155** captures a region on the lower part of the face, head-mounted camera **156** captures a region on the forehead, and the left clip-on device **154** further includes other electronics **157** (such as a processor, a battery, and/or a wireless communication module). The clip-on devices **153** and **154** may include additional cameras illustrated in the drawings as black circles.

It is noted that the elliptic and other shapes of the ROIs in some of the drawings are just for illustration purposes, and the actual shapes of the ROIs are usually not as illustrated. It is possible to calculate the accurate shape of an ROI using various methods, such as a computerized simulation using a 3D model of the face and a model of a head-mounted system (HMS) to which a camera is physically coupled, or by placing a LED instead of the sensor, while maintaining the same field of view (FOV) and observing the illumination pattern on the face. Furthermore, illustrations and discussions of a camera represent one or more cameras, where each camera may have the same FOV and/or different FOVs. Unless indicated to the contrary, the cameras may include one or more sensing elements (pixels), even when multiple sensing elements do not explicitly appear in the figures; when a camera includes multiple sensing elements then the illustrated ROI usually refers to the total ROI captured by the camera, which is made of multiple regions that are respectively captured by the different sensing elements. The positions of the cameras in the figures are just for illustration, and the cameras may be placed at other positions on the HMS.

Sentences in the form of an "ROI on an area", such as ROI on the forehead or an ROI on the nose, refer to at least a portion of the area. Depending on the context, and especially when using a camera having a small number of pixels, the ROI may cover another area (in addition to the area). For example, a sentence in the form of "an ROI on the nose" may refer to either: 100% of the ROI is on the nose, or some of the ROI is on the nose and some of the ROI is on the upper lip.

Various embodiments described herein involve detections of physiological responses based on user measurements. Some examples of physiological responses include stress, an allergic reaction, an asthma attack, a stroke, congestive heart failure, dehydration, intoxication (including drunkenness), a headache (which includes a migraine), and/or fatigue. Other examples of physiological responses include manifestations of fear, startle, sexual arousal, anxiety, joy, pain or guilt. Still other examples of physiological responses include physiological signals such as cardiovascular parameters (such as heart rate, blood pressure, and/or cardiac output), temperature, values of eye-related parameters (such as eye movements and/or pupil diameter), values of speech related parameters (such as frequencies and/or tempo), and/or values of respiratory related parameters (such as respiration rate, tidal volume, and/or exhale duration) of the user. Optionally, detecting a physiological response may involve one or more of the following: determining whether the user has/had the physiological response, identifying an imminent attack associated with the physiological response, and/or calculating the extent of the physiological response.

In some embodiments, detection of the physiological response is done by processing measurements that fall within a certain window of time that characterizes the physiological response. For example, depending on the physiological response, the window may be five seconds long, thirty seconds long, two minutes long, five minutes long, fifteen minutes long, or one hour long. Detecting the physiological response may involve analysis of measurements taken during multiple of the above-described windows, such as measurements taken during different days. In some embodiments, a computer may receive a stream of measurements, taken while the user wears an HMS with coupled cameras and/or other sensors during the day, and periodically evaluate measurements that fall within a sliding window of a certain size.

In some embodiments, models are generated based on measurements taken over long periods. Sentences of the form of "measurements taken during different days" or "measurements taken over more than a week" are not limited to continuous measurements spanning the different days or over the week, respectively. For example, "measurements taken over more than a week" may be taken by eyeglasses equipped with cameras and/or other sensors, which are worn for more than a week, 8 hours a day. In this example, the user is not required to wear the eyeglasses while sleeping in order to take measurements over more than a week. Similarly, sentences of the form of "measurements taken over more than 5 days, at least 2 hours a day" refer to a set comprising at least 10 measurements taken over 5 different days, where at least two measurements are taken each day at times separated by at least two hours.

Utilizing measurements taken over a long period (e.g., measurements taken on "different days") may have an advantage, in some embodiments, of contributing to the generalizability of a trained model. Measurements taken over the long period likely include measurements taken in different environments, and/or measurements taken while the measured user was in various physiological and/or mental states (e.g., before/after meals, and/or while the measured user was sleepy/energetic/happy/depressed, etc.). Training a model on such data can improve the performance of systems that utilize the model in the diverse settings often encountered in real-world use (as opposed to controlled laboratory-like settings). Additionally, taking the measurements over the long period may have the advantage of enabling collection of a large amount of training data that is required for some machine learning approaches (e.g., "deep learning").

Detecting the physiological response may involve performing various types of calculations by a computer.

Optionally, detecting the physiological response may involve performing one or more of the following operations: comparing measurements to a threshold (when the threshold is reached that may be indicative of an occurrence of the physiological response), comparing measurements to a reference time series, and/or by performing calculations that involve a model trained using machine learning methods. Optionally, the measurements upon which the one or more operations are performed are taken during a window of time of a certain length, which may optionally depend on the type of physiological response being detected. In one example, the window may be shorter than one or more of the following durations: five seconds, fifteen seconds, one minute, five minutes, thirty minutes, one hour, four hours, one day, or one week. In another example, the window may be longer than one or more of the aforementioned durations. Thus, when measurements are taken over a long period, such as measurements taken over a period of more than a week, detection of the physiological response at a certain time may be done based on a subset of the measurements that falls within a certain window near the certain time; the detection at the certain time does not necessarily involve utilizing all values collected throughout the long period.

In some embodiments, detecting the physiological response of a user may involve utilizing baseline measurement values, most of which were taken when the user was not experiencing the physiological response. Optionally, detecting the physiological response may rely on observing a change to typical measurement value at one or more ROIs (the baseline), where different users might have different typical measurement values at the ROIs (i.e., different baselines). Optionally, detecting the physiological response may rely on observing a change to a baseline level, which is determined based on previous measurements taken during the preceding minutes and/or hours.

In some embodiments, detecting a physiological response involves determining the extent of the physiological response, which may be expressed in various ways that are indicative of the extent of the physiological response, such as: (i) a binary value indicative of whether the user experienced, and/or is experiencing, the physiological response, (ii) a numerical value indicative of the magnitude of the physiological response, (iii) a categorial value indicative of the severity/extent of the physiological response, (iv) an expected change in measurements of an ROI, and/or (v) rate of change in measurements of an ROI. Optionally, when the physiological response corresponds to a physiological signal (e.g., a heart rate, a breathing rate, or an extent of frontal lobe brain activity), the extent of the physiological response may be interpreted as the value of the physiological signal.

One approach for detecting a physiological response, which may be utilized in some embodiments, involves comparing measurements of one or more ROIs to a threshold. In these embodiments, the computer may detect the physiological response by comparing the measurements, and/or values derived therefrom (e.g., a statistic of the measurements and/or a function of the measurements), to the threshold to determine whether it is reached. Optionally, the threshold may include a threshold in the time domain, a threshold in the frequency domain, an upper threshold, and/or a lower threshold. When a threshold involves a certain change to a value (such as temperature or heart rate), the certain change may be positive or negative. Different physiological responses described herein may involve different types of thresholds, which may be an upper threshold (where reaching the threshold means≥the threshold) or a lower threshold (where reaching the threshold means≤the threshold).

Another approach for detecting a physiological response, which may be utilized in some embodiments, may be applicable when the measurements of a user are treated as time series data. In some embodiments, the computer may compare measurements (represented as a time series) to one or more reference time series that correspond to periods of time in which the physiological response occurred. Additionally or alternatively, the computer may compare the measurements to other reference time series corresponding to times in which the physiological response did not occur. Optionally, if the similarity between the measurements and a reference time series corresponding to a physiological response reaches a threshold, this is indicative of the fact that the measurements correspond to a period of time during which the user had the physiological response. Optionally, if the similarity between the measurements and a reference time series that does not correspond to a physiological response reaches another threshold, this is indicative of the fact that the measurements correspond to a period of time in which the user did not have the physiological response. Time series analysis may involve various forms of processing involving segmenting data, aligning data, clustering, time warping, and various functions for determining similarity between sequences of time series data. Some of the techniques that may be utilized in various embodiments are described in Ding, Hui, et al. "Querying and mining of time series data: experimental comparison of representations and distance measures." Proceedings of the VLDB Endowment 1.2 (2008): 1542-1552, and in Wang, Xiaoyue, et al. "Experimental comparison of representation methods and distance measures for time series data." Data Mining and Knowledge Discovery 26.2 (2013): 275-309.

Herein, "machine learning" methods refers to learning from examples using one or more approaches. Optionally, the approaches may be considered supervised, semi-supervised, and/or unsupervised methods. Examples of machine learning approaches include: decision tree learning, association rule learning, regression models, nearest neighbors classifiers, artificial neural networks, deep learning, inductive logic programming, support vector machines, clustering, Bayesian networks, reinforcement learning, representation learning, similarity and metric learning, sparse dictionary learning, genetic algorithms, rule-based machine learning, and/or learning classifier systems.

Herein, a "machine learning-based model" is a model trained using machine learning methods. For brevity's sake, at times, a "machine learning-based model" may simply be called a "model". Referring to a model as being "machine learning-based" is intended to indicate that the model is trained using machine learning methods (otherwise, "model" may also refer to a model generated by methods other than machine learning).

In some embodiments, which involve utilizing a machine learning-based model, a computer is configured to detect the physiological response by generating feature values based on the measurements (and possibly other values), and/or based on values derived therefrom (e.g., statistics of the measurements). The computer then utilizes the machine learning-based model to calculate, based on the feature values, a value that is indicative of whether, and/or to what extent, the user is experiencing (and/or is about to experience) the physiological response. Optionally, calculating said value is considered "detecting the physiological

response". Optionally, the value calculated by the computer is indicative of the probability that the user has/had the physiological response.

Herein, feature values may be considered input to a computer that utilizes a model to perform the calculation of a value, such as the value indicative of the extent of the physiological response mentioned above. It is to be noted that the terms "feature" and "feature value" may be used interchangeably when the context of their use is clear. However, a "feature" typically refers to a certain type of value, and represents a property, while "feature value" is the value of the property with a certain instance (sample). For example, a feature may be temperature at a certain ROI, while the feature value corresponding to that feature may be 36.9° C. in one instance and 37.3° C. in another instance.

In some embodiments, a machine learning-based model used to detect a physiological response is trained based on data that includes samples. Each sample includes feature values and a label. The feature values may include various types of values. At least some of the feature values of a sample are generated based on measurements of a user taken during a certain period of time. Optionally, some of the feature values may be based on various other sources of information described herein. The label is indicative of a physiological response of the user corresponding to the certain period of time. Optionally, the label may be indicative of whether the physiological response occurred during the certain period, and/or the extent of the physiological response during the certain period. Additionally or alternatively, the label may be indicative of how long the physiological response lasted. Labels of samples may be generated using various approaches, such as self-report by users, annotation by experts that analyze the training data, automatic annotation by a computer that analyzes the training data and/or analyzes additional data related to the training data, and/or utilizing additional sensors that provide data useful for generating the labels. It is to be noted that herein when it is stated that a model is trained based on certain measurements, it means that the model was trained on samples comprising feature values generated based on the certain measurements and labels corresponding to the certain measurements. Optionally, a label corresponding to a measurement is indicative of the physiological response at the time the measurement was taken.

Various types of feature values may be generated based on measurements and/or changes to the measurements. In order to better detect physiological responses that take some time to manifest, in some embodiments, some feature values may describe measurements at a certain ROI at different points of time. Optionally, these feature values may include various functions and/or statistics of the measurements such as minimum/maximum measurement values and/or average values during certain windows of time.

It is to be noted that when it is stated that feature values are generated based on data comprising multiple sources, it means that for each source, there is at least one feature value that is generated based on that source (and possibly other data). Optionally, a sample is considered generated based on measurements of a user when it includes feature values generated based on the measurements of the user.

In addition to feature values that are generated based on measurements, in some embodiments, at least some feature values utilized by a computer (e.g., to detect a physiological response or train a mode) may be generated based on additional sources of data that may affect the user's measurements. Some examples of the additional sources include: (i) measurements of the environment such as temperature, humidity level, noise level, elevation, air quality, a wind speed, precipitation, and infrared radiation; (ii) contextual information such as the time of day (e.g., to account for effects of the circadian rhythm), day of month (e.g., to account for effects of the lunar rhythm), day in the year (e.g., to account for seasonal effects), and/or stage in a menstrual cycle; and/or (iii) information about the user being measured such as sex, age, weight, height, and/or body build. It is noted that the feature values may be generated based on physiological signals of the user obtained by one or more sensors, such as a visible-light camera, a thermal camera, a microphone, a head-mounted accelerometer, an eye-tracker, a photoplethysmogram (PPG) sensor, an electrocardiogram (ECG) sensor, an electroencephalography (EEG) sensor, a galvanic skin response (GSR) sensor, and/or a thermistor.

The machine learning-based model used to detect a physiological response may be trained, in some embodiments, based on data collected in day-to-day, real world scenarios. As such, the data may be collected at different times of the day, while users perform various activities, and in various environmental conditions. Utilizing such diverse training data may enable a trained model to be more resilient to the various effects different conditions can have on the values of the user measurements, and consequently, be able to achieve better detection of the physiological response in real world day-to-day scenarios.

