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Lapetina et al.

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(54) **WRIST-MOUNTED ELECTROCARDIOGRAPHY DEVICE**

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A61B 5/00 (2006.01)

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CPC ***A61B 5/04085*** (2013.01); ***A61B 5/681*** (2013.01); ***A61B 5/6824*** (2013.01); *A61B 2560/0443* (2013.01)

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USPC 600/390, 509
See application file for complete search history.

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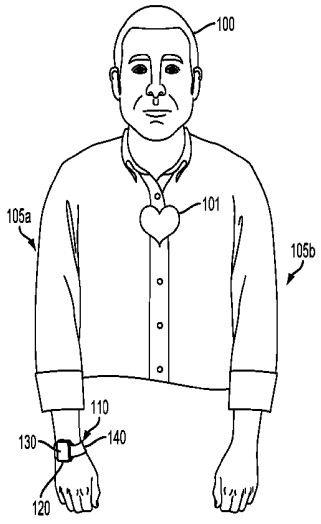
(57) **ABSTRACT**

Wearable devices are described herein including a housing and a mount configured to mount the housing to a wrist of a wearer. The wearable devices further include first and second electrical contacts configured such that the first electrical contact is in contact with skin proximate of the wrist when the wearable device is so mounted. The second electrical contact is disposed on a surface of the wearable device away from the wrist such that, when the wearer contacts the second electrical contact with a finger or other element of the arm opposite the wrist, an electrocardiographic waveform of the wearer can be extracted from

(Continued)



voltage fluctuations between the first and second electrodes. Such wearable devices can be used for periodic logging or other applications of the electrocardiographic waveforms of the wearer. Such logged electrocardiographic waveforms could be used to determine a medical or health state of the wearer.

20 Claims, 11 Drawing Sheets

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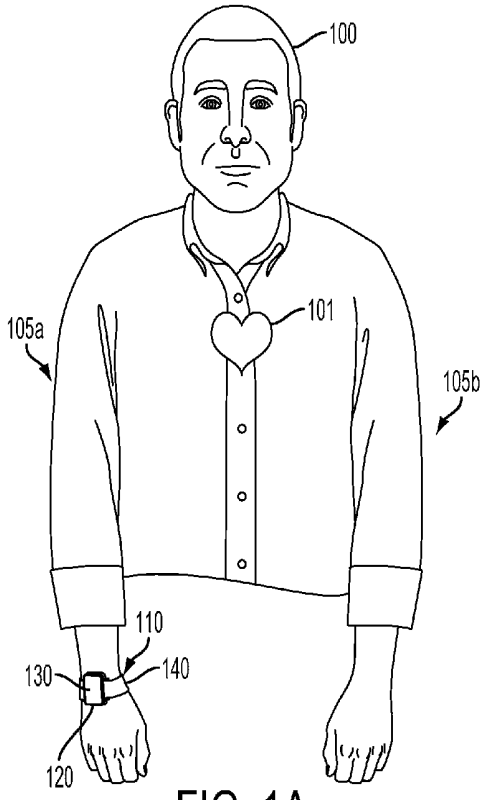