Since real world day-to-day conditions are not the same all the time, sometimes detection of the physiological response may be hampered by what is referred to herein as "confounding factors". Some examples of confounding factors include: (i) environmental phenomena such as direct sunlight, air conditioning, and/or wind; (ii) things that are on the user's face, which are not typically there and/or do not characterize the faces of most users (e.g., cosmetics, ointments, sweat, hair, facial hair, skin blemishes, acne, inflammation, piercings, body paint, and food leftovers); (iii) physical activity that may affect the user's heart rate, blood circulation, and/or blood distribution (e.g., walking, running, jumping, and/or bending over); (iv) consumption of substances to which the body has a physiological response, such as various medications, alcohol, caffeine, tobacco, and/or certain types of food; and/or (v) disruptive facial movements (e.g., frowning, talking, eating, drinking, sneezing, and coughing).

Occurrences of confounding factors may not always be easily identified in the measurements. Thus, in some embodiments, systems may incorporate measures designed to accommodate for the confounding factors. In some embodiments, these measures may involve generating feature values that are based on additional sensors, other than the sensor affected gy the confounding factors. In some embodiments, these measures may involve refraining from detecting the physiological response, which should be interpreted as refraining from providing an indication that the user has the physiological response.

Training data used to train a model for detecting a physiological response may include, in some embodiments, a diverse set of samples corresponding to various conditions, some of which involve occurrence of confounding factors (when there is no physiological response, and/or when there is a physiological response). Having samples in which a confounding factor occurs can lead to a model that is less susceptible to wrongfully detect the physiological response (which may be considered an occurrence of a false positive) in real world situations.

When a model is trained with training data comprising samples generated from measurements of multiple users, the

model may be considered a general model. When a model is trained with training data comprising at least a certain proportion of samples generated from measurements of a certain user, and/or when the samples generated from the measurements of the certain user are associated with at least a certain proportion of weight in the training data, the model may be considered a personalized model for the certain user. Optionally, the personalized model for the certain user provides better results for the certain user, compared to a general model that was not personalized for the certain user. Optionally, personalized model may be trained based on measurements of the certain user, which were taken while the certain user was in different situations; for example, train the model based on measurements taken while the certain user had a headache/epilepsy/stress/anger attack, and while the certain user did not have said attack. Additionally or alternatively, the personalized model may be trained based on measurements of the certain user, which were taken over a duration long enough to span different situations; examples of such long enough durations may include: a week, a month, six months, a year, and three years.

Training a model that is personalized for a certain user may require collecting a sufficient number of training samples that are generated based on measurements of the certain user. Thus, initially detecting the physiological response with the certain user may be done utilizing a general model, which may be replaced by a personalized model for the certain user, as a sufficiently large number of samples are generated based on measurements of the certain user. Another approach involves gradually modifying a general model based on samples of the certain user in order to obtain the personalized model.

After a model is trained, the model may be provided for use by a system that detects the physiological response. Providing the model may involve performing different operations. In one embodiment, providing the model to the system involves forwarding the model to the system via a computer network and/or a shared computer storage medium (e.g., writing the model to a memory that may be accessed by the system that detects the physiological response). In another embodiment, providing the model to the system involves storing the model in a location from which the system can retrieve the model, such as a database and/or a cloud-based storage from which the system may retrieve the model. In still another embodiment, providing the model involves notifying the system regarding the existence of the model and/or regarding an update to the model. Optionally, this notification includes information needed in order for the system to obtain the model.

A model for detecting a physiological response may include different types of parameters. Following are some examples of various possibilities for the model and the type of calculations that may be accordingly performed by a computer in order to detect the physiological response: (a) the model comprises parameters of a decision tree. Optionally, the computer simulates a traversal along a path in the decision tree, determining which branches to take based on the feature values. A value indicative of the physiological response may be obtained at the leaf node and/or based on calculations involving values on nodes and/or edges along the path; (b) the model comprises parameters of a regression model (e.g., regression coefficients in a linear regression model or a logistic regression model). Optionally, the computer multiplies the feature values (which may be considered a regressor) with the parameters of the regression model in order to obtain the value indicative of the physiological response; and/or (c) the model comprises parameters of a neural network. For example, the parameters may include values defining at least the following: (i) an interconnection pattern between different layers of neurons, (ii) weights of the interconnections, and (iii) activation functions that convert each neuron's weighted input to its output activation. Optionally, the computer provides the feature values as inputs to the neural network, computes the values of the various activation functions and propagates values between layers, and obtains an output from the network, which is the value indicative of the physiological response.

A user interface (UI) may be utilized, in some embodiments, to notify the user and/or some other entity, such as a caregiver, about the physiological response, and/or present an alert responsive to an indication that the extent of the physiological response reaches a threshold. The UI may include a screen to display the notification and/or alert, a speaker to play an audio notification, a tactile UI, and/or a vibrating UI. In some embodiments, "alerting" about a physiological response of a user refers to informing about one or more of the following non-limiting examples: the occurrence of a physiological response that the user does not usually have (e.g., a stroke, intoxication, and/or dehydration), an imminent physiological response (e.g., an allergic reaction, an epilepsy attack, and/or a migraine), and an extent of the physiological response reaching a threshold (e.g., stress and/or blood pressure reaching a predetermined level).

Due to the mostly symmetric nature of the human body, when the face undergoes temperature changes, e.g., due to external factors such as the temperature in the environment or internal factors such as an activity-related rise in body temperature, the changes to the face are generally symmetric. That is, the temperature changes at a region of interest (ROI) on the left side of the face (e.g., the left side of the forehead) are usually similar to the temperature changes at the symmetric ROI on the right side of the face (e.g., the right side of the forehead). However, when the temperature on the face changes in an asymmetric way, this can be indicative of various physiological responses and/or undesirable phenomena. Some examples of phenomena that may be identified by detecting asymmetric thermal patterns ("thermal asymmetry") on a user's face include some types of strokes. In the case of stroke, often the decreased blood flow in certain regions of the head (due to the stroke) can cause a decrease in the cutaneous temperatures near those certain regions.

Some embodiments utilize head-mounted sensors in order to detect stroke signs that involve detectable changes in temperature and/or blood flow due to a stroke event.

In some embodiments, "stroke symptoms" refers to changes to function/sensation reported by the patient. In some embodiments, "stroke signs" refers to objective changes observable by a human individual and/or a sensor. Detecting stroke symptoms and/or stroke signs may also be referred to herein as detecting "whether the user has suffered from a stroke". It is to be noted that a detection that the user has suffered from a stroke may be interpreted, in some cases, as indicating that there is a higher than normal risk that the user has suffered from a stroke, and that certain actions should be taken (such as further investigation of the user's state by other means or seeking medical attention). Thus, in some embodiments, detection by the computer that the user has suffered from a stroke may serve as an initial step that triggers further steps for diagnosing the user's condition and not a definitive final step in diagnosing the user's state.

In some embodiments, a system configured to detect a stroke based on thermal measurements includes at least one

inward-facing head-mounted thermal camera (CAM) and computer. The at least one CAM is/are configured to take thermal measurements of at least first and second regions on the right and left sides of the head (TH_{R1} and TH_{L1}, respectively) of a user. Optionally, the at least one CAM is located below the first and second regions, and does not occlude the first and second regions. The computer is configured to detect, based on TH_{R1} and TH_{L1}, whether the user has suffered a stroke. Optionally, detecting whether the user has suffered from a stroke refers to a recent stroke event, such as an ischemic or hemorrhagic stroke event that started a short while before TH_{R1} and TH_{L} were taken, where "a short while" may be a period between minutes and several hours before TH_{R1} and TH_{L1} were taken. In this scenario, detection that the user has suffered from a stroke may enable an intervention that can reduce the permanent damage of the stroke. Additionally detecting whether the user has suffered from a stroke may also refer, in some embodiments, to earlier stroke events, which occurred more than six hours before TH_{R1} and TH_{L1} were taken.

The first and second regions of which measurements are taken may include portions of various parts of the head. For example, in different embodiments, the first and second regions may cover a portion of at least one of the following pairs of regions: the right and left sides of the forehead, the right and left temples, the right and left cheeks, the right and left earlobes, behind the right and left ears, periorbital areas around the right and left eyes, the area of the right and left mastoid processes.

In one embodiment, each of the at least one CAM is physically coupled to a frame worn on a user's head, and is located less than 15 cm, 5 cm, or 2 cm from the user's face. In another embodiment, the at least one CAM is physically coupled to a clip-on, and the clip-on comprises a body configured to be attached and detached, multiple times, from a frame configured to be worn on the user's head. FIG. **30***a* to FIG. **34** illustrate various examples of embodiments of systems that include a clip-on which may have the at least one CAM coupled thereto.

In one embodiment, due to the angle between the optical axis of a certain CAM from among the at least one CAM and the Frankfort horizontal plane, the Scheimpflug principle may be employed in order to capture sharper images with the certain CAM. For example, when the user wears a frame to which the certain CAM is coupled, the certain CAM has a certain tilt greater than 20 between its sensor and lens planes, in order to capture the sharper images. Additional details regarding application of the Scheimpflug are provided herein further below.

The at least one CAM may be a single CAM, in one embodiment, such as a single FPA that captures images that include a portion of both sides of the forehead. In this embodiment, TH_{R1} and TH_{L1} include measurements that cover portions of the left side and right side of user's forehead, respectively. Optionally, TH_{R1} and TH_{L1} may be measured by different subsets of pixels of the FPA. An example of a single thermal camera that may be utilized to measure TH_{R1} and TH_{L1} is camera **149** illustrated in FIG. **31***a*, which in this example, is an inward-facing head-mounted thermal camera. Another example, of a system that includes a single thermal camera is illustrated in FIG. **3**, which illustrates a user wearing glasses with a single thermal sensor **605** that measures ROIs **606***a* and **606***b* on the right and left of the forehead, respectively. The user in the figure has already been affected by a stroke, as is evident by the lower temperature detected on the left side of the forehead and the drooping of the left side of the face.

In other embodiments, the at least one CAM may include two or more CAMs. Optionally, the at least one CAM includes two CAMs, denoted CAM**1** and CAM**2**. Optionally, CAM**1** and CAM**2** are located at least 0.5 cm to the right and to the left of the vertical symmetry axis that divides the face, respectively. Optionally, each of CAM**1** and CAM**2** weighs below 10 g, 5 g, or 1 g.

FIG. **4** illustrates one example of a system for detecting a stroke that includes at least CAM**1** and CAM**2** described above. The figure illustrates a user wearing a frame with CAM**1** and CAM**2** (**562** and **563**, respectively) coupled thereto, which measure ROIs on the right and left cheeks (ROIs **560** and **561**, respectively). The measurements indicate that the left side of the face is colder than the right side of the face. Based on these measurements, and possibly additional data, the system detects the stroke and issues an alert. Optionally, the user's facial expression is slightly distorted and asymmetric, and a video camera provides additional data in the form of images that may help in detecting the stroke.

FIG. **22** to FIG. **25** illustrate HMSs that may be used to detect a stroke that include two or more CAMs. FIG. **22** illustrates inward-facing head-mounted cameras **30** and **31** that measure regions **32** and **33** on the forehead, respectively. FIG. **25** illustrates (i) inward-facing head-mounted cameras **91** and **92** that are mounted to protruding arms and measure regions **97** and **98** on the forehead, respectively, (ii) inward-facing head-mounted cameras **95** and **96**, which are also mounted to protruding arms, which measure regions **101** and **102** on the lower part of the face, respectively, and (iii) head-mounted cameras **93** and **94** that measure regions on the periorbital areas **99** and **100**, respectively.

Depending on the locations the at least first and second regions on the right and left sides of the head, CAM**1** and CAM**2** mentioned above may be located in specific locations with respect to the face. In one example, CAM**1** and CAM**2** are located outside the exhale stream of the mouth and/or the exhale streams of the nostrils. In another example, each of CAM**1** and CAM**2** is located less than 10 cm from the face and there are angles greater than 200 between the Frankfort horizontal plane and the optical axes of CAM**1** and CAM**2**.

Measurements of additional regions on the head may be used to detect whether the user suffered from a stroke. In one embodiment, the at least one CAM is further configured to take thermal measurements of at least third and fourth regions on the right and left sides of the head (TH_{R2} and TH_{L2}, respectively), and the computer is further configured to detect whether the user has suffered a stroke also based on TH_{R2} and TH_{L2} (in addition to TH_{R1} and TH_{L1}). Optionally, the middles of the first and second regions are at least 1 cm above the middles of the third and fourth regions, respectively. Optionally, the third and fourth regions cover at least a portion of one of the following pairs of regions (which is not covered by the first and second regions): the right and left sides of the forehead, the right and left temples, the right and left cheeks, the right and left earlobes, behind the right and left ears, periorbital areas around the right and left eyes, the area of the right and left mastoid processes.

In one embodiment, the system optionally includes at least one outward-facing head-mounted thermal camera (CAM_{out}), which is configured to take thermal measurements of the environment (TH_{ENV}). Optionally, the computer is further configured to also utilize $TH_{EN}V$ (in addition to TH_{R1} and TH_{L1}) to detect whether the user has suffered a stroke.

There are various approaches that may be used by the computer, in different embodiments, to detect based on TH_{R1}

and TH_{L1} whether the user has suffered a stroke. In some embodiments, detecting whether the user has suffered a stroke involves comparing TH_{R1} and TH_{L1} (referred to as current measurements) to previously taken thermal measurements (previous measurements), such as previously taken TH_{R1} and TH_{L1} of the user. Optionally, the previous measurements are taken at least fifteen minutes before the current measurements. Optionally, the previous measurements are taken at least one hour before the current measurements. Optionally, the previous measurements are taken at least one six hours before the current measurements. Optionally, the previous measurements are taken at least one day before the current measurements.

In some embodiments, the previous measurements are taken over a long period and are used to calculate baseline thermal values of regions of the face, and/or used to generate various models, which are used to detect a stroke, as discussed below. It is to be noted that discussion below regarding detection of the stroke based on TH_{R1} and TH_{L1} can be generalized to involve thermal measurements of other regions (such as TH_{R2} and TH_{L2} discussed above).

In one embodiment, the computer calculates a magnitude of thermal asymmetry of the head of the user based on a difference between TH_{R1} and TH_{L1}, and compares the magnitude to a threshold. Responsive to the magnitude reaching the threshold, the computer detects that the user has suffered a stroke. Optionally, the difference between TH_{R1} and TH_{L1} needs to have reached the threshold (i.e., equal the threshold value or exceed it) for at least a predetermined minimal duration, such as at least one minute, at least five minutes, at least fifteen minutes, or at least some other period that is greater than 30 minutes. Optionally, the threshold is calculated based on previous magnitudes of thermal asymmetry of the head of the user, which were calculated based on previously taken TH_{R1} and TH_{L1} of the user. Thus, this threshold may be set according to a baseline thermal asymmetry that represents the typical difference in the temperatures of the first and second regions; a stroke may be detected when the thermal asymmetry becomes significantly different from this baseline.

In another embodiment, the computer calculates feature values and utilizes a model to calculate, based on the feature values, a value indicative of whether the user has suffered a stroke. At least some of the feature values are generated based on TH_{R1} and TH_{L1} of the user; examples of feature values that may be generated are given in the discussion regarding feature values that may be generated to detect a physiological response (herein suffering from a stroke is considered a type of physiological response). Optionally, at least some feature values are generated based on additional sources of information (other than the at least one CAM), such as additional thermal cameras, additional sensors that measure physiological signals of the user (e.g., heart rate or galvanic skin response), and/or additional sensors that measure the environment. Optionally, one or more of the feature values are indicative of the extent of difference between TH_{R1} and TH_{L1} of the user and previous TH_{R1} and TH_{L1} of the user, taken at least a certain period earlier (such as at least fifteen minutes earlier, one hour earlier, a day earlier, or more than a day earlier). Thus, these one or more feature values may represent a difference between the current thermal measurements and baseline thermal values for the first and second regions. Optionally, the model is generated based on data that includes previously taken TH_{R1} and TH_{L1} of the user and/or other users. Optionally, when data includes previously taken TH_{R1} and TH_{L1} of other users, at least some of the measurements of the other users were taken while they did not suffer from a stroke, and at least some of the measurements of the other users were taken while they did suffer from a stroke.

In another embodiment, the computer calculates a value indicative of a joint probability of TH_{R1} and TH_{L1} based on a model that includes distribution parameters calculated based on previously taken TH_{R1} and TH_{L1} of the user. Thus, the model describes a typical distribution of thermal measurements on regions of the user's head (when the user did not suffer from a stroke). The computer may compare the value indicative of the joint probability to a threshold, and responsive to the value being below the threshold, the computer detects that the user has suffered a stroke. The threshold may represent an atypical thermal asymmetry, with very low probability to normally occur, which warrants an alert of the possibility that the user has had a stroke.

In some embodiments described herein, detecting whether the user has suffered a stroke may involve calculating a change to thermal asymmetry on the head based on a change between thermal measurements taken at different times. This calculation can be performed in different ways, as described below.

In one embodiment, the computer calculates the change between the thermal measurements as follows: calculate a temperature difference between the first and second regions at time x (ΔT_x) based on [TH_{R1} and TH_{L1}] taken at time x, calculate a temperature difference between the first and second regions at time y (ΔT_y) based on [TH_{R1} and TH_{L1}] taken at time y, and calculate the output indicative of the change in the thermal asymmetry on the face based on a difference between ΔT_x and ΔT_y.

The embodiment described above may optionally be implemented using a differential amplifier that receives TH_{R1} and TH_{L1} as inputs, and outputs the temperature difference between the first and second regions. Optionally, the at least one CAM is/are based on thermopile sensors. Alternatively, the at least one CAM is/are based on pyroelectric sensors. In one example, pairs of thermal sensor elements are wired as opposite inputs to a differential amplifier in order for the thermal measurements to cancel each other and thereby remove the average temperature of the field of view from the electrical signal. This allows the at least one CAM to be less prone to providing false indications of temperature changes in the event of being exposed to brief flashes of radiation or field-wide illumination. This embodiment may also minimize common-mode interference, and as a result improve the accuracy of the thermal cameras.

In another embodiment, the computer calculates the change between the thermal measurements as follows: the computer calculates a temperature change between TH_{R1} taken at times t_1 and t_2 (ΔTH_{R1}), calculates a temperature change between TH_{L1} taken at times t_1 and t_2 (ΔTH_{L1}), and then calculates the output indicative of the thermal asymmetry on the face based on a difference between ΔTH_{R1} and ΔTH_{L1}.

It is noted that sentences such as "calculate a difference between X and Y" or "detect a difference between X and Y" may be achieved by any function that is proportional to the difference between X and Y.

The detection of a stroke based on TH_{R1} on TH_{L1}, and optionally other inputs, such as additional thermal measurements or additional physiological signals, may be sufficient, in some embodiments, to prompt the computer to take an action such as alerting the user, a caregiver, and/or emergency services. In other embodiments, the detection may be considered an indication that there is a risk that the user has

suffered a stroke, and the computer may encourage the user to take a test (e.g., the FAST test described below or portions thereof), in order to validate the detection. Optionally, measurements and/or results taken during the test may be used in addition to TH_{R1} and TH_{L1} and the optional additional inputs, or instead of that data, in order to make a second, more accurate detection of whether the user has suffered from a stroke.

Upon detecting that the user has suffered from a stroke, in some embodiments, the computer may prompt the user to take a test to validate and/or increase the confidence in the detection. This test may involve performing one or more steps of a FAST test. Herein, FAST is an acronym used as a mnemonic to help detect and enhance responsiveness to the needs of a person having a stroke. The acronym stands for Facial drooping, Arm weakness, Speech difficulties and Time to call emergency services. Facial drooping involves a section of the face, usually only on one side, that is drooping and hard to move (often recognized by a crooked smile). Arm weakness typically involves an inability to raise one's arm fully. Speech difficulties typically involve an inability or difficulty to understand or produce speech.

FIG. **5** to FIG. **8** illustrate physiological and behavioral changes that may occur following a stroke, which may be detected using embodiments described herein. FIG. **5** illustrates a person at time zero, at the very beginning of the onset of the stroke. At this time there may be no detectable signs of the stroke. FIG. **6** illustrates the person's state after 5 minutes since the beginning of the stroke. By this time, certain changes to the blood flow in the head, which were caused by the stroke, may be detectable. For example, the blood flow on one side of the face may decrease. FIG. **7** illustrates the person's state 15 minutes after the beginning of the stroke. At this time, temperature changes to regions of the face, which are due to the changes in blood flow, may be detectable. FIG. **8** illustrates the person's state 45 minutes after the beginning of the stroke. At this time, droopiness of one side of the face (e.g., due to reduced blood flow and impaired neurologic control) may be observable.

The following are some examples of steps that may be taken to further diagnose whether the user has suffered from a stroke (e.g., steps from a FAST test). Optionally, results of these steps may be used to further strengthen the computer's detection (e.g., to increase confidence in the detection) or change the detection (e.g., and decide the detection was a false alarm). Optionally, upon determining, based on one or more of the steps, that the user may have a suffered a stroke, the computer performs at least one of the following steps: (i) instruct the user to seek emergency medical assistance, (ii) connect the user through live video chat with a medical specialist, and (iii) automatically alert a predetermined person and/or entity about the user's condition.

In one embodiment, a camera (e.g., a cellphone camera or an inward-facing camera coupled to a frame worn by the user) takes images of at least a portion of the user's face. Optionally, the computer is further configured to (i) instruct the user, via a user interface, to smile and/or stick out the tongue, and (ii) detect, based on analysis of the images taken by the camera, whether a portion of one side of the user's face droops and/or whether the user was able to stick out the tongue. Detecting that the portion of the one side of the user's face droops may be done based on a comparison of the images of at least a portion of the user's face to previously taken images of at least the portion of the user's face, which were taken at least one hour before. Optionally, the computer utilizes a machine learning based model to determine whether the comparison indicates that the face droops. In this case, the model may be trained based on sets of images that include before and after images of people who suffered a stroke. Additionally or alternatively, detecting that the portion of the one side of the user's face droops is done using a machine learning-based model trained on examples of images of faces of people with a portion of one side of the face drooping. Optionally, detecting whether the tongue is sticking out may be done using image analysis and/or machine learning approaches (e.g., utilizing a model trained on previous images of the user and/or other users sticking out their tongue). FIG. **9** illustrates a user who is requested by a smartphone app to smile. Images of the user may be taken by the smartphone and analyzed in order to determine whether the user has smiled and/or to what extent the smile is considered "normal". Similarly, FIG. **10** illustrates a user who is requested by a smartphone app to stick out his tongue.

In another embodiment, a microphone is used to record the user's speech. The computer is configured to (i) instruct the user, via a user interface, to speak (e.g., say a predetermined phrased), and (ii) detect, based on analysis of a recording of the user taken by the microphone, whether the user's speech is slurred, and/or whether a difference between the recording and previous recordings of the user exceeds a threshold that indicates excessively slurred or difficult. Optionally, the computer uses a model trained based on examples of peoples' normal and incoherent speech (e.g., recordings of people before and after they had a stroke). FIG. **11** illustrates a user who is requested by a smartphone app to say a sentence. The user's speech can be recorded by the smartphone and analyzed to detect slurry and/or uncharacteristic speech.

In yet another embodiment, a sensor is used to take measurements indicative of at least one of movement and position, of at least one of the user's arms. Optionally, the computer is further configured to (i) instruct the user, via a user interface, to raise at least one the arms, and (ii) detect, based on analysis of the measurements taken by the sensor, whether an arm of the user drifts downward. In one example, the sensor is in a cellphone held by the user. In another example, the sensor is in a smartwatch or bracelet on the user's wrist. In still another example, the sensor is embedded in a garment worn by the user. FIG. **12** illustrates a user who is requested by a smartphone app to raise his arms. The user's movements can be detected by the smartphone in order to determine whether one arm falls. In the illustrated example, the user may be requested to raise the arms at least twice, each time holding the phone in a different hand. Such measurements can serve as a baseline to compare the rate of ascent and descent of each of the arms.

In still another embodiment, a sensor is used to take measurements indicative of how the user walks. Optionally, the computer is further configured to (i) instruct the user, via a user interface, to walk, and (ii) detect, based on analysis of the measurements taken by the sensor, whether a difference between the measurements taken by the sensor and previous measurements of the user taken by the sensor exceeds a threshold. Optionally, exceeding the threshold is indicative of a sudden loss of balance or coordination. In one example, the sensor is coupled to a frame worn on the user's head (e.g., a glasses frame). In another example, the sensor is in a cellphone, smartwatch, bracelet, garment, or shoe worn by the user.

Early detection of a stroke, e.g., using one or more of the approaches described above, can be essential for minimizing the stroke-related damage. With strokes, it is certainly the case that time is of the essence. Early administration of

treatment (e.g., within a few hours) can in many cases lead to minimal long term stroke-related damage. However, following a certain window of time (e.g., six hours since the start of the stroke), severe and irreversible long term damage may occur; impacting both quality of life and cost of care. FIG. **13** and FIG. **14** illustrate the difference between a timely intervention and intervention that comes too late. In FIG. **13**, a patient arrives a short while (about an hour and fifteen minutes) after beginning of a stroke. This patient has moderate stroke damage (denoted by reference numeral **655**). Intervention at this early stage is mostly successful, and after two months the patient has only slight long term damage (denoted by reference numeral **656**), which involves a relatively small impact on the quality of life and a relatively low cost in terms of future medical expenses. FIG. **14** illustrates a case in which the patient arrives too late (e.g., six hours after the start of the stroke). In this scenario, the patient already has more severe stroke damage (denoted by reference numeral **657**). Intervention at this late stage is mostly unsuccessful. Two months later, there is severe long term stroke-related damage, which involves a relatively large impact on the quality of life and a relatively high cost in terms of future medical expenses.