FIG. 1A

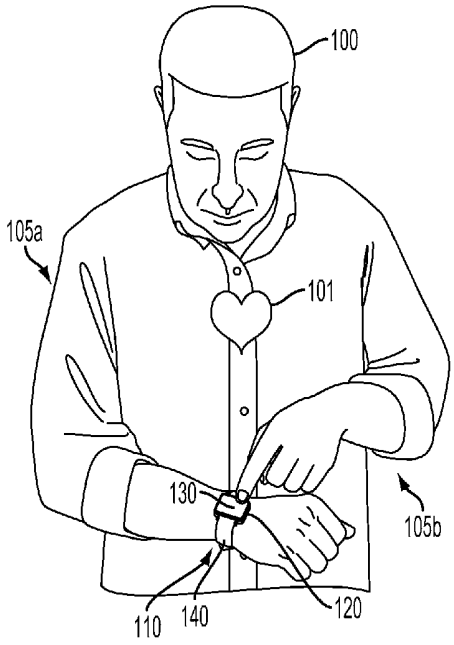

FIG. 1B

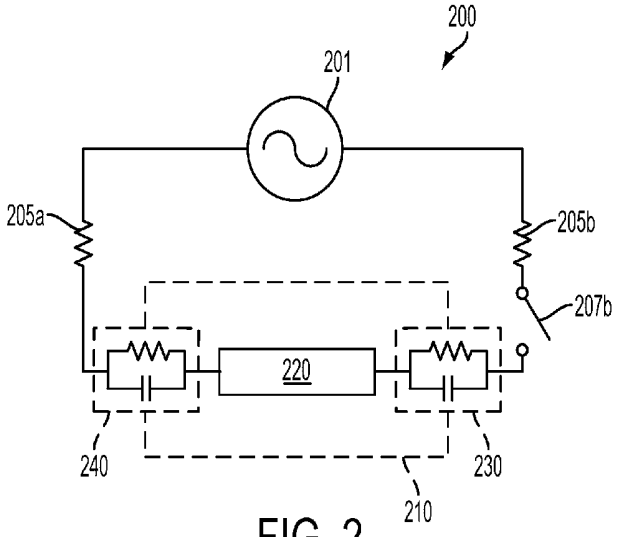

FIG. 2

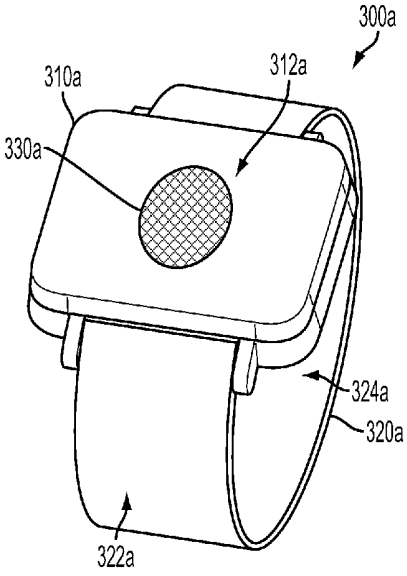

FIG. 3A

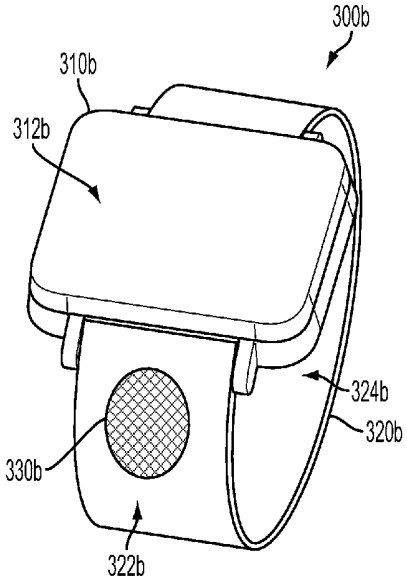

FIG. 3B

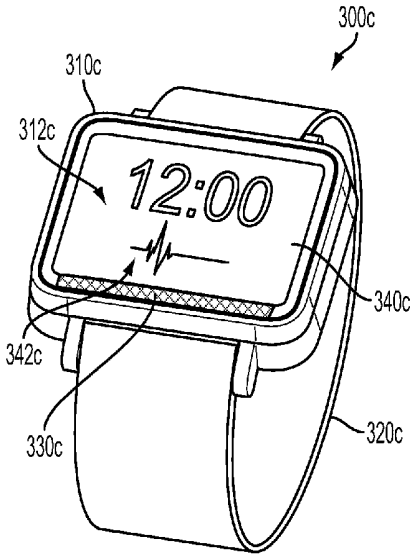

FIG. 3C

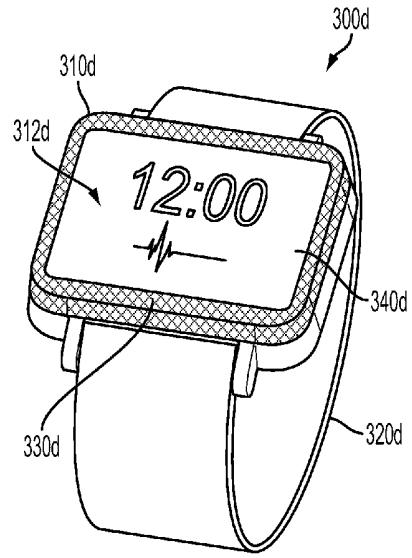

FIG. 3D

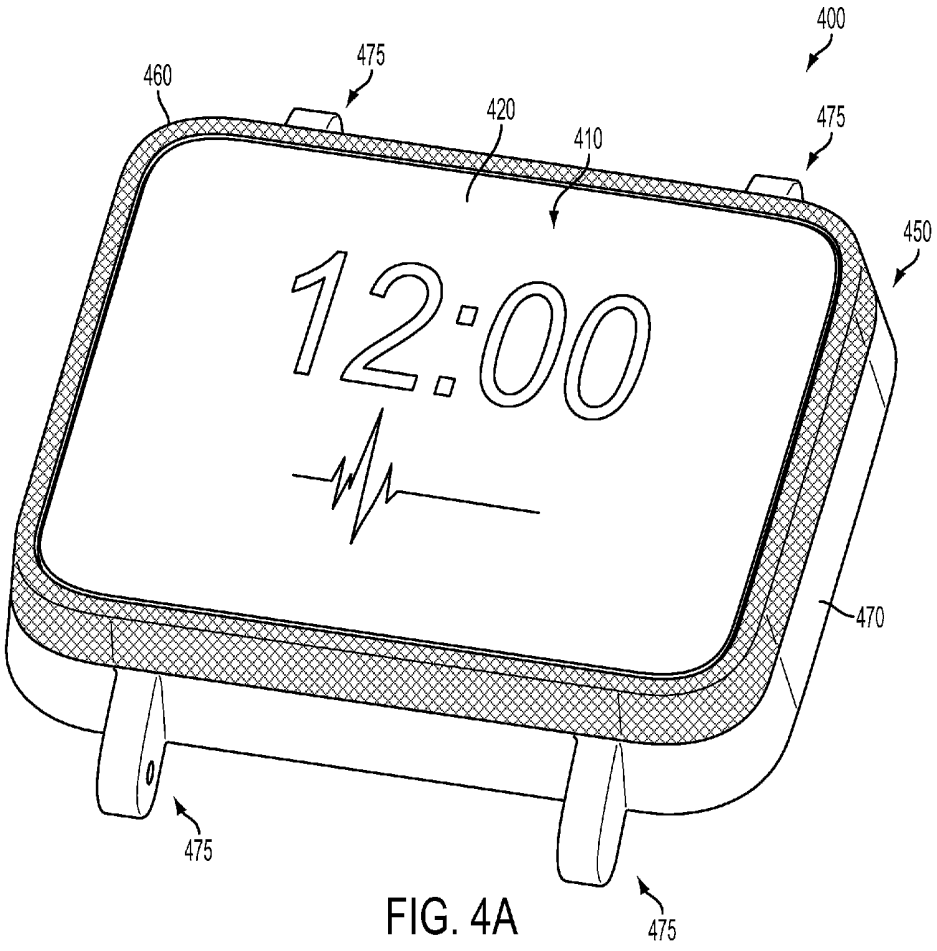

FIG. 4A

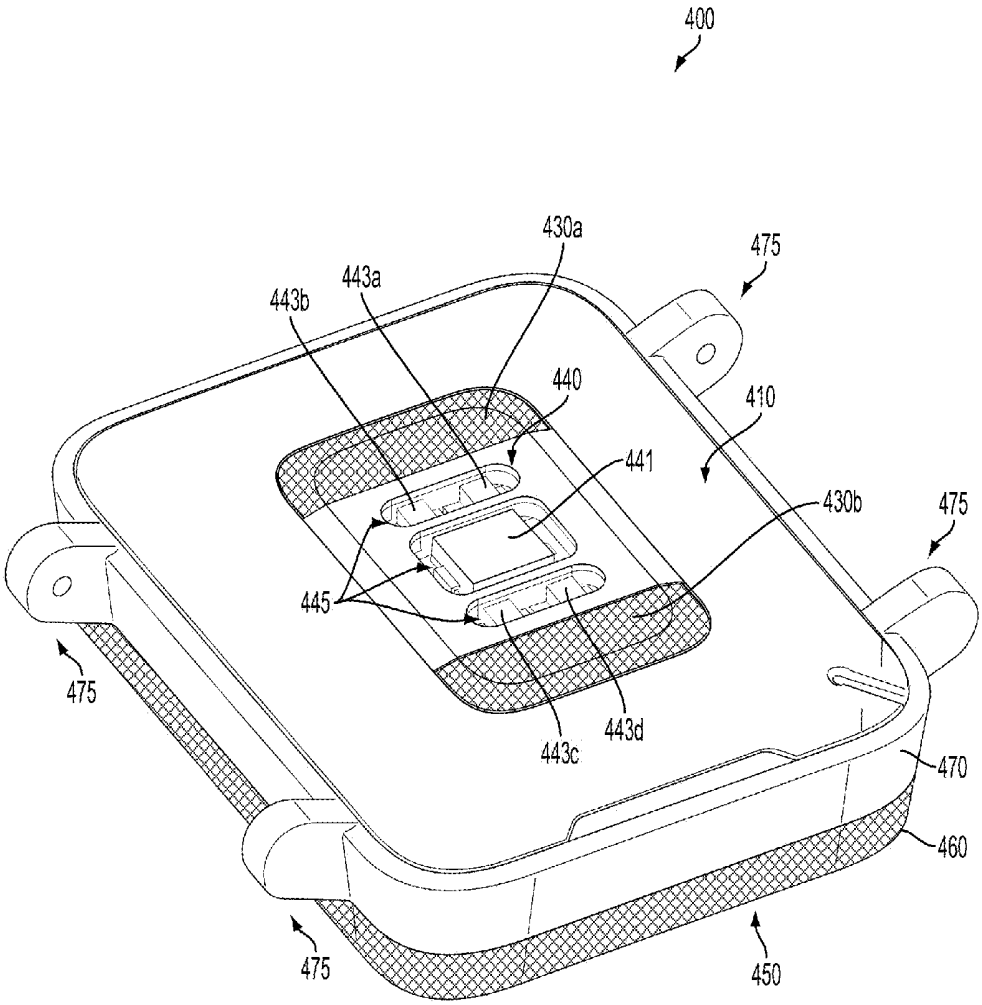
400
430a
475
443a
443b
440
410
441
430b
475
445
475
443c
443d
470
460
475
450