In addition to detecting a stroke, some embodiments may be used to detect an occurrence of a migraine attack. In one embodiment, the first and second regions are located above the user's eye level, and the computer is further configured to detect occurrence of a migraine attack based on asymmetry between TH_{R1} and TH_{L1}. In another embodiment, the first and second regions are located above the user's eye level. The computer is further configured to generate feature values based on TH_{R1} and TH_{L1}, and to utilize a model to calculate, based on the feature values, a value indicative of whether the user is experiencing a migraine attack or whether a migraine attack is imminent. Optionally, the model if generated based on previous TH_{R1} and TH_{L} of the user taken while the user had a migraine attack or taken 30 minutes or less before the user had a migraine attack.

In some embodiments, a system configured to detect a stroke based on asymmetric changes to blood flow includes at least first and second devices and a computer. The first and second devices are located to the right and to the left of the vertical symmetry axis that divides the face of a user, respectively; the first and second devices are configured to measure first and second signals (S_{BF1} and S_{BF2}, respectively) indicative of blood flow in regions to right and to the left of the vertical symmetry axis. The computer detects whether the user has suffered a stroke based on an asymmetric change to blood flow, which is recognizable in S_{BF1} and S_{BF2}. Optionally, the system includes a frame configured to be worn on a user's head, and the first and second devices are head-mounted devices that are physically coupled to the right and left sides of the frame, respectively.

The first and second devices may be devices of various types. Optionally, the first and second devices are the same type of device. Alternatively, the first and second devices may be different types of devices. The following are some examples of various types of devices that can be used in embodiments described herein in order to measure a signal indicative of blood flow in a region of the body of the user.

In one embodiment, the first and second devices comprise first and second cameras, respectively. The first and second cameras are based on sensors comprising at least 3×3 pixels configured to detect electromagnetic radiation having wavelengths in at least a portion of the range of 200 nm to 1200 nm. Optionally, the asymmetric changes to blood flow lead to asymmetric facial skin color changes to the face of the user. Optionally, the system includes first and second active light sources configured to illuminate the first and second regions, respectively. In one example, the first and second devices and first and second active light sources are head-mounted, and the first and second active light sources are configured to illuminate the first and second regions with electromagnetic radiation having wavelengths in at least a portion of the range of 800 nm to 1200 nm.

In addition to the first and second cameras mentioned above, some embodiments may include first and second outward-facing cameras that take images of the environment to the right and left of the user's head, respectively. Optionally, the computer utilizes the images to detect whether the user has suffered a stroke. Optionally, the images of the environment are indicative of illumination towards the face, images taken by the inward-facing cameras are indicative of reflections from the face. Thus, the images of the environment may be used to account, at least in part, for variations in ambient light that may cause errors in detections of blood flow.

In another embodiment, the first and second devices function as imaging photoplethysmography devices, and/or the first and second devices function as pulse oximeters.

There are various types of devices that may be used in embodiments described herein, and ways in which the devices may be attached to the user and/or located the user's proximity. In one example, the first and second device may be head-mounted devices, such as devices physically coupled to a frame worn on the user's head (e.g., a frame of smartglasses, such as augmented reality glasses, virtual reality glasses, or mixed reality glasses). In another example, the first and second devices are embedded in a garment worn by the user (e.g., a smart shirt) or some other wearable accessory (e.g., a necklace, bracelets, etc.). In yet another, the first and second devices may be located in headrests of a chair in which the user sits. In still another example, the first and second devices are attached to walls (e.g., of a vehicle cabin in which the user sits or a room in which the user spends time). In yet another example, the first and second devices may be coupled to robotic arms. Optionally, the robotic arms may be used to move and/or orient the devices in order to account for the user's movements, which may enable the first and second devices to measure the same regions on the user's head despite the user's movement.

The first and second devices may be utilized to measure various regions on the right and left sides of the user's head. In one embodiment, the regions on the right and left sides include portions of the right and left temples, respectively. In another embodiment, the regions on the right and left sides include portions of the right and left sides of the forehead, respectively. Optionally, the center of the region on the right is at least 3 cm from the center of the region on the left. In still another embodiment, the regions on the right and left sides include portions of the right and left cheeks, respectively. In still another embodiment, the regions on the right and left sides include areas behind the right and left ears, respectively. Optionally, the areas behind the right and left ears are below the hairline and cover at least a portion of the mastoid process in their respective sides of the head.

FIG. **15***a* illustrates an embodiment of a system that includes multiple pairs of right and left cameras, and locations on the face that they may be used to measure. The cameras illustrated in the figure are coupled to a frame worn by the user, which may be, for example, any of the cameras mentioned herein. The illustrated example include: (i) cameras **641***a* and **641***b* that are coupled to the right and left sides of the top of the frame, respectively, which measure ROIs

644*a* and **644***b* on the right and left of the forehead, respectively; (ii) cameras **642***a* and **642***b* that are coupled to the right and left sides of the bottom of the frame, respectively, which measure ROIs **645***a* and **645***b* on the right and left cheeks, respectively; and (iii) cameras **643***a* and **643***b* that are coupled to the frame near the right and left sides of the nose, respectively, which measure ROIs **646***a* and **646***b* in the right and left periorbital regions, respectively.

FIG. **15***b* illustrates a stroke sign **647**, which involves decreased blood flow in the forehead, and may be detected using the system illustrated in FIG. **15***a*. Another stroke sign that may be detected by the system illustrated in FIG. **15***c* is stroke sign **648**, which involves decreased temperature in the periorbital region.

FIG. **16***a* illustrates a system in which the first and second devices are head-mounted cameras that are located behind the ears. The figure illustrates cameras **651**, which may be a downward-facing video camera that takes images that include portions of the side of the neck. FIG. **16***b* illustrates a variant of the system illustrated in FIG. **16***a* in which camera **652** is a downward-facing camera that includes an extender body which enables the camera to move beyond the hairline in order to obtain unobstructed images of the side of the neck.

FIG. **16***c* illustrates ischemic stroke **650**, which restricts the blood flow to the side of the head (illustrated as patch **653**), which may be detected based on measurements of device **652** in order to alert about the user having suffered from a stroke.

Various types of values, which are indicative of blood flow (and taken by the first or second devices), can be determined based on a signal, which is denoted S_{BF} in the discussion below. S_{BF} may be, for example, aforementioned S_{BF1} or S_{BF2}. Propagation of a cardiac pulse wave can lead to changes in the blood flow, with increased blood flow as a result of blood pumped during the systole, and lower blood flow at other times (e.g., during diastole). The changes in blood flow often manifest as changes to values in S_{BF}. For example, higher blood flow may correspond to increased intensity of certain colors of pixels (when S_{BF} includes images), temperatures of pixels (when S_{BF} includes thermal images), or increased absorption of certain wavelengths (when S_{BF} includes measurements of a photoplethysmography device).

In some embodiments, calculating a statistic of S_{BF} may provide an indication of the extent of the blood flow. For example, the statistic may be an average value (e.g., average pixel values), which is a calculated over a period, such as ten seconds, thirty seconds, or a minute. For example, in an embodiment in which the devices are cameras and S_{BF} includes images, the average hue of pixels in the images can be indicative of the blood flow (e.g., a redder hue may correspond to more intense blood flow). In an embodiment in which the devices are thermal sensors and S_{BF} includes thermal images, the average temperature of pixels in the thermal images can be indicative of the blood flow (e.g., a higher average temperature may correspond to more intense blood flow).

In other embodiments, analysis of propagation of cardiac pulse waves, as manifested in the values of S_{BF}, can be used to provide indications of the extent of blood flow. When S_{BF} includes multiple pixels values (e.g., images or thermal images), propagation of a pulse wave typically involves an increase in pixel values that correspond to a period of a high blood flow during the pulse wave (e.g., when blood flow is driven by a systole) followed by a decrease in pixel values that correspond to a period of a lower blood flow during the pulse wave (e.g., decreasing towards a diastolic trough). The speed at which the pulse wave propagates along a segment of the images of S_{BF} is indicative of the speed of blood flow in the segment depicted in the images. For example, the speed at which a peak (e.g., corresponding to the systole) is seen to propagate in the images is directly correlated with the blood flow.

Another parameter indicative of blood flow that can be derived from analysis of a propagation of a pulse wave, as it is manifested in values of S_{BF}, is the amplitude of the signal. For example, signals that display a periodic increase and decrease in values of S_{BF}, which corresponds to the heart rate, can be analyzed to determine the difference in values (e.g., difference in color, temperature, or intensity) between the peak and the trough observed in the values of S_{BF} during the transition of a pulse wave. In some embodiments, the amplitude of the signal (e.g., the difference between the value at the peak and the value at the trough) is correlated with the blood flow. In one example, the higher the amplitude of the signal, the higher the blood flow.

Another parameter indicative of blood flow that can be derived from analysis of a propagation of a pulse wave, as it is manifested in values of S_{BF}, is the extent to which pixels in images (or thermal images) display a periodic change to their values that reaches a certain threshold. For example, the area on the face in which the periodic facial skin color changes (which correspond to the cardiac pulse) reach a certain threshold is correlated with the blood flow. The higher the blood flow, the larger the area.

The extent of Blood flow (e.g., the speed at which the blood flows) is correlated with the times at which a pulse wave is detected at different locations of the body. Typically, the farther a location from the heart, the later the pulse wave is detected (e.g., detection of a pulse wave may correspond to the time at which a systolic peak is observed). This phenomenon can be utilized, in some embodiments, to calculate values indicative of blood flow based on the difference in times at which pulse waves are detected at different locations. For example, analysis of one or more S_{BF} signals, which include values that are indicative of propagation of a pulse wave at various locations, can determine the difference in time (Δt) between detection of a pulse wave at different locations. The value of Δt is typically correlated with the blood flow: the higher the blood flow, the smaller Δt is expected to be.

The computer is configured, in some embodiments, to detect whether the user has suffered a stroke based on an asymmetric change to blood flow, which is recognizable in S_{BF1} and S_{BF2}.

Herein, sentences of the form "asymmetric change to blood flow recognizable in S_{BF1} and S_{BF2}" refer to effects of blood flow that may be identified and/or utilized by the computer, which are usually not recognized by the naked eye (in the case of images), but are recognizable algorithmically when the signal values are analyzed. For example, blood flow may cause facial skin color changes (FSCC) that corresponds to different concentrations of oxidized hemoglobin due to varying blood pressure caused by the cardiac pulse. Similar blood flow dependent effects may be viewed with other types of signals (e.g., slight changes in cutaneous temperatures due to the flow of blood.

When the blood flow on both sides of the head and/or body are monitored, asymmetric changes may be recognized. These changes are typically different from symmetric changes that can be caused by factors such as physical activity (which typically effects the blood flow on both sides in the same way). An asymmetric change to the blood flow

can mean that one side has been affected by an event, such as a stroke, which does not influence the other side. In one example, the asymmetric change to blood flow comprises a change in blood flow velocity on left side of the face that is 10% greater or 10% lower than a change in blood flow velocity on one right side of the face. In another example, the asymmetric change to blood flow comprises a change in the volume of blood the flows during a certain period in the left side of the face that is 10% greater or 10% lower than the volume of blood that flows during the certain period in the right side of the face. In yet another example, the asymmetric change to blood flow comprises a change in the direction of the blood flow on one side of the face (e.g., as a result of a stroke), which is not observed at the symmetric location on the other side of the face.

In some embodiments, the computer detects whether the user has suffered a stroke based on a comparison between values belonging to a current set of S_{BF1} and S_{BF2} and values belonging to a previous set of S_{BF1} and S_{BF2} of the user. Optionally, the previous set was measured at least fifteen minutes before the current set, at least one hour before the current set, or at least one day before the current set. Optionally, the previous set serves to establish baseline blood flow values for both regions when the user was assumed not to be effected by a stroke.

In one embodiment, the computer uses a machine learning model to detect whether the user has suffered a stroke. Optionally, the computer is configured to: generate feature values based on data comprising a current set of S_{BF1} and S_{BF2} and a previous set of S_{BF1} and S_{BF2} of the user, and utilize the model to calculate, based on the feature values, a value indicative of whether the user has suffered a stroke. Optionally, the previous set was measured at least one hour before the current set. Optionally, at least some of the feature values are indicative of changes to the blood flow in each of the first and second regions between the time the current set was measured and when the previous set was measured.

In one embodiment, the model was generated based on data comprising "after" sets of S_{BF1} and S_{BF2} of other users and corresponding "before" sets of S_{BF1} and S_{BF2} of the other users. In these embodiments, the "after" sets were measured after the other users had suffered from a stroke (and the "before" sets were measured before they suffered from the stroke). Thus, training samples generated based on this data can reflect some of the types of asymmetric changes to blood flow that characterize suffering from a stroke.

In the event that a stroke is detected, the computer may prompt the user to take a FAST test (or portions thereof), as described above. In another example, the computer may suggest to the user to take images of the retinas. In this example, the computer is further configured to compare the images of the retinas with previously taken images of the retinas of the user, and to detect whether the user has suffered a stroke based on the comparison. Optionally, the comparison can take into account diameter of retinal arteries, swelling and blurring of the boundaries of the optic disk.

Blood flow usually exhibits typical patterns in the user's body. When a blood flow pattern changes, this usually happens in a predictable way (e.g., increase in blood flow due to physical activity, certain emotional responses, etc.). When a person's blood flow changes in an atypical way, this may indicate an occurrence of a certain medical incident, such as a stroke. Therefore, atypical blood flow patterns should be detected in order to investigate their cause.

In some embodiments, a system configured to detect an atypical blood flow pattern in the head of a user includes one or more head-mounted devices and a computer. The one or more head-mounted devices are configured to measure at least three signals (S_{BF1}, S_{BF2} and S_{BF3}, respectively), indicative of blood flow in at least three corresponding regions of interest on the head (ROI_1, ROI_2, and ROI_3, respectively) of a user. Optionally, the centers of ROI_1, ROI_2 and ROI_3 are at least 1 cm away from each other. Optionally, the one or more head-mounted devices do not occlude ROI_1, ROI_2 and ROI_3.

There are various types of devices the one or more head-mounted devices may be. Optionally, each of the one or more head-mounted devices are the same type of device. Alternatively, when the one or more head-mounted devices are a plurality of devices, the plurality of devices may be of different types of devices. The following are some examples of various types of devices that can be used in embodiments described herein in order to measure a signal indicative of blood flow in a region of the body of the user.

In one embodiment, the one or more head-mounted devices include a camera that is based on a sensor comprising at least 3×3 pixels configured to detect electromagnetic radiation having wavelengths in at least a portion of the range of 200 nm to 1200 nm. Optionally, the system includes one or more light sources configured to ROI_1, ROI_2 and ROI_3. Optionally, the one or more light sources are configured to illuminate ROI_1, ROI_2 and ROI_3 with electromagnetic radiation having wavelengths in at least a portion of the range of 800 nm to 1200 nm.

In another embodiment, the one or more head-mounted devices include a device that functions as an imaging photoplethysmography device and/or a device that functions as a pulse oximeter.

The computer is configured, in one embodiment, to generate a blood flow pattern based on a current set of S_{BF1}, S_{BF2} and S_{BF3}. The computer is also configured to calculate, based on a set of previous blood flow patterns of the user, a value indicative of the extent to which the blood flow pattern is atypical. Optionally, the set of previous blood flow patterns were generated based on sets of S_{BF1}, S_{BF2} and S_{BF3} measured at least one day prior to when the current set was measured. That is, the previous sets of blood flow patterns were generated based on data the comprises S_{BF1}, S_{BF2} and S_{BF3} measured at least one day before S_{BF1}, S_{BF2} and S_{BF3} in the current set. Optionally, the previous sets of blood flow patterns were generated based on data that was measured when the user was not known to be in an atypical condition (e.g., the user was considered healthy at the time).

In some embodiments, the value indicative of the extent to which the blood flow pattern is atypical is compared to a threshold. If the value reaches the threshold, the computer may take different actions. In one embodiment, responsive to the value reaching the threshold, the computer issues an alert. For example, the computer may send a message to a predetermined recipient (e.g., emergency services or a caregiver). In another example, the computer may command a user interface to generate an alert (e.g., a beeping sound, a text message, or vibrations. In another embodiment, responsive to the value reaching the threshold, the computer may prompt the user to perform a test, using an electronic device, to determine whether the user has suffered a stroke. For example, the user may be prompted to perform a FAST test (or portions thereof), as described elsewhere in this disclosure.

There are various ways in which a blood flow pattern may be generated based on S_{BF1}, S_{BF2} and S_{BF3}. In one embodiment, S_{BF1}, S_{BF2} and S_{BF3} themselves may constitute the pattern. Optionally, the blood flow pattern comprises a time series that is indicative of blood flow at each of ROI_1, ROI_2,

and ROI_3. In one example, the blood flow pattern may be a time series of the raw (unprocessed) values of S_{BF1}, S_{BF2} and S_{BF3} (e.g., a time series of values measured by the one or more head-mounted devices). In another example, blood flow pattern may be a time series of processed values, such as various statistics of S_{BF1}, S_{BF2} and S_{BF3} at different points of time (e.g., average pixel intensity for images taken by a camera at different points of time).

In another embodiment, the blood flow pattern may include statistics of the values of S_{BF1}, S_{BF2} and S_{BF3}, such as values representing the average blood flow during the period S_{BF1}, S_{BF2} and S_{BF3} were measured. Values in a blood flow pattern, such as the statistics of the values of S_{BF1}, S_{BF2} and S_{BF3} may be of various types of values. The following are some examples of types of values that may be used in a "blood flow pattern". In one example, the blood flow pattern includes one or more values that describe the intensity of blood flow at each of ROI_1, ROI_2, and/or ROI_3. In another example, the blood flow pattern includes one or more values that describe the amplitude of changes to measurement values at ROI_1, ROI_2, and/or ROI_3, such as the amplitude of periodic changes (which correspond to the heart rate) to color, temperature, and/or absorbance at certain wavelengths. In yet another example, the blood flow pattern includes one or more values that describe the speed at which a pulse wave propagates through ROI_1, ROI_2, and/or ROI_3. In still another example, the blood flow pattern includes one or more values that describe the direction at which a pulse wave propagates in ROI_1, ROI_2, and/or ROI_3.

There are various ways in which the computer may utilize the previous blood flow patterns in order to determine the extent to which the blood flow pattern is atypical.

In one embodiment, the computer calculates the value indicative of the extent to which the blood flow pattern is atypical by calculating distances between the blood flow pattern and each of the previous blood flow patterns, and determining a minimal value among the distances. The larger this minimal value, the more atypical the blood flow pattern may be considered (due to its difference from all previous blood flow patterns considered). In one example, in which blood flow patterns include time series data, the distances may be calculated by finding the extent of similarity between the blood flow pattern and each of the previous blood flow patterns (e.g., using methods described in in Wang, Xiaoyue, et al. "Experimental comparison of representation methods and distance measures for time series data", Data Mining and Knowledge Discovery 26.2 (2013): 275-309). In another example, distances between blood flow patterns that include dimensional data, such as blood flow patterns that may be represented as vectors of values, may be calculated using various similarity metrics known in the art such as Euclidean distances or vector dot products.

In another embodiment, the computer calculates, based on the previous sets of S_{BF1}, S_{BF2} and S_{BF3}, parameters of a probability density function (pdf) for blood flow patterns. For example, each blood flow pattern may be represented as a vector of values and the pdf may be a multivariate distribution (e.g., a multivariate Gaussian) whose parameters are calculated based on vectors of values representing the previous blood flow patterns. Given a vector of values representing the blood flow pattern, the probability of the vector of values is calculated based on the parameters of the pdf. Optionally, if the probability is below a threshold, the blood flow pattern may be considered atypical. Optionally, the threshold is determined based on probabilities calculated for the vectors of values representing the previous blood flow patterns, such the at least a certain proportion of the vectors have a probability that reaches the threshold. For example, the certain proportion may be at least 75%, at least 90%, at least 99%, or 100%.

In yet another embodiment, the computer calculates the value indicative of the extent to which the blood flow pattern is atypical using a model of a one-class classifier generated based on the set of previous blood flow patterns.

In still another embodiment, the computer calculates feature values and utilizes a model to calculate, based on the feature values, the value indicative of the extent to which the blood flow pattern is atypical. Optionally, one or more of the feature values are generated based on the blood flow pattern, and at least one of the feature values is generated based on the previous blood flow patterns. Optionally, feature values generated based on a blood flow pattern include one or more of the values described in examples given above as examples of values in a blood flow pattern. Optionally, one or more of the feature values describe differences between values representing the blood flow pattern, and values representing the previous blood flow patterns. The model is generated based on samples, with each sample comprising: (i) feature values calculated based on a blood flow pattern of a certain user, from among a plurality of users, and previous blood flow patterns of the certain user, and (ii) a label indicative of an extent to which the blood flow pattern of the certain user is atypical. Additional details regarding generating the model can be found herein in the discussion regarding machine learning approaches that may be used to detect a physiological response.

In some embodiments, the computer may use additional inputs to determine whether the blood flow pattern is an atypical blood flow pattern. In one example, the computer may receive measurements of various physiological signals (e.g., heart rate, respiration, or brain activity) and use these measurements to generate at least some of the feature values. In another example, the computer may receive an indication of a state of the user and to generate one or more of the feature values based on the indication. Optionally, the state of the user is indicative of at least one of the following: an extent of physical activity of the user, and consuming a certain substance by the user (e.g., alcohol or a drug).

The physiological and emotional state of a person can often be associated with certain cortical activity. Various phenomena, which may be considered abnormal states, such as anger or displaying symptomatic behavior of Attention Deficit Disorder (ADD) or Attention Deficit Hyperactivity Disorder (ADHD), are often associated with certain atypical cortical activity. This atypical cortical activity can change the blood flow patterns on the face, and especially on the forehead area. Thus, there is a need for a way to detect such changes in blood flow in real world day-to-day situations. Preferably, in order to be comfortable and more aesthetically acceptable, these measurements should be taken without involving direct physical contact with the forehead or occluding it.

In some embodiments, a system configured to detect an attack characterized by an atypical blood flow pattern includes the one or more head-mounted devices (described above) and a computer. The one or more head-mounted devices are configured to measure at least three signals (S_{BF1}, S_{BF2} and S_{BF3}, respectively), indicative of blood flow in at least three corresponding regions of interest on the head (ROI_1, ROI_2, and ROI_3, respectively) of a user. Optionally, the centers of ROI_1, ROI_2 and ROI_3 are at least 1 cm away from each other. Optionally, the one or more head-mounted devices do not occlude ROI_1, ROI_2 and ROI_3. Optionally,

ROI_1, ROI_2 and ROI_3 are on the same side of the face. Alternatively, ROI_1, ROI_2 and ROI_3 are on all on the same side of the face. For example, ROI_1 may be on the left side of the face, and ROI_2 on the right side of the face.

The computer is configured, in one embodiment, to calculate a value, based on S_{BF1}, S_{BF2}, and S_{BF3}, indicative of whether the user is in a normal or abnormal state.

In one embodiment, the state of the user is determined by comparing a blood flow pattern generated based on S_{BF1}, S_{BF2}, and S_{BF3} to reference blood flow patterns of the user that include at least one reference blood flow pattern that corresponds to the normal state and at least one reference blood flow pattern that corresponds to the abnormal state. Optionally, a reference blood flow pattern is determined from previous S_{BF1}, S_{BF2}, and S_{BF3} of the user, taken while the user was in a certain state corresponding to the reference blood flow pattern (e.g., normal or abnormal states). Optionally, if the similarity reaches a threshold, the user is considered to be in the state to which the reference blood flow pattern corresponds.

In another embodiment, the computer determines that the user is in a certain state (e.g., normal or abnormal) by generating feature values (at least some of which are generated based on S_{BF1}, S_{BF2}, and S_{BF3}) and utilizing a model to calculate, based on the feature values, the value indicative of whether the user is in a normal or abnormal state. Optionally, the model is trained based on samples, each comprising feature values generated based on previous S_{BF1}, S_{BF2}, and S_{BF3} of the user, taken while the user was in the certain state.

In yet another embodiment, S_{BF1}, S_{BF2}, and S_{BF3} comprise time series data, and the computer calculates the value indicative of whether the user is in a normal or abnormal state based on comparing the time series to at least first and second reference time series, each generated based on previously taken S_{BF1}, S_{BF2}, and S_{BF3} of the user; the first reference time series is based on previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was in a normal state, and the second reference time series is based on previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was in an abnormal state. Optionally, the time series data and/or the first and second reference time series includes data taken over at least a certain period of time (e.g., at least ten seconds, at least one minute, or at least ten minutes).

Being in a normal/abnormal state may correspond to different behavioral and/or physiological responses. In one embodiment, the abnormal state involves the user displaying symptoms of one or more of the following: an anger attack, Attention Deficit Disorder (ADD), and Attention Deficit Hyperactivity Disorder (ADHD). In this embodiment, being in the normal state refers to usual behavior of the user that does not involve displaying said symptoms. In another embodiment, when the user is in the abnormal state, the user will display within a predetermined duration (e.g., shorter than an hour), with a probability above a predetermined threshold, symptoms of one or more of the following: anger, ADD, and ADHD. In this embodiment, when the user is in the normal state, the user will display the symptoms within the predetermined duration with a probability below the predetermined threshold. In yet another embodiment, when the user is in the abnormal state the user suffers from a headache and/or migraine (or an onset of a migraine attack will occur is a short time such as less than one hour), and when the user is in the normal state, the user does not suffer from a headache and/or a migraine. In still another embodiment, the abnormal state refers to times in which the user has a higher level of concentration compared to the normal state that refers to time in which the user has a usual level of concentration. Although the blood flow patterns of the forehead are usually specific to the user, they are usually repetitive, and thus the system may able to learn some blood flow patterns of the user that correspond to various states.