FIG. 4B

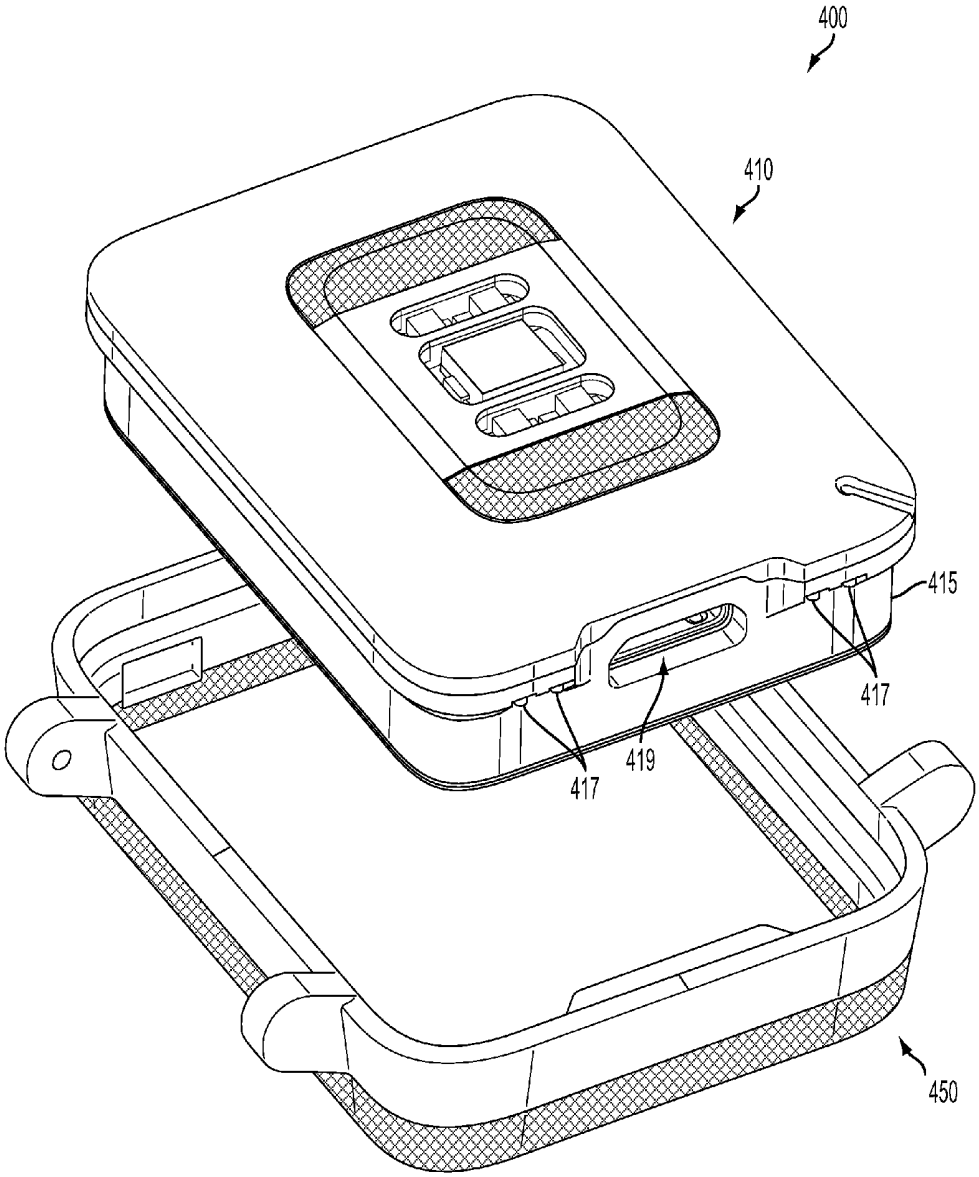

FIG. 4C

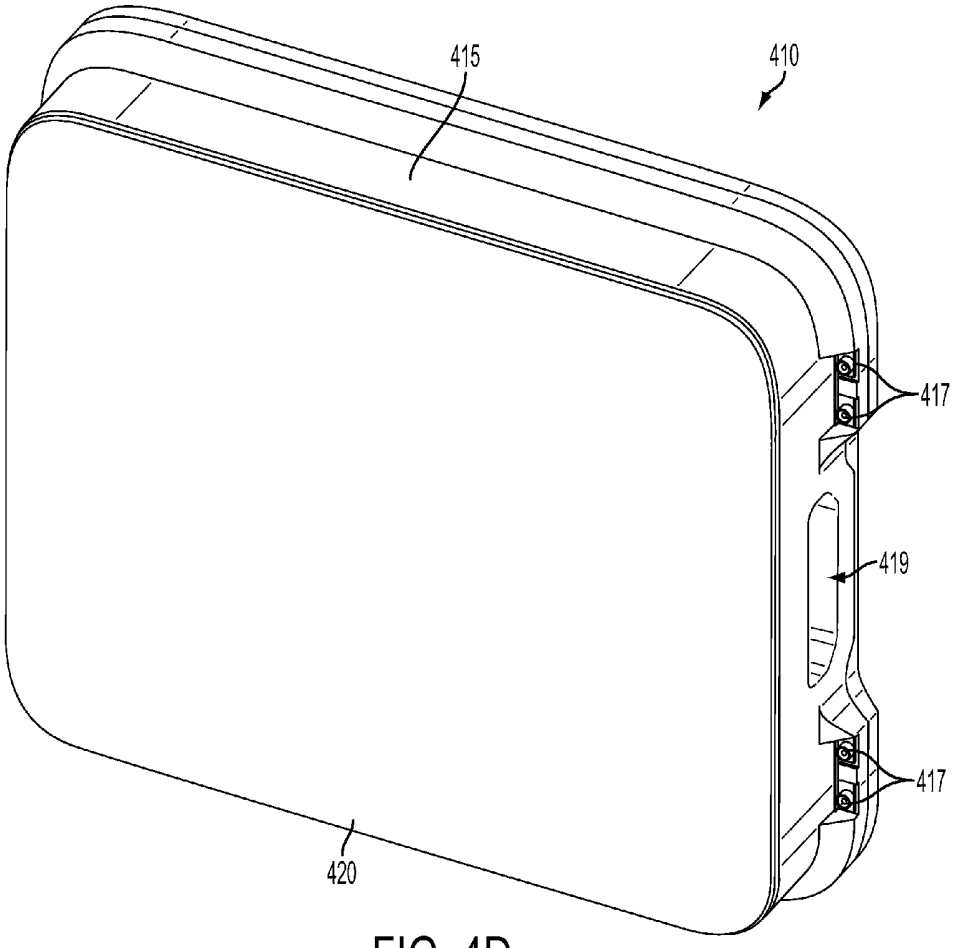

FIG. 4D

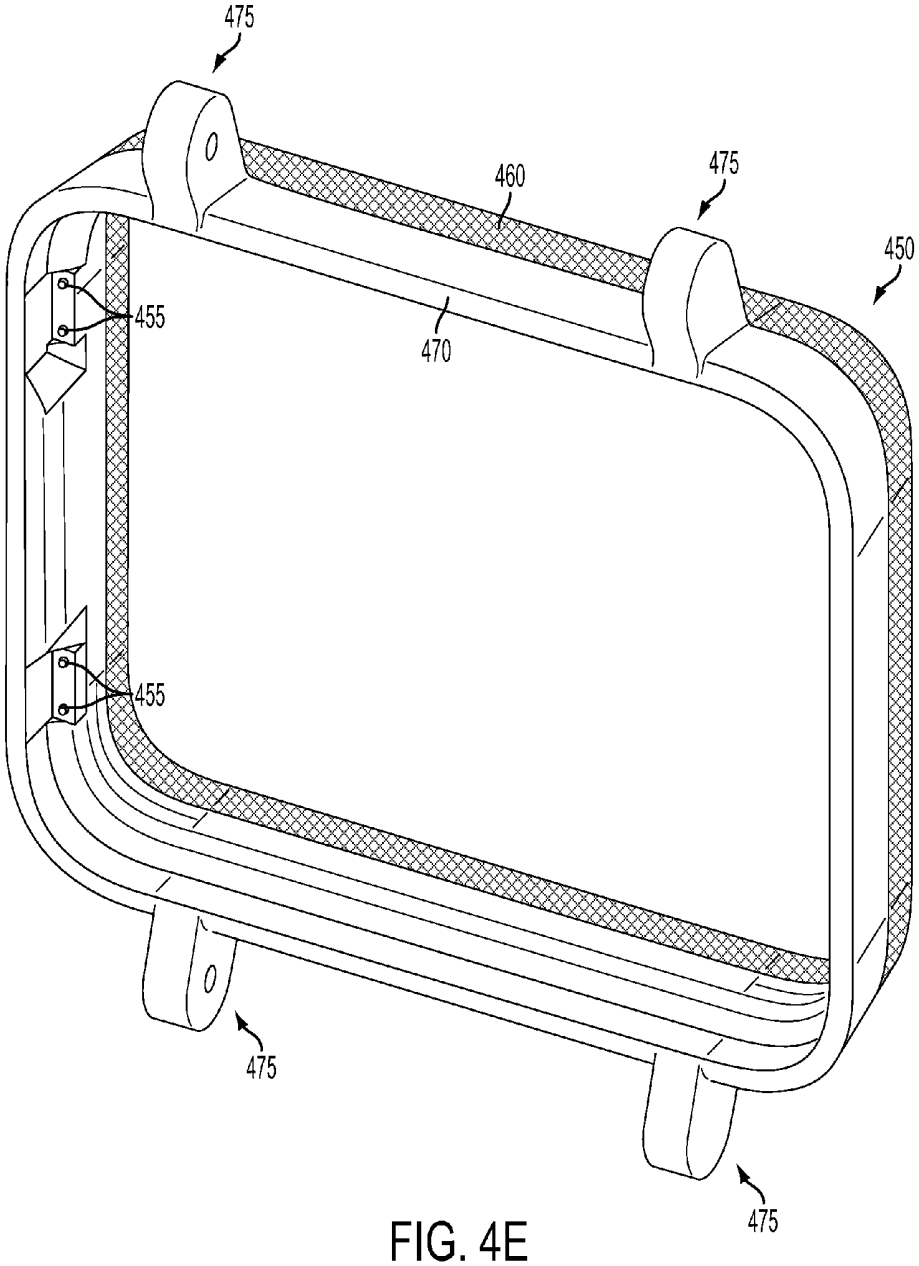

FIG. 4E

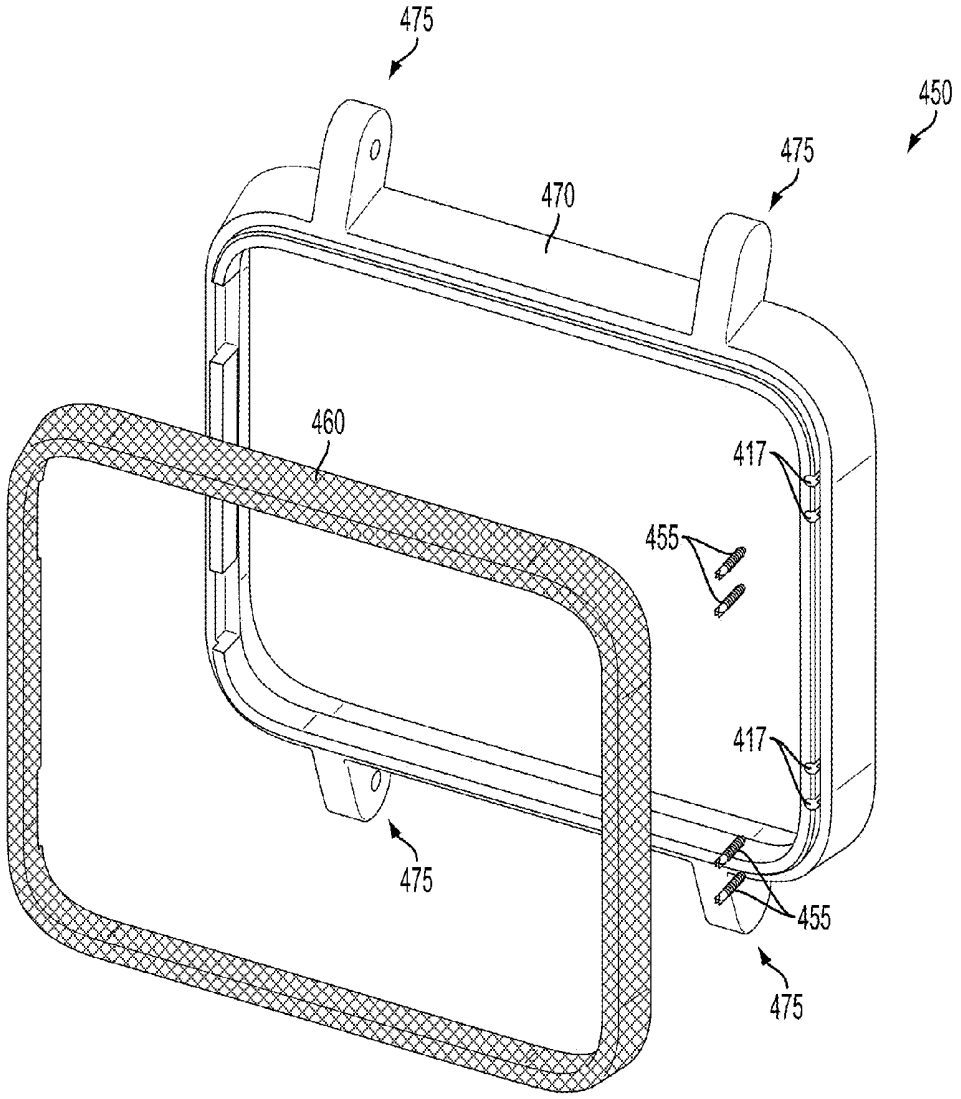