Determining the user's state based on S_{BF1}, S_{BF2}, and S_{BF3} (and optionally other sources of data) may be done using a machine learning-based model. Optionally, the model is trained based on samples comprising feature values generated based on previous S_{BF1}, S_{BF2}, and S_{BF3} taken when the user was in a known state (e.g., for different times it was known whether the user was in the normal or abnormal state). Optionally, the user may provide indications about his/her state at the time, such as by entering values via an app when having a headache, migraine, or an anger attack. Additionally or alternatively, an observer of the user, which may be another person or a software agent, may provide the indications about the user's state. For example, a parent may determine that certain behavior patterns of a child correspond to displaying symptomatic behavior of ADHD. In another example, indications of the state of the user may be determined based on measurements of physiological signals of the user, such as measurements of the heart rate, heart rate variability, breathing rate, galvanic skin response, and/or brain activity (e.g., using EEG). Optionally, the various indications described above are used to generate labels for the samples generated based on the previous S_{BF1}, S_{BF2}, and S_{BF3}.

In some embodiments, one or more of the feature values in the samples may be based on other sources of data (different from S_{BF1}, S_{BF2}, and S_{BF3}). These may include additional physiological measurements of the user and/or measurements of the environment in which the user was while S_{BF1}, S_{BF2}, and S_{BF3} were taken. In one example, at least some of the feature values used in samples include additional physiological measurements indicative of one or more of the following signals of the user: heart rate, heart rate variability, brainwave activity, galvanic skin response, muscle activity, and extent of movement. In another example, at least some of the feature values used in samples include measurements of the environment that are indicative of one or more of the following values of the environment in which the user was in: temperature, humidity level, noise level, air quality, wind speed, and infrared radiation level.

Given a set of samples comprising feature values generated based on S_{BF1}, S_{BF2}, and S_{BF3} (and optionally the other sources of data) and labels generated based on the indications, the model can be trained using various machine learning-based training algorithms. Optionally, the model is utilized by a classifier that classifies the user's state (e.g., normal/abnormal) based on feature values generated based on S_{BF1}, S_{BF2}, and S_{BF3} (and optionally the other sources).

The model may include various types of parameters, depending on the type of training algorithm utilized to generate the model. For example, the model may include parameters of one or more of the following: a regression model, a support vector machine, a neural network, a graphical model, a decision tree, a random forest, and other models of other types of machine learning classification and/or prediction approaches.

In some embodiments, the model is trained utilizing deep learning algorithms. Optionally, the model includes parameters describing multiple hidden layers of a neural network. Optionally, the model includes a convolution neural network (CNN), which is useful for identifying certain patterns in images, such as patterns of color changes on the forehead. Optionally, the model may be utilized to identify a progres-

sion of a state of the user (e.g., a gradual forming of a certain blood flow pattern on the forehead). In such cases, the model may include parameters that describe an architecture that supports a capability of retaining state information. In one example, the model may include parameters of a recurrent neural network (RNN), which is a connectionist model that captures the dynamics of sequences of samples via cycles in the network's nodes. This enables RNNs to retain a state that can represent information from an arbitrarily long context window. In one example, the RNN may be implemented using a long short-term memory (LSTM) architecture. In another example, the RNN may be implemented using a bidirectional recurrent neural network architecture (BRNN).

In order to generate a model suitable for identifying the state of the user in real-world day-to-day situations, in some embodiments, the samples used to train the model are based on S_{BF1}, S_{BF2}, and S_{BF3} (and optionally the other sources of data) taken while the user was in different situations, locations, and/or conducting different activities. In a first example, the model may be trained based on a first set of previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was indoors and in the normal state, a second set of previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was indoors and in the abnormal state, a third set of previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was outdoors and in the normal state, and a fourth set of previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was outdoors and in the abnormal state. In a second example, the model may be trained based on a first set of previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was sitting and in the normal state, a second set of previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was sitting and in the abnormal state, a third set of previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was standing and/or moving around and in the normal state, and a fourth set of previous S_{BF1}, S_{BF2}, and S_{BF3} taken while the user was standing and/or moving around and in the abnormal state. Usually the movements while standing and/or moving around, and especially when walking or running, are greater compared to the movement while sitting; therefore, a model trained on samples taken during both sitting and standing and/or moving around is expected to perform better compared to a model trained on samples taken only while sitting.

Having the ability to determine the state of the user can be advantageous when it comes to scheduling tasks for the user and/or making recommendations for the user, which suits the user's state. In one embodiment, responsive to determining that the user is in the normal state, the computer prioritizes a first activity over a second activity, and responsive to determining that the user is in the abnormal state, the computer prioritizes the second activity over the first activity. Optionally, accomplishing each of the first and second activities requires at least a minute of the user's attention, and the second activity is more suitable for the abnormal state than the first activity. Optionally, and the first activity is more suitable for the normal state than the second activity. Optionally, prioritizing the first and second activities is performed by a calendar management program, a project management program, and/or a "to do" list program. Optionally, prioritizing a certain activity over another means one or more of the following: suggesting the certain activity before suggesting the other activity, suggesting the certain activity more frequently than the other activity (in the context of the specific state), allotting more time for the certain activity than for the other activity, and giving a more prominent reminder for the certain activity than for the other activity (e.g., an auditory indication vs. a mention in a calendar program that is visible only if the calendar program is opened).

Such state-dependent prioritization may be implemented in various scenarios. In one example, the normal state refers to a normal concentration level, the abnormal state refers to a lower than normal concentration level, and the first activity requires a high attention level from the user compared to the second activity. For instance, the first and second activities may relate to different topics of a self-learning program for school; when identifying that the user is in the normal concentration state, a math class is prioritized higher than a sports lesson; and when identifying that the user is in the lower concentration state, the math class is prioritized lower than the sports lesson. In another example, the normal state refers to a normal anger level, the abnormal state refers to a higher than normal anger level, and the first activity involves more interactions of the user with other humans compared to the second activity. In still another example, the normal state refers to a normal fear level, the abnormal state refers to a panic attack, and the second activity is expected to have a more relaxing effect on the user compared to the first activity.

Passively taken sensor based measurements may be used, in some embodiments, in order to detect whether a user exhibits stroke signs. However, in some scenarios, sensors that may be used to detect stroke signs may provide inaccurate signals that can lead to a high rate of false alarms. Detecting whether a user exhibits stroke signs can also be done by an app that prompts the user to perform one or more activities involved in a FAST test, and analyzing the user's actions while performing the one or more activities. However, apps for detecting stroke signs are often not used because the person suffering from a stroke is not aware of the incident (and thus does not initiate a test). Thus, the combination of the two approaches can increase the rate at which stroke signs may be detected based on possibly inaccurate measurements, by having the sensor measurements serve as a trigger to activate an app to prompt the user to perform the one or more activities involved in the FAST test.

In one embodiment, a system configured detect stroke signs includes at least first, second, and third sensors, and a computer.

The first and second sensors configured to take first and second measurements (M_R and M_L, respectively) of regions belonging to the right and left sides of a user's body. Optionally, M_R and M_L are indicative of blood flow in the regions on the right and left sides of the user's body, respectively. The following are examples of various types of sensors that may be used, in some embodiments, as the first and second sensors.

In one example, the first and second sensors are electroencephalography (EEG) electrodes that measure brain activity and are positioned on the right and left sides of the head, respectively. Optionally, the first and second sensors are EEG electrodes implanted under the user's scalp.

In another example, the first and second sensors are electromyography (EMG) sensors implanted in the left and right sides of the user's body, respectively. Alternatively, the first and second sensors may be EMG sensors attached to the surface of the user's body.

In yet another example, the first and second sensors may be ultrasound sensors. Optionally, the ultrasound sensors are positioned such that they are in contact with the surface of the right and left sides of the user's body respectively.

In still another example, the first and second sensors are photoplethysmogram (PPG) sensors that provide measurements indicative of the blood flow on the right and left sides of the user's body, respectively.

In yet another example, the first and second sensors comprise cameras based on a sensor comprising at least 3×3 pixels configured to detect electromagnetic radiation having wavelengths in at least a portion of the range of 200 nm to 1200 nm.

In yet another example, the first and second sensors are thermistors in contact with the right and left sides of the user's body. For example, the first and second sensors may be embedded in one or more of the following: a clothing item worn by the user, gloves, or a scarf.

And in still another example, the first and second sensors are thermal cameras each comprising at least 3×3 pixels configured to detect electromagnetic radiation having wavelengths above 2500 nm.

The computer calculates, based on M_R and M_L, a value indicative of a risk that the user has suffered from a stroke. Responsive to determining that the value reaches a threshold, the computer may instruct the user, via a user interface, to perform the predetermined activity. The computer may then detect whether the user exhibits stroke signs based on measurements (M_A) of a third sensor, which were taken while the user performed the predetermined activity. Optionally, the computer utilizes M_R and M_L along with M_A in order to make a more accurate detection of stroke signs. Optionally, detection based on M_R, M_L, and M_A is more accurate than detection based on M_R alone M_L.

Calculating the value indicative of the risk that the user has suffered from a stroke may be done in different ways in different embodiments. In one embodiment, the value indicative of the risk is indicative difference between of extents of physiological changes in the right and left sides of the body, which are calculated based on M_R and M_L, respectively. For example, the value may be indicative of a difference in blood flow between the right and left sides of the body, a difference in the temperature between the right and left sides, and/or a difference in skin color and/or extent of changes to skin color between the right and left sides. Optionally, when the difference reaches the threshold, this means that the user is at a risk of having suffered a stroke that is sufficiently high to warrant an additional test that involves performing the predetermined activity and measuring the user with the third sensor.

In another embodiment, the computer generates feature values based on M_R and M_L and utilizes a model to calculate, based on the feature values, the value indicative of the risk that the user has suffered from a stroke. Optionally, the model is generated based on previous M_R and M_L of multiple users. For example, the model may be generated based on data that comprises M_R and M_L of users who were healthy at the time the measurements were taken, and also based on M_R and M_L of users who suffered from a stroke while the measurements were taken.

There are various predetermined activities the computer may prompt the user to perform in order to detect whether the user exhibits stroke signs. These activities may be measured using different sensors. The following are examples of combinations of activities, and sensors that may be used to take the measurements M_A of the user while the user performs the activities.

In one embodiment, performing the predetermined activity comprises smiling. Optionally, in this embodiment, the third sensor is a camera. For example, the camera may be a camera embedded in a cell phone (or some other device) held by the user or some other person. In another example, the camera may be coupled to a frame worn on the user's head. In this embodiment, M_A include images of the user's face that capture the user's facial expressions while the user was instructed to smile. The computer may detect the stroke signs based on analysis of images of the user which are indicative of one side of the face drooping. Optionally, the analysis involves comparing M_A to previously taken images of the user's face.

In another embodiment, performing the predetermined activity comprises raising both arms. Optionally, in this embodiment, the third sensor is an inertial measurement unit (IMU). For example, the IMU may be embedded in a cell phone, a smart watch, or another device on worn or held by the user (e.g., on the hand, wrist, or arm). In this embodiment, the computer detects the stroke signs based on analysis of measurements of movements of the user (taken by the IMU) which are indicative of one arm drifting downward.

In yet another embodiment, performing the predetermined activity comprises walking. Optionally, in this embodiment, the third sensor is an inertial measurement unit (IMU). For example, the IMU may be coupled to a frame worn on the user's head or in a device carried by the user (e.g., a smartphone or a smartwatch). In this embodiment, computer detects the stroke signs based on analysis measurements of movements of the user (taken by the IMU) which are indicative of imbalance of the user.

In still another embodiment, performing the predetermined activity comprises repeating a phrase. Optionally, in this embodiment, the third sensor is a microphone. For example, the microphone may belong to a device carried or worn by the user (e.g., a smartphone, a smartwatch, or microphone embedded in a head-mounted display). In this embodiment, computer detects the stroke signs based on analysis of a recording of voice of the user which is indicative of the user's speech being slurry. Optionally, the analysis of the recording of the user's voice is done based on a comparison with previous recordings of the user's voice.

In some embodiments, the computer may conduct tests to determine whether the user's brain function has been affected. For example, the computer may prompt the user to perform various tasks using an app that can test for memory and cognitive skills, such as answering trivia questions, solving puzzles, etc.

In some embodiments, following the user's performance of the predetermined activity and analysis of M_A, results of the analysis may be used to improve the accuracy of the calculation of the risk. For example, responsive to determining, based on specific M_A, that the user does not exhibit stroke signs after measuring specific M_R and M_L values (which indicated that there is sufficient risk), the computer is configured to adjust the threshold based on the specific M_R and M_L values. In another example, the computer may utilize the specific M_R and M_L to retrain a model used to calculate the risk. In this example, the specific M_R and M_L can constitute an example of a false positive that is used to adjust the model parameters.