FIG. 4F

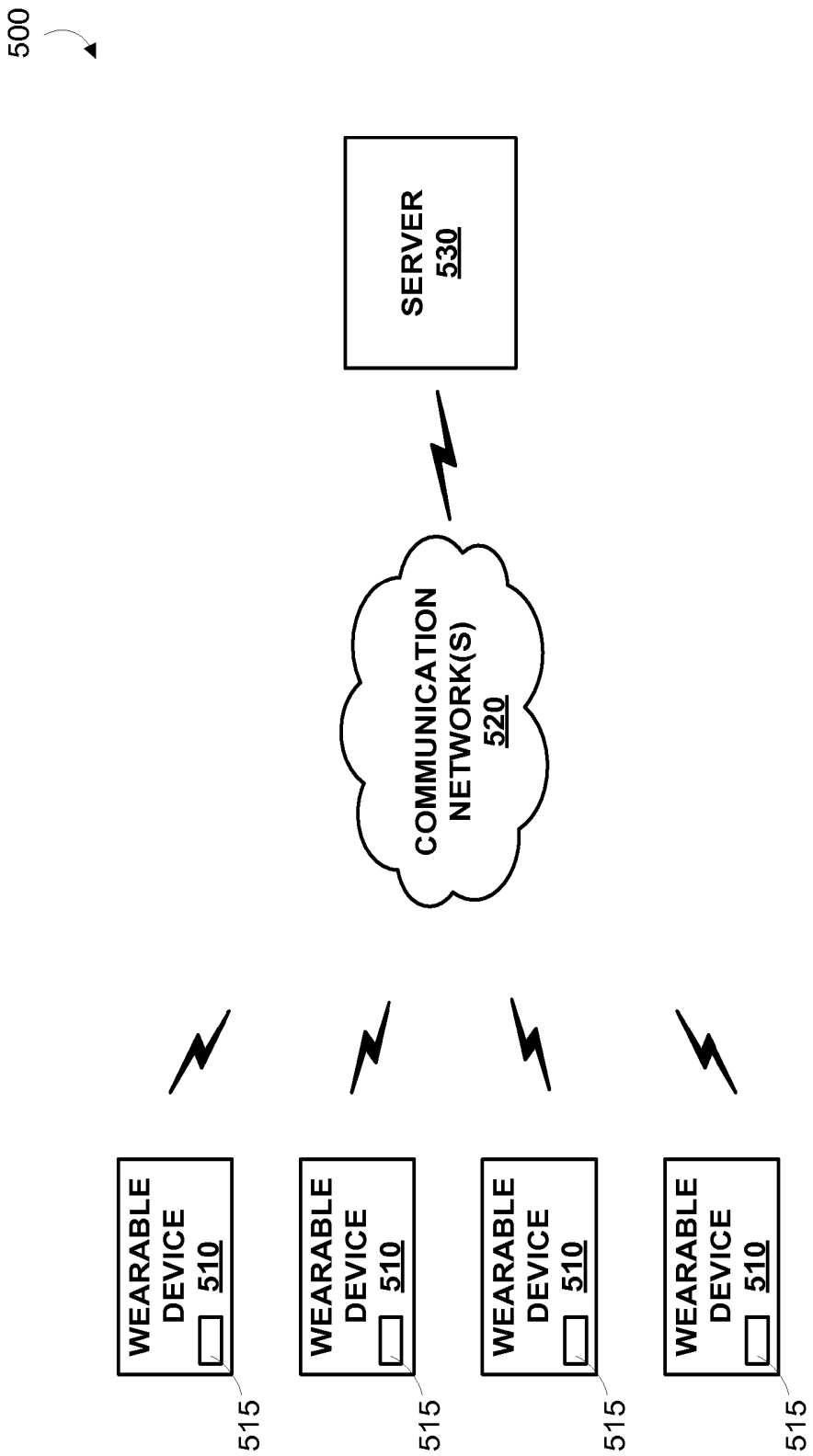
500
SERVER
530
COMMUNICATION
NETWORK(S)
520
WEARABLE
DEVICE
510
515
WEARABLE
DEVICE
510
515
WEARABLE
DEVICE
510
515
WEARABLE
DEVICE
510
515