One of the signs to having a stroke is sudden loss of balance or coordination. It is easier to identify loss of balance or coordination from measurements taken by a head-mounted IMU compared to measurements taken by an IMU inside a wrist band or a phone in the hand. The reason is that the movements of the head include much less noise compared to movements of a hand that is used to manipulate items. Therefore, a head-mounted IMU can be more beneficial for identifying loss of balance or coordination than a wrist-mounted IMU.

In one embodiment, a system configured to detect a medical condition, which involves a loss of at least one of balance and coordination, includes at least a head-mounted inertial measurement unit (IMU) and a computer. Some examples of medical conditions that involve loss of balance and/or coordination include a stroke and a spell of dizziness.

The IMU is configured to measure movements of the head of a user wearing the IMU, and a computer. Optionally, the IMU comprises at least one of the following elements: an accelerometer, a gyroscope, and a magnetometer. Optionally, the IMU is coupled to a frame worn on the user's head.

The computer is configured to detect the medical condition based on measurements of the IMU ($M_{current}$) and previous measurements of movements of the head of the user wearing the IMU ($M_{previous}$). Optionally, at least some of $M_{previous}$ were taken while the user did not have the medical condition. Optionally, the computer is further configured to alert a predetermined recipient (e.g., a caregiver or emergency services) responsive to detecting the medical condition.

There are various ways in which the medical condition may be detected based on $M_{current}$ and $M_{previous}$. In one embodiment, the computer is configured to detect the medical condition by calculating a difference between movement characteristics determined based on $M_{current}$ and typical movement characteristics of the user calculated based on $M_{previous}$. Optionally, if the difference reaches a threshold, the user is considered to have the medical condition.

In another embodiment, the computer is configured to detect the medical condition by generating feature values and utilizing a model to calculate a value, based on the feature values, which is indicative of whether the user has the medical condition. Optionally, one or more of the feature values are calculated based on $M_{current}$ and the model is generated based $M_{previous}$ of the user.

In yet another embodiment, the computer is configured to detect the medical condition by generating feature values and utilizing a model to calculate a value, based on the feature values, which is indicative of whether the user has the medical condition. Optionally, one or more of the feature values are calculated based on movements of the head of one or more other users wearing an IMU.

The user's movement characteristics may be affected by various factors, as discussed below. Thus, receiving an indication of such factors that influence movement and balance can help improve accuracy of detecting the medical condition based on $M_{current}$ and $M_{previous}$. In some embodiments, the computer is further configured to receive an indication of a situation in which the user is in while $M_{current}$ are taken, and to utilize the indication to detect the medical condition.

In one embodiment, the situation comprises being under influence of a medication, and the indication of the situation is received from at least one of: a pill dispenser, a sensor-enabled pill, and a user tracking application. Examples of user tracking applications include: (i) software that requires a user to log events, such as consumption of a certain item, usage of a certain item, having a certain experience, and/or being in a certain situation, (ii) an image analysis software that receives images taken by the user or a third party nearby the user, and infers the situation from the images using image processing techniques. Examples of sources for the image include: smart-glasses with outfacing camera, augmented reality devices, mobile phones, and webcams.

In another one embodiment, the situation comprises being under influence of at least one of alcohol and caffeine, and the indication of the situation is received from at least one of: a refrigerator, a pantry, a serving robot, and a user tracking application; and wherein the indication indicates that the user took an alcoholic beverage.

In yet another embodiment, the situation comprises being under a certain stress level, and the indication of the situation is received from a sensor that measures a physiological signal of the user, such as a thermal sensor, a heart rate sensor, a sensor of galvanic skin response, or an EEG sensor.

In still another embodiment, the situation is selected from a group comprising: being inside a moving vehicle, and being on a static floor; and the indication of the situation is received from a positioning system. Examples of positioning systems include: GPS, wireless positioning systems, image processing to infer position.

Typically having a stroke will influence brain activity, which can be detected through electroencephalography (EEG). However, this signal may at times be noisy and insufficient to reliably detect a stroke. Thus, additional tests may be needed.

In one embodiment, a system configured to detect stroke signs based on electroencephalography (EEG) includes at least a sensor configured to take measurements (M_A) of the user, and a computer.

The computer is configured to: receive EEG signals of the user, and to utilize a model to calculate, based on the EEG signals, a value indicative of a risk that the user has suffered from a stroke. The value indicative of the risk is compared by the computer to a threshold, and responsive to determining that the value reaches a threshold, the computer instructs the user, via a user interface, to perform a predetermined activity. The computer then detects whether the user has stroke signs based on M_A taken while the user performed the predetermined activity. Optionally, the computer utilizes the EEG signals along with M_A in order to make a more accurate detection of stroke signs. Optionally, detection based on the EEG signals and M_A is more accurate than detection based on the EEG signals alone.

Calculating the value indicative of the risk that the user has suffered from a stroke may be done in different ways in different embodiments. In one embodiment, the value indicative of the risk is indicative difference between of extents of electrical potential changes in the right and left sides of the brain, which are calculated based on EEG signals from electrodes on the right and left sides of the head. Optionally, when the difference reaches the threshold, this means that the user is at a risk of having suffered a stroke that is sufficiently high to warrant an additional test that involves performing the predetermined activity and measuring the user with the third sensor.

In another embodiment, the computer generates feature values based on the EEG signals and utilizes a model to calculate, based on the feature values, the value indicative of the risk that the user has suffered from a stroke. Optionally, the model is generated based on previous EEG signals of multiple users. For example, the model may be generated based on data that comprises EEG signals of users who were healthy at the time the measurements were taken, and also based on EEG signals of users who suffered from a stroke while the measurements were taken.

There are various predetermined activities the computer may prompt the user to perform in order to detect whether the user exhibits stroke signs. These activities may be measured using different sensors. Examples of combinations of activities, and sensors that may be used to take the measurements M_A of the user while the user performs the activities are given above (e.g., smiling, raising hands, walking, and speaking a phrase).

In some embodiments, following the user's performance of the predetermined activity and analysis of M_A results of the analysis may be used to improve the accuracy of the calculation of the risk. For example, responsive to determining, based on specific M_A, that the user does not exhibit stroke signs after measuring specific EEG signals values (which indicated that there is sufficient risk), the computer is configured to adjust the threshold based on the specific EEG signals. In another example, the computer may utilize the specific EEG signals to retrain a model used to calculate the risk. In this example, the specific EEG signals can constitute an example of a false positive that is used to adjust the model parameters.

Normally, the lens plane and the sensor plane of a camera are parallel, and the plane of focus (PoF) is parallel to the lens and sensor planes. If a planar object is also parallel to the sensor plane, it can coincide with the PoF, and the entire object can be captured sharply. If the lens plane is tilted (not parallel) relative to the sensor plane, it will be in focus along a line where it intersects the PoF. The Scheimpflug principle is a known geometric rule that describes the orientation of the plane of focus of a camera when the lens plane is tilted relative to the sensor plane.

FIG. **35***a* is a schematic illustration of an inward-facing head-mounted camera **550** embedded in an eyeglasses frame **551**, which utilizes the Scheimpflug principle to improve the sharpness of the image taken by the camera **550**. The camera **550** includes a sensor **558** and a lens **555**. The tilt of the lens **555** relative to sensor **558**, which may also be considered as the angle between the lens plane **555** and the sensor plane **559**, is determined according to the expected position of the camera **550** relative to the ROI **552** when the user wears the eyeglasses. For a refractive optical lens, the "lens plane" **556** refers to a plane that is perpendicular to the optical axis of the lens **555**. Herein, the singular also includes the plural, and the term "lens" refers to one or more lenses. When "lens" refers to multiple lenses (which is usually the case in most modern cameras having a lens module with multiple lenses), then the "lens plane" refers to a plane that is perpendicular to the optical axis of the lens module.

The Scheimpflug principle may be used for both thermal cameras (based on lenses and sensors for wavelengths longer than 2500 nm) and visible-light and/or near-IR cameras (based on lenses and sensors for wavelengths between 400-900 nm). FIG. **35***b* is a schematic illustration of a camera that is able to change the relative tilt between its lens and sensor planes according to the Scheimpflug principle. Housing **311** mounts a sensor **312** and lens **313**. The lens **313** is tilted relative to the sensor **312**. The tilt may be fixed according to the expected position of the camera relative to the ROI when the user wears the HMS, or may be adjusted using motor **314**. The motor **314** may move the lens **313** and/or the sensor **312**.

Because the face is not planar and the inward-facing head-mounted camera is located close to the face, an image captured by a camera having a wide field of view (FOV) and a low f-number may not be perfectly sharp, even after applying the Scheimpflug principle. Therefore, in some embodiments, the tilt between the lens plane and the sensor plane is selected such as to adjust the sharpness of the various areas covered in the ROI according to their importance for detecting the user's physiological signals. In one embodiment, the ROI covers first and second areas, where the first area includes finer details and/or is more important for detecting the physiological signals than the second area. Therefore, the tilt between the lens and sensor planes is adjusted such that the image of the first area is shaper than the image of the second area.

In one embodiment, the tilt between the lens plane and sensor plane is fixed. The fixed tilt is selected according to an expected orientation between the camera and the ROI when a user wears the frame.

In another embodiment, the system includes an adjustable electromechanical tilting mechanism configured to change the tilt between the lens and sensor planes according to the Scheimpflug principle based on the orientation between the camera and the ROI when the frame is worn by the user. The tilt may be achieved using at least one motor, such as a brushless DC motor, a stepper motor (without a feedback sensor), a brushed DC electric motor, a piezoelectric motor, and/or a micro-motion motor.

Various embodiments described herein involve an HMS that may be connected, using wires and/or wirelessly, with a device carried by the user and/or a non-wearable device. The HMS may include a battery, a computer, sensors, and a transceiver.

FIG. **36***a* and FIG. **36***b* are schematic illustrations of possible embodiments for computers (**400**, **410**) that are able to realize one or more of the embodiments discussed herein that include a "computer". The computer (**400**, **410**) may be implemented in various ways, such as, but not limited to, a server, a client, a personal computer, a network device, a handheld device (e.g., a smartphone), an HMS (such as smart glasses, an augmented reality system, and/or a virtual reality system), a computing device embedded in a wearable device (e.g., a smartwatch or a computer embedded in clothing), a computing device implanted in the human body, and/or any other computer form capable of executing a set of computer instructions. Herein, an augmented reality system refers also to a mixed reality system. Further, references to a computer or processor include any collection of one or more computers and/or processors (which may be at different locations) that individually or jointly execute one or more sets of computer instructions. For example, a first computer may be embedded in the HMS that communicates with a second computer embedded in the user's smartphone that communicates over the Internet with a cloud computer.

The computer **400** includes one or more of the following components: processor **401**, memory **402**, computer readable medium **403**, user interface **404**, communication interface **405**, and bus **406**. The computer **410** includes one or more of the following components: processor **411**, memory **412**, and communication interface **413**.

Functionality of various embodiments may be implemented in hardware, software, firmware, or any combination thereof. If implemented at least in part in software, implementing the functionality may involve a computer program that includes one or more instructions or code stored or transmitted on a computer-readable medium and executed by one or more processors. Computer-readable media may include computer-readable storage media, which corresponds to a tangible medium such as data storage media, or communication media including any medium that facilitates transfer of a computer program from one place to another. Computer-readable medium may be any media that can be accessed by one or more computers to retrieve instructions, code, data, and/or data structures for implementation of the described embodiments. A computer program product may include a computer-readable medium. In one example, the computer-readable medium **403** may include one or more of the following: RAM, ROM, EEPROM, optical storage, magnetic storage, biologic storage, flash memory, or any other medium that can store computer readable data.

A computer program (also known as a program, software, software application, script, program code, or code) can be written in any form of programming language, including compiled or interpreted languages, declarative or procedural languages. The program can be deployed in any form, including as a standalone program or as a module, component, subroutine, object, or another unit suitable for use in a computing environment. A computer program may correspond to a file in a file system, may be stored in a portion of a file that holds other programs or data, and/or may be stored in one or more files that may be dedicated to the program. A computer program may be deployed to be executed on one or more computers that are located at one or more sites that may be interconnected by a communication network.

Computer-readable medium may include a single medium and/or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store one or more sets of instructions. In various embodiments, a computer program, and/or portions of a computer program, may be stored on a non-transitory computer-readable medium, and may be updated and/or downloaded via a communication network, such as the Internet. Optionally, the computer program may be downloaded from a central repository, such as Apple App Store and/or Google Play. Optionally, the computer program may be downloaded from a repository, such as an open source and/or community run repository (e.g., GitHub).

At least some of the methods described herein are "computer-implemented methods" that are implemented on a computer, such as the computer (**400**, **410**), by executing instructions on the processor (**401**, **411**). Additionally, at least some of these instructions may be stored on a non-transitory computer-readable medium.

As used herein, references to "one embodiment" (and its variations) mean that the feature being referred to may be included in at least one embodiment of the invention. Moreover, separate references to "one embodiment", "some embodiments", "another embodiment", "still another embodiment", etc., may refer to the same embodiment, may illustrate different aspects of an embodiment, and/or may refer to different embodiments.