FIGURE 5

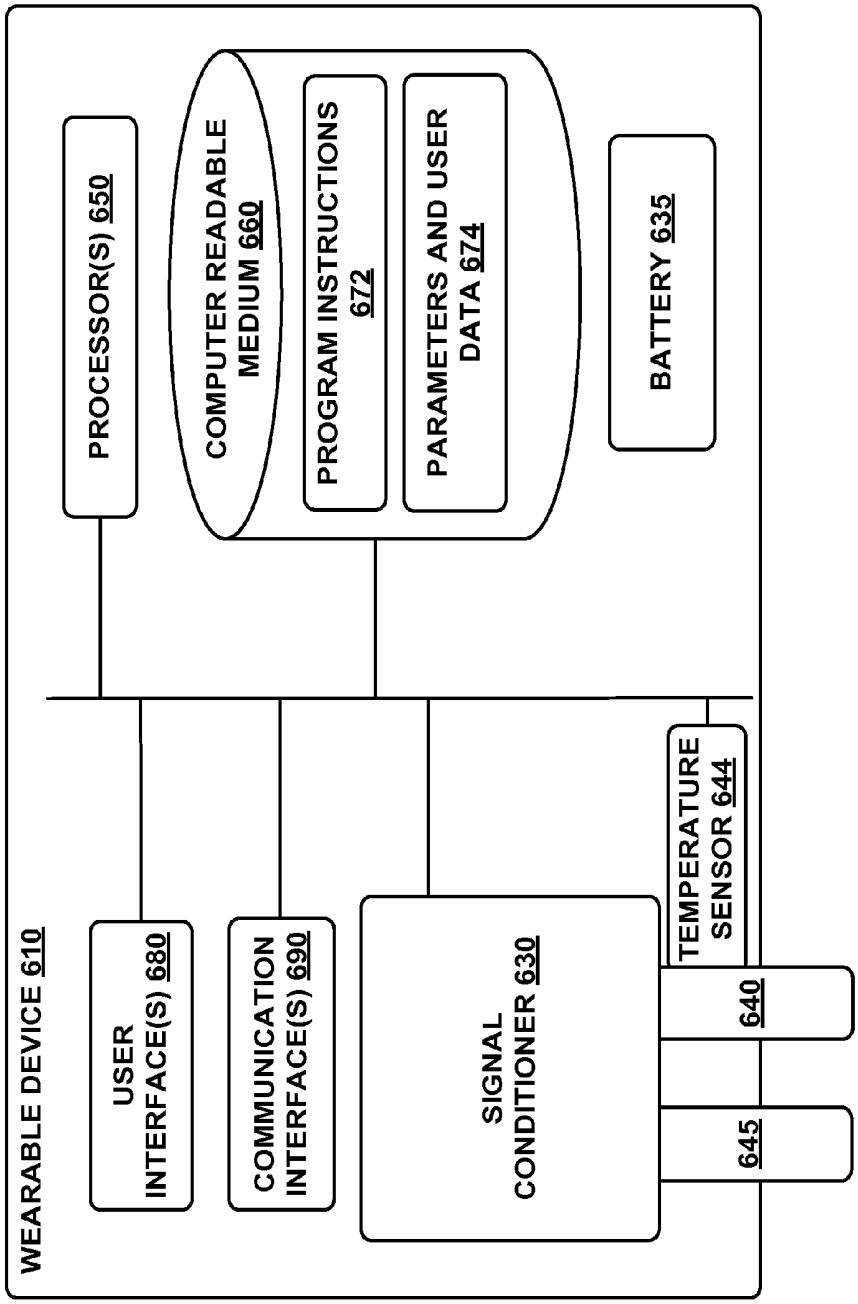
WEARABLE DEVICE 610
PROCESSOR(S) 650
COMPUTER READABLE MEDIUM 660
PROGRAM INSTRUCTIONS 672
PARAMETERS AND USER DATA 674
BATTERY 635
USER INTERFACE(S) 680
COMMUNICATION INTERFACE(S) 690
SIGNAL CONDITIONER 630
TEMPERATURE SENSOR 644
640
645

FIGURE 6

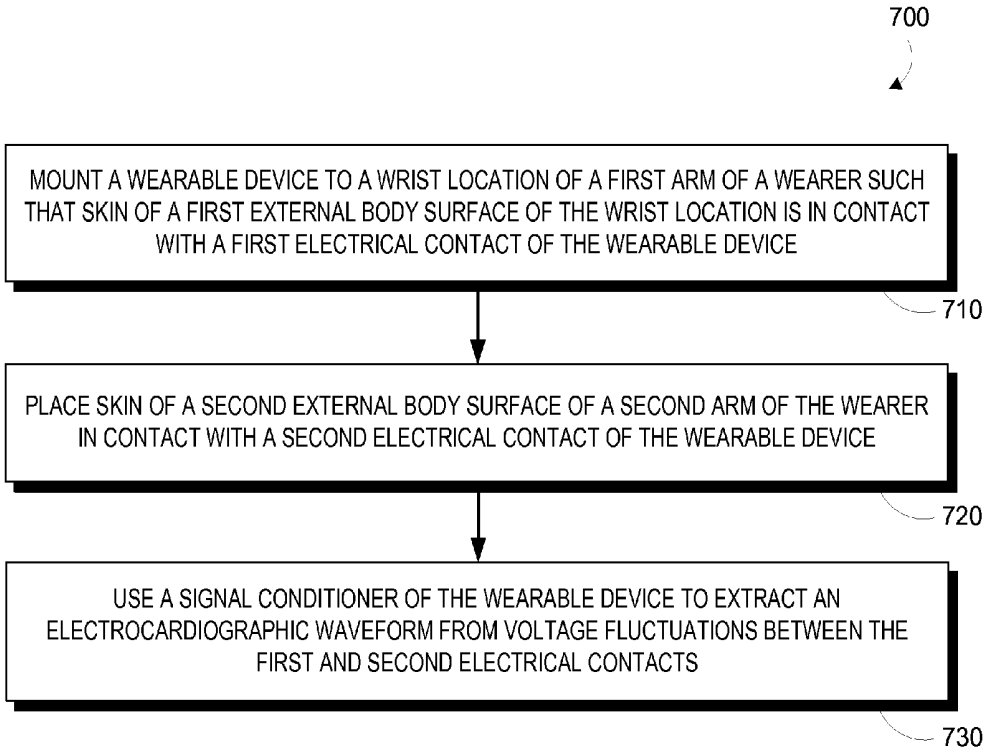
700
MOUNT A WEARABLE DEVICE TO A WRIST LOCATION OF A FIRST ARM OF A WEARER SUCH THAT SKIN OF A FIRST EXTERNAL BODY SURFACE OF THE WRIST LOCATION IS IN CONTACT WITH A FIRST ELECTRICAL CONTACT OF THE WEARABLE DEVICE
710
PLACE SKIN OF A SECOND EXTERNAL BODY SURFACE OF A SECOND ARM OF THE WEARER IN CONTACT WITH A SECOND ELECTRICAL CONTACT OF THE WEARABLE DEVICE
720
USE A SIGNAL CONDITIONER OF THE WEARABLE DEVICE TO EXTRACT AN ELECTROCARDIOGRAPHIC WAVEFORM FROM VOLTAGE FLUCTUATIONS BETWEEN THE FIRST AND SECOND ELECTRICAL CONTACTS
730

FIGURE 7

WRIST-MOUNTED ELECTROCARDIOGRAPHY DEVICE

BACKGROUND

Unless otherwise indicated herein, the materials described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section.

Electrocardiography (ECG) is a technique that records electrical activity of the heart by measuring electrical signals from two or more points on the skin. The measurements result in one or more waveforms (electrocardiograms) that are related to the beating of the heart. The waveforms may also include other features that may be indicative of heart health, abnormalities, or medical conditions. The electrocardiographic measurements can be obtained by placing electrodes on the skin at multiple body locations (e.g., on the chest, arms, and/or legs) and electrically connecting the electrodes to a heart monitor or other electronic measurement device. Typically, electrocardiograms are obtained in clinical settings in which a physician, nurse, or other medical professional is involved in placing the electrodes on the body and operating the heart monitor.

SUMMARY

Some embodiments of the present disclosure provide a wearable device including: (i) a housing; (ii) a mount configured to mount the housing to a first external body surface, wherein the first external body surface is a wrist location of a first arm of a wearer; (iii) a first electrical contact disposed on the housing, wherein the first electrical contact is configured to contact skin at the first external body surface when the housing is mounted on the first external body surface; (iv) a second electrical contact, wherein the second electrical contact is configured to be contacted by skin of a second external body surface, wherein the second external body surface is a location of a second arm of the wearer; and (v) a signal conditioner disposed in the housing and electrically connected to the first and second electrical contacts, wherein the signal conditioner is configured to extract an electrocardiographic waveform from voltage fluctuations between the first electrical contact and the second electrical contact.

Some embodiments of the present disclosure provide a wearable device including: (i) a housing; (ii) means for mounting the housing to a first external body surface, wherein the first external body surface is a wrist location of a first arm of a wearer; (iii) a first electrical contact disposed on the housing, wherein the first electrical contact is configured to contact skin at the first external body surface when the housing is mounted on the first external body surface; (iv) a second electrical contact, wherein the second electrical contact is configured to be contacted by skin of a second external body surface, wherein the second external body surface is a location of a second arm of the wearer; and (v) means for extracting an electrocardiographic waveform from voltage fluctuations between the first electrical contact and the second electrical contact.

Some embodiments of the present disclosure present a method including: (i) mounting a wearable device to a wrist location of a first arm of a wearer, wherein the device comprises: (a) a housing; (b) a mount configured to mount the housing to the wrist location; (c) a first electrical contact disposed on the housing, wherein the first electrical contact is configured to contact skin at a first external body surface when the housing is mounted on the first external body surface; (d) a second electrical contact, wherein the second electrical contact is configured to be contacted by skin of a second external body surface, wherein the second external body surface is a location of a second arm of the wearer; and (e) a signal conditioner disposed in the housing and electrically connected to the first and second electrical contacts, wherein the signal conditioner is configured to extract an electrocardiographic waveform from voltage fluctuations between the first electrical contact and the second electrical contact; (ii) while the wearable device is mounted to the wrist location of the first arm of the wearer such that the first electrical contact is in contact with skin at the first external body surface, placing skin of the second external body surface in contact with the second electrical contact; and (iii) while the first electrical contact is in contact with skin at the first external body surface and the second electrical contact is in contact with skin of the second external body surface, using the signal conditioner to extract the electrocardiographic waveform.

These as well as other aspects, advantages, and alternatives, will become apparent to those of ordinary skill in the art by reading the following detailed description, with reference where appropriate to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a view of a person wearing an example wearable device.

FIG. **1**B is a view of the person and wearable device illustrated in FIG. **1**A, when the user is contacting an electrical contact of the wearable device with a finger.

FIG. **2** is a diagram illustrating an example electrical model of elements of the person and wearable device illustrated in FIGS. **1**A and **1**B.

FIG. **3**A is a perspective view of an example wearable device.

FIG. **3**B is a perspective view of an example wearable device.

FIG. **3**C is a perspective view of an example wearable device.

FIG. **3**D is a perspective view of an example wearable device.

FIG. **4**A is a top perspective view of elements of an example wearable device.

FIG. **4**B is a bottom perspective view of the elements of the example wearable device illustrated in FIG. **4**A.

FIG. **4**C is a bottom perspective view of the elements of the example wearable device illustrated in FIG. **4**A, when a housing and a frame of the elements are disengaged from each other.

FIG. **4**D is a top perspective view of the housing of the elements of the example wearable device illustrated in FIG. **4**A.

FIG. **4**E is a bottom perspective view of the frame of the elements of the example wearable device illustrated in FIG. **4**A.

FIG. **4**F is an exploded top perspective view of the frame of the elements of the example wearable device illustrated in FIG. **4**A.

FIG. **5** is a block diagram of an example system that includes a plurality of wearable devices in communication with a server.

FIG. **6** is a functional block diagram of components disposed in an example wearable device.

FIG. **7** is a flowchart of an example method.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying figures, which form a part hereof. In the

figures, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, figures, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

I. Overview

A wearable device may be configured to measure one or more physiological parameters of the wearer. The one or more physiological parameters can include an electrocardiographic waveform (ECG), which may be related to the electrical activity of the wearer's heart and, thus, a medical and/or health state of the wearer. To measure an ECG waveform, the wearable device may include two electrical contacts that can be placed in contact with the wearer's skin at respective locations such as the wearer's wrist(s), forearm(s), upper arm(s), leg(s), thigh(s), etc. For example, first and second electrical contacts could contact skin on the left and right arms of the wearer, respectively (e.g., skin at the left and right wrists of the wearer, skin at the left wrist and right index finger of the wearer, etc.), and the ECG waveform may be extracted from voltage fluctuations between the first and second electrical contacts. One or more properties of a detected ECG waveform and/or of a plurality of detected ECG waveforms (detected, e.g., during a plurality of respective periods of time) could be determined and/or related to one or more physiological and/or health states of the wearer.

In some examples, the wearable device includes a housing (e.g., a water-resistant and/or water-proof housing) and a mount (e.g., a band) that can mount the housing on a particular external body location, such as a wrist of a first arm of the wearer (i.e., a first external body surface). The first electrical contact may protrude from a side of the housing facing the skin at the wrist location of the first arm, such that the first electrical contact contacts the skin of the wrist location when the housing is mounted on the wrist. The second electrical contact could be configured to be contacted by skin at a location on a second arm of the wearer (e.g., skin of a finger, hand, wrist, or other location on the arm of the wearer opposite the arm to which the wearable device is mounted). For example, the second electrical contact could be disposed on an outside surface of the housing and/or the mount (e.g., an outside surface of a band used to mount the wearable device to the wrist of the first arm) such that the wearer could move his or her second arm (i.e., the arm opposite the arm to which the wearable device is mounted) to touch the second electrical contact without the second arm being in electrical contact with the first arm. When the wearable device is operated in this way, a signal conditioner or other electronics of the wearable device may extract an ECG waveform from voltage fluctuations between the first and second electrical contacts. The wearable device could be used to extract such ECG waveforms while the wearer is involved in certain activities (e.g., while running or engaged in other forms of exercise) or throughout the day. Thus, the wearable device may facilitate repeated and/or near-continuous cardiac monitoring. Such cardiac monitoring could allow the detection of rare events (e.g., arrhythmias, transient bradycardia and/or tachycardia), cardiac electrical activity during a wider range of wearer behaviors than occur in a hospital or other controlled medical setting, the detection of changes in the electrical activity of the heart over protracted (e.g., weeks, months) periods of time, or other properties of the physiological state of a wearer.