Some embodiments may be described using the verb "indicating", the adjective "indicative", and/or using variations thereof. Herein, sentences in the form of "X is indicative of Y" mean that X includes information correlated with Y, up to the case where X equals Y. Stating that "X indicates Y" or "X indicating Y" may be interpreted as "X being indicative of Y". Additionally, sentences in the form of "provide/receive an indication indicating whether X happened" may refer herein to any indication method, including but not limited to: sending/receiving a signal when X happened and not sending/receiving a signal when X did not happen, not sending/receiving a signal when X happened and sending/receiving a signal when X did not happen, and/or sending/receiving a first signal when X happened and sending/receiving a second signal X did not happen.

Herein, "most" of something is defined as above 51% of the something (including 100% of the something). Both a "portion" of something and a "region" of something refer herein to a value between a fraction of the something and 100% of the something. For example, sentences in the form of a "portion of an area" may cover between 0.1% and 100% of the area. As another example, sentences in the form of a "region on the user's forehead" may cover between the smallest area captured by a single pixel (such as 0.1% or 5% of the forehead) and 100% of the forehead. The word "region" refers to an open-ended claim language, and a camera said to capture a specific region on the face may capture just a small part of the specific region, the entire specific region, and/or a portion of the specific region together with additional region(s).

The terms "comprises," "comprising," "includes," "including," "has," "having", or any other variation thereof, indicate an open-ended claim language that does not exclude additional limitations. The "a" or "an" is employed to describe one or more, and the singular also includes the plural unless it is obvious that it is meant otherwise. For example, "a computer" refers to one or more computers, such as a combination of a wearable computer that operates together with a cloud computer.

The phrase "based on" is intended to mean "based, at least in part, on". Additionally, stating that a value is calculated "based on X" and following that, in a certain embodiment, that the value is calculated "also based on Y", means that in the certain embodiment, the value is calculated based on X and Y.

The terms "first", "second" and so forth are to be interpreted merely as ordinal designations, and shall not be limited in themselves. A predetermined value is a fixed value and/or a value determined any time before performing a calculation that compares a certain value with the predetermined value. A value is also considered to be a predetermined value when the logic, used to determine whether a threshold that utilizes the value is reached, is known before start performing computations to determine whether the threshold is reached.

The embodiments of the invention may include any variety of combinations and/or integrations of the features of the embodiments described herein. Although some embodiments may depict serial operations, the embodiments may perform certain operations in parallel and/or in different orders from those depicted. Moreover, the use of repeated reference numerals and/or letters in the text and/or drawings is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed. The embodiments are not limited in their applications to the order of steps of the methods, or to details of implementation of the devices, set in the description, drawings, or examples. Moreover, individual blocks illustrated in the figures may be functional in nature and therefore may not necessarily correspond to discrete hardware elements.

Certain features of the embodiments, which may have been, for clarity, described in the context of separate embodiments, may also be provided in various combinations in a single embodiment. Conversely, various features of the embodiments, which may have been, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable sub-combination. Embodiments described in conjunction with specific examples are presented by way of example, and not limitation. Moreover, it is evident that many alternatives, modifications, and variations will be apparent to those skilled in the art. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the embodiments. Accordingly, this disclosure is intended to embrace all such alternatives, modifications, and variations that fall within the spirit and scope of the appended claims and their equivalents.

We claim:

1. A system configured to detect an abnormal medical event, comprising:

at least one right-side head-mounted device configured to measure at least two signals indicative of photoplethys-

mographic signals (PPG_{SR1} and PPG_{SR2}, respectively) at first and second regions of interest (ROI_{R1} and ROI_{R2}, respectively) on the right side of a user's head; wherein ROI_{R1} and ROI_{R2} are located at least 2 cm apart;

at least one left-side head-mounted device configured to measure at least two signals indicative of photoplethysmographic signals (PPG_{SL1} and PPG_{SL2}, respectively) at first and second regions of interest (ROI_{L1} and ROI_{L2}, respectively) on the left side of the user's head; wherein ROI_{L1} and ROI_{L2} are located at least 2 cm apart; and

a computer configured to detect the abnormal medical event based on an asymmetrical change to blood flow recognizable in PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}.

2. The system of claim **1**, wherein the asymmetrical change to the blood flow corresponds to a deviation of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} compared to a baseline based on previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, taken before the abnormal medical event.

3. The system of claim **2**, wherein the computer is further configured to generate feature values based on data comprising: (i) PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, and (ii) the previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user; and wherein the computer is further configured to utilize a model to calculate, based on the feature values, a value indicative of whether the user is experiencing the abnormal medical event.

4. The system of claim **3**, wherein the feature values comprise a certain feature value indicative of a difference in maximal amplitudes of one or more of the following pairs: (i) PPG_{SR1} and PPG_{SR2}, (ii) PPG_{SR1} and PPG_{SL1}, and (iii) PPG_{SR1} and PPG_{SL2}.

5. The system of claim **3**, wherein the feature values comprise a certain feature value indicative of a difference in a pulse arrival time between the following pairs of regions of interest: (i) ROI_{R1} and ROI_{R2}, (ii) ROI_{R1} and ROI_{L1}, and (iii) ROI_{R1} and ROI_{L2}.

6. The system of claim **2**, wherein the abnormal medical event is ischemic stroke, and the deviation involves an increase in asymmetry between blood flow on the left side of the head and blood flow on the right side of the head, with respect to baseline asymmetry of the user between blood flow on the left side of the head and blood flow on the right side of the head.

7. The system of claim **2**, wherein the abnormal medical event is ischemic stroke, and the deviation involves a monotonic increase in a variation between blood flow at ROI_{R1} and ROI_{R2}, with respect to a baseline variation between blood flow at ROI_{R1} and ROI_{R2}, during a period longer than 10 minutes.

8. The system of claim **7**, wherein ROI_{R1} is located in proximity of the mastoid process behind the right ear, and ROI_{R2} is located before of the right ear.

9. The system of claim **2**, wherein the abnormal medical event is migraine attack, and the deviation is indicative of a pattern of a certain change to facial blood flow, which is associated with a pattern of a change to facial blood flow of at least one previous migraine attack, determined based on data comprising previous PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}, which were measured starting from at least 5 minutes before the previous migraine attack.

10. The system of claim **2**, wherein the abnormal medical event is headache, and the deviation is indicative of at least one of: a change in directionality of facial blood flow, and an asymmetrical reduction in blood flow to one side of the face.

11. The system of claim **2**, wherein the at least one right-side head-mounted device comprises first and second contact photoplethysmographic devices (PPG_1, PPG_2, respectively), and the at least one left-side head-mounted device comprise third and fourth contact photoplethysmographic devices (PPG_3, PPG_4, respectively); wherein PPG_1, PPG_2, PPG_3, and PPG_4 are physically coupled to an eyeglasses frame, PPG_1 and PPG_3 are in contact with the nose, and PPG_2 and PPG_4 are in contact with regions in the vicinities of the ears, respectively.

12. The system of claim **2**, wherein the at least one right-side head-mounted device comprises first and second contact photoplethysmographic devices, and the at least one left-side head-mounted device comprise third and fourth contact photoplethysmographic devices.

13. The system of claim **2**, wherein the at least one right-side head-mounted device comprises a first inward-facing camera located more than 0.5 cm away from ROI_{R1} and ROI_{R2}, and PPG_{SR1} and PPG_{SR2} are recognizable from color changes in regions in images taken by the first inward-facing camera; and wherein the at least one left-side head-mounted device comprise a second inward-facing camera located more than 0.5 cm away from ROI_{L1} and ROI_{L2}, and PPG_{SL1} and PPG_{SL2} are recognizable from color changes in regions in images taken by the second inward-facing camera.

14. The system of claim **13**, wherein each of the first and second inward-facing cameras utilizes a sensor having more than 30 pixels, and each of ROI_{R1} and ROI_{L1} covers an area greater than 6 cm^2 on the user's right and left cheeks, respectively, which is illuminated by ambient light.

15. The system of claim **13**, wherein each of the first and second inward-facing cameras utilizes a sensor having more than 20 pixels, and each of ROI_{R1} and ROI_{L1} covers an area greater than 4 cm^2 on the right and left sides of the user's forehead, respectively, which is illuminated by ambient light.

16. The system of claim **2**, further comprising first and second outward-facing head-mounted cameras configured to take images of the environment to the right and left of the user's head, respectively; and wherein the computer is further configured to utilize the images of the environment to improve the accuracy of detecting the abnormal medical event.

17. The system of claim **1**, further comprising right and left head-mounted thermometers, located at least 2 cm to the right and to the left of a vertical symmetry axis that divides the face, respectively, and are configured to provide right and left temperature measurements, respectively; and the computer is further configured to detect the abnormal medical event also based on a deviation of the right and left temperature measurements from a baseline temperature for the user; wherein the baseline temperature for the user is calculated based on data comprising previous right and left temperature measurements of the user, taken more than a day before the abnormal medical event; and wherein the abnormal medical event is selected from a group comprising cellulitis and dermatitis.

18. The system of claim **1**, further comprising right and left head-mounted thermometers, located less than 4 cm from the right and left earlobes, respectively, and are configured to provide right and left temperature measurements, respectively; and the computer is further configured to detect the abnormal medical event also based on a deviation of the

right and left temperature measurements from a baseline temperature for the user; wherein the baseline temperature for the user is calculated based on data comprising previous right and left temperature measurements of the user, taken more than a day before the abnormal medical event.

19. The system of claim **18**, wherein the abnormal medical event is selected from a group comprising ear infection, cerebrovascular accident, and mastoiditis.

20. A method for detecting an abnormal medical event, comprising:

measuring, utilizing at least one right-side head-mounted device, at least two signals indicative of photoplethysmographic signals (PPG_{SR1} and PPG_{SR2}, respectively) at first and second regions of interest (ROI_{R1} and ROI_{R2}, respectively) on the right side of a user's head; wherein ROI_{R1} and ROI_{R2} are located at least 2 cm apart;

measuring, utilizing at least one left-side head-mounted device, at least two signals indicative of photoplethysmographic signals (PPG_{SL1} and PPG_{SL2}, respectively) at first and second regions of interest (ROI_{L1} and ROI_{L2}, respectively) on the left side of the user's head; wherein ROI_{L1} and ROI_{L2} are located at least 2 cm apart; and

detecting the abnormal medical event based on an asymmetrical change to blood flow recognizable in PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2}, relative to a baseline based on previous measurements of PPG_{SR1}, PPG_{SR2}, PPG_{SL1}, and PPG_{SL2} of the user, taken before the abnormal medical event.

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专利名称(译)	眼镜以检测异常医疗事件，包括中风和偏头痛		
公开(公告)号	US10638938	公开(公告)日	2020-05-05
申请号	US16/551654	申请日	2019-08-26
[标]申请(专利权)人(译)	FACENSE有限公司		
申请(专利权)人(译)	FACENSE有限公司		
当前申请(专利权)人(译)	FACENSE有限公司		
[标]发明人	FRANK ARI M TZVIELI ARIE THIEBERGER GIL		
发明人	TZVIELI, ORI FRANK, ARI M TZVIELI, ARIE THIEBERGER, GIL		
IPC分类号	G01J5/12 A61B5/01 A61B5/00 G01J5/02 A61B5/16 G01J5/00		
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代理机构(译)	ACTIVE知识LTD.		
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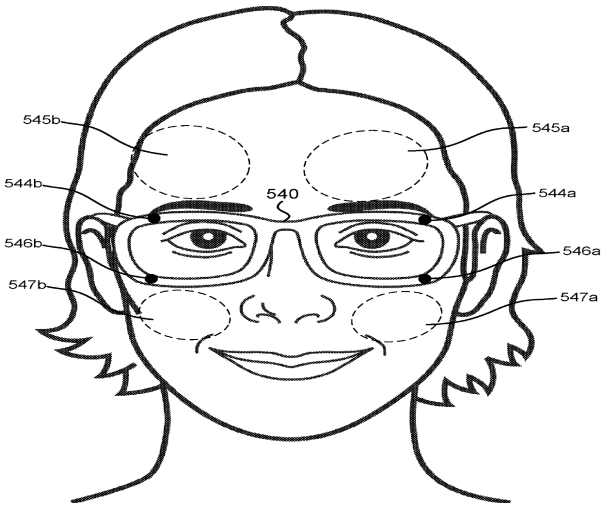
外部链接	Espacenet		

摘要(译)

基于血流的不对称变化来检测异常医疗事件的系统和方法。 该系统包括右侧和左侧头戴式设备，用于测量指示用户头部右侧和左侧的光电容积描记信号（PPG信号）的信号，以及基于不对称变化检测异常医疗事件的计算机 PPG信号中可识别的血流。 可选地，与血流的不对称变化对应于与基于异常医疗事件之前采取的用户的PPG信号的先前测量的基线相比的PPG信号的偏差。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