The electronics of the wearable device may include a signal conditioner, a microprocessor, an analog-to-digital converter (which may be part of the microprocessor), data storage, a wireless transmitter, and/or other components. The signal conditioner may be electrically connected to the first and second electrical contacts and may be configured to extract an ECG waveform from voltage fluctuations between the electrical contacts. The signal conditioner may, for example, include at least one amplifier, at least one high-pass filter, and at least one low-pass filter. The microprocessor may obtain data related to the electrocardiographic signal (e.g., after the signal is digitized by the analog-to-digital converter), and the microprocessor may use the wireless transmitter to transmit the data related to the ECG waveform to a remote computing device (e.g., to the "cloud"). Additionally or alternatively, the microprocessor may log the data related to the ECG waveform in the data storage. In some examples, the electronics (e.g., the signal conditioner) includes circuitry or other elements configured to detect that the first and second electrical contacts are contacting skin and/or that an ECG waveform may be extracted from voltage fluctuations between the electrical contacts. The wearable device may be operated relative to such a determination; for example, an ECG waveform may be extracted using the signal conditioner and logged, transmitted, or used in some other way in response to the determination that the first and second electrical contacts are in contact with skin at respective first and second skin locations.

The first and second electrical contacts (and any further electrical contacts) of the wearable device could be configured in a variety of ways to allow the extraction of an ECG waveform from voltage fluctuations between the electrical contacts under a range of physiological and environmental conditions. The electrodes could have a variety of surface compositions to allow ohmic and/or capacitive electrical coupling between the electrodes and skin locations of a wearer. Such surface compositions could include stainless steel, gold, platinum, silver, silver/silver-chloride, polymers or rubbers containing conductive particles, or other conductive or partially conductive materials. Further, the shape and/or surface texture of the electrodes could be specified to allow electrical contact with skin. In some examples, the electrodes could be configured to have a substantially capacitive electrical contact with skin; e.g., the electrodes could include a flat conductor having a substantially non-conductive dielectric coating configured to be in contact with skin. Other compositions and configurations of electrodes are anticipated.

The wearable device could include further sensors. In some examples, this could include the wearable device having additional electrical contacts configured to provide additional electrophysiological signals (e.g., EMG signals) or other information (e.g., skin resistance, Galvanic skin response). Further sensors could include temperature sensors, light sensors, galvanic sensors, proximity sensors, GPS sensors, accelerometers, or other sensors or combinations of sensors. In some examples, the device could include a photoplethysmographic sensor or some other sensor(s) configured to detect a volume and/or a change in the volume of blood in subsurface vasculature of a wearer. Such detected information could be used, in combination with an extracted

ECG waveform, to determine one or more properties of the heart and/or vasculature of the wearer. For example, a diastolic, systolic, or other blood pressure of the wearer could be determined.

In some examples, the wearable device may include a user interface that is configured to provide user-discernible indications (e.g., visual, audible, and/or tactile indications) of one or more physiological parameters measured and/or determined by the device. For example, the user interface could indicate an ECG waveform extracted using the first and second electrical contacts during a period of time when the user is contacting the second electrode with, e.g., a finger of an arm opposite the arm to which the wearable device is mounted. In some examples, the user interface could additionally provide a means for one or more settings of the wearable device (e.g., a frequency at which to operate the user interface to indicate that the user should contact the second electrical contact with, e.g., a finger of the opposite arm) to be specified by a wearer according to the wearer's preferences. In some examples, the wearable device may include a wireless communication interface that can transmit data to an external device, for example, using Bluetooth, ZigBee, WiFi, and/or some other wireless communication protocol. The data transmitted by the wireless communication interface may include data indicative of one or more physiological parameters measured by the device, such as extracted ECG waveforms.

It should be understood that the above embodiments, and other embodiments described herein, are provided for explanatory purposes, and are not intended to be limiting.

Further, the term "medical condition" as used herein should be understood broadly to include any disease, illness, disorder, injury, condition or impairment—e.g., physiologic, psychological, cardiac, vascular, orthopedic, visual, speech, or hearing—or any situation requiring medical attention.

II. ECG Performed Between the Arms of a Wearer

The heart creates an electric field within the body during the process of pumping blood. The temporal and spatial properties of this field are related to the sum of a plurality of ionic currents that flow within the heart as a result of the depolarization and repolarization of electrically active cells of the heart (e.g., cardiomyocytes) during activity of the heart (e.g., during a heartbeat). This electric field within the body results in voltage fluctuations at the skin (and other locations within the body) being related at least in part to the electrical activity of the heart. As a result, measurement of these voltage fluctuations could be used to detect and/or determine information about the activity of the heart, e.g., to determine a health or medical state (e.g., a disease state) of the heart.

An electrocardiographic (ECG) waveform can be extracted from voltage fluctuations between two (or more) location on the skin of a person (e.g., by using electrodes to grant a measurement device electrical access to the two or more skin locations). ECG waveforms can be extracted from pairs of skin locations on a person, such as between the left and right arms, between the right arm and left leg, and between the left arm and left leg. ECG waveforms can also be extracted from combinations of voltage fluctuations at more than two skin locations; for example, an ECG waveform could be generated based on the difference between the voltage at a first electrode (e.g., an electrode over the heart) and a mean of the voltages of a set of other electrodes (e.g., a mean over the voltages of electrodes at the right arm, left arm, and left leg).

Further, an extracted ECG waveform corresponding to a particular heartbeat generally includes a number of temporal features corresponding to phases of the activity of the heart during the particular heartbeat. Specifically, such an extracted ECG waveform may include a P wave (corresponding to depolarization of the atria of the heart), QRS complex (corresponding to depolarization of the ventricles of the heart), and a T wave (corresponding to repolarization of the ventricles). Such an extracted ECG waveform may include additional features (e.g., a U wave) and/or lack features (e.g., the T wave) according to a medical state of a person, an anatomical or physiological property of the person, and/or the properties of the electrodes and/or measurement equipment used to extract the ECG waveform. One or more properties of the extracted ECG waveform (e.g., a Q-T interval, an R-R interval, a P-R interval, an S-T interval, a Q-T interval, an amplitude and/or polarity of a T-wave, and amplitude, polarity, or some other parameter(s) of some other aspect of the ECG waveform) could be determined and used to determine a medical and/or health state of the heart and/or of the person containing the heart (e.g., a metabolic rate, a degree of physical exertion, an elevated or depressed level of one or more electrolytes, coronary ischemia, heart attack, cardiac hypertrophy, the presence of certain drugs and/or toxins).

A wearable device could be configured to extract one or more ECG waveforms from skin of a wearer by measuring voltage fluctuations between two or more skin locations of the wearer. This could include accessing the voltage fluctuations at the two or more skin locations by applying respective two or more electrical contacts or electrodes to the two or more skin locations, and electrically connecting the two or more electrical contacts or electrodes to a signal conditioner or other electrical measurement device of the wearable device. This connection could include long flexible leads connecting between a particular skin location to the wearable device, which could be located at some other location on or near the body of the wearer (e.g., the wearable device could be connected to a belt worn by the wearer, and leads could run from the belt location to electrical contacts at two skin locations at the wrists of the wearer). Additionally or alternatively, two or more electrical contacts could be disposed on the wearable device and configured to contact respective two or more skin locations. The two or more skin locations could be proximate to each other (e.g., the wearable device could be mounted to a wrist of the wearer, and the two skin locations could be skin location on the wrist of the wearer). Alternatively, the two or more skin locations could be distant locations and the wearer could move skin locations of the wearer's body to contact electrical contacts of the wearable device.

As an example, a wearable device could be configured to mount to a first wrist (e.g., the left wrist) of the wearer and to have a first electrical contact configured to contact a first skin location on the first wrist. The wearable device could further include a second electrical contact configured to be contacted by a second skin location of the wearer. That is, the wearer could move a portion of the wearer's body (e.g., a right hand) proximate to the wearable device such that a second skin location (e.g., a finger, hand, or wrist location of the arm of the wearer opposite the arm to which the wearable device is mounted) is in contact with the second electrical contact of the wearable device. In this way, the wearable device could enable periodic extraction of ECG waveforms from voltage fluctuations between the two skin locations (e.g., between a wrist location of the left arm and a finger location of the right arm). Such a wearable device could be

configured in the form of a wristwatch or other wrist-mounted device (i.e., having a central housing (on or within which could be mounted first and/or second electrical contacts) mounted to the wrist by e.g., a strap or band configured to encircle the wrist) and could include means for performing additional functions, e.g., indicating a time and/or information about extracted ECG waveforms to the wearer.

FIG. **1**A illustrates such an example wearable device **110** mounted to a wrist of a first arm **105***a* of a wearer **100** during a first period of time. The wearable device **110** includes a housing **120** mounted to the wrist of the first arm **105***a* by a mount **140** (e.g., a strap or band). The wearable device further includes first (not shown) and second **130** electrical contacts. The first electrical contact is disposed on an inside (i.e., wrist-facing) side of the housing **120** and configured to contact skin at a first external body surface (i.e., skin of the wrist of the first arm **105***a*) when the housing **120** is mounted on the wrist of the first arm **105***a*. The second electrical contact **130** is configured to be contacted by skin of a second external body surface (e.g., by finger, hand, wrist, or other skin of a second arm **105***b* of the wearer **100**). The wearable device **110** additionally includes electronics (e.g., a signal conditioner, not shown) electrically connected to the first and second **130** electrical contacts and configured to extract an ECG waveform (related to the electrical activity of the heart **101** of the wearer **100**) from voltage fluctuations between the first and second **130** electrical contacts.

FIG. **1**B illustrates the wearable device **110** and wearer **100** during a second period of time when the wearer **100** is positioning skin of a finger of the second arm **105***b* in contact with the second electrical contact **130**. In this state, electronics (e.g., a signal conditioner) of the wearable device **110** could extract an ECG waveform related to the electrical activity of the wearer's **100** heart **101** during the second period of time from voltage fluctuations between the first and second **130** electrical contacts.

The wearer positioning skin of the finger (or some other location) of the second arm **105***b* proximate to the second electrical contact **130** could be performed a plurality of times to enable to extraction of ECG waveforms during a plurality of respective periods of time. The wearer positioning skin of the finger of the second arm **105***b* proximate to the second electrical contact **130** could be performed at the initiative of the wearer, e.g., in response to the wearer having performed and/or being about to perform a strenuous task (e.g., exercise), experiencing some symptoms (e.g., fatigue, nausea, vertigo, heart palpitations, orthostatic hypertension), having received and/or being about to receive a drug (e.g., having taken nitroglycerin). In some examples, the wearer could additionally operate the device to indicate some symptoms or other information related to an extracted ECG waveform. Additionally or alternatively, the wearer positioning skin of the finger of the second arm **105***b* proximate to the second electrical contact **130** could be performed in response to an indication (e.g., a vibration, a sound, a visual indication on a display of the device **100**, an indication through some other device in communication with the wearable device **110**) that the wearer should perform such an action to enable the extraction of an ECG waveform by the wearable device **110**.

FIG. **2** illustrates an electrical circuit **200** modeling elements of the wearer **100** and wearable device **110** of FIGS. **1**A and **1**B. The electrical circuit **200** includes a time-varying voltage source **201** corresponding to the time-varying electrical field generated by the heart **101** of the wearer **100**. The electrical circuit **200** additionally includes elements corresponding to the wearable device **110** (illustrated by bounding box **210**). These elements **210** include equivalent resistor/capacitor networks **230**, **240** corresponding to the electrical properties of the first and second **130** electrical contacts and their electrical coupling to respective first and second skin locations. The elements of the wearable device **210** additionally include a signal conditioner **220** electrically connected to the first **230** and second **240** electrical contacts and configured to extract an ECG waveform from voltage fluctuations between the first **240** and second **240** electrical contacts. The electrical circuit **200** further includes two resistors **205***a*, **205***b* representing the electrical properties (e.g., resistance to current flow) of the arms **105***a*, **105***b* and other tissue (e.g., chest tissue) between the heart **101** and the first and second **130** electrical contacts. A switch **207***b* represents the control-able electrical contact between the second electrical contact **130** and skin of the second arm **105***b*. Thus, the switch **207***b* is open to model the electrical behavior of the wearer **100** and wearable device **110** during the first period of time (corresponding to the scenario illustrated by FIG. **1**A) and open to model the electrical behavior of the wearer **100** and wearable device **110** during the second period of time (corresponding to the scenario illustrated by FIG. **1**B).

Thus, an ECG waveform extracted when the wearer **100** positions skin of the finger (or some other location) of the second arm **105***b* proximate to the second electrical contact **130** could correspond to a lead I ECG recording. That is, in embodiments wherein the wearable device **110** is mounted to a right wrist location and the signal conditioner extracts an ECG waveform by sensing the voltage fluctuations of the first electrical contact relative to the second electrical contact, the extracted ECG waveform corresponds to a lead I ECG recording. Alternatively, the wearable device **110** could be mounted to a left wrist location, and the extracted ECG waveform could correspond to an inverted lead I ECG recording. The user could indicate to the wearable device **110** (e.g., using a user interface of the wearable device **110**) that the wearable device is mounted to a left (or right) wrist location. Additionally or alternatively, the wearable device **110** could determine that it is mounted to a left (or right) wrist location based on features (e.g., the polarity of the QRS complex) of an extracted ECG waveform.

Note that parameters of the electrical circuit **200** are related to electrical properties of the body of the wearer **100**, of the first and second **130** electrical contacts, and to properties of the interface between the first and second **130** electrical contacts and respective first and second skin locations. Thus, the parameters of the electrical circuit **200** could be related to a dryness of other state of the skin locations, a type of skin at the skin locations, a degree of force applied between the skin locations and respective electrical contacts, or other considerations. Further, the parameters of the electrical circuit **200** could be related to the composition and configuration of the electrical contacts (e.g., a composition of a surface of the electrical contacts, a texture of the surface of the electrical contacts, a geometry of the electrical contacts). Correspondingly, one or more properties (e.g., an input impedance, a frequency response, a bandwidth, a sensitivity, a maximum input amplitude) of the signal conditioner **220** could be specified and/or controlled relative to expected values of those properties of the body of the wearer **100**, of the first and second **130** electrical contacts, and/or of the interface between the first and second **130** electrical contacts and respective first and second skin locations (e.g., to allow the extraction of low-noise, high-amplitude, or otherwise optimized ECG waveforms).

Electrical contacts of the wearable device **110** could be configured in a variety of ways to allow the extraction of an ECG waveform from voltage fluctuations between the electrical contacts under a range of physiological and environmental conditions. The electrical contacts could have a variety of surface compositions to allow ohmic (i.e., related to conduction by ionic and/or redox reaction across the surface of the electrical contacts) and/or capacitive (i.e., related to the accumulation of opposite charges on opposite sides of a surface of the electrical contacts) electrical coupling between the electrodes and skin locations of a wearer. Such surface compositions could include stainless steel, gold, platinum, silver, silver/silver-chloride, polymers or rubbers containing conductive particles, or other conductive or partially conductive materials. Further, the shape and/or surface texture of the electrical contacts could be specified to control one or more properties of the electrical interface of the electrical contacts with skin. For example, the electrical contacts could have a specified large area in contact with skin, could protrude from a housing toward the skin (e.g., could have a rounded and/or pointed protruding geometry), could have a surface texture (e.g., to increase an effective surface area between a conductor of the electrical contact and fluids on the surface of the skin), or could be configured in some other way.

In some examples, the electrical contacts could be configured to have a substantially capacitive electrical contact with skin; that is, an electrical contact could engage in substantially no direct ionic and/or redox conduction across the interface between the electrical contact and the skin. Conduction of currents between such an electrode and the skin could instead consist substantially of the accumulation of opposite charges on respective opposite sides of a substantially nonconductive barrier between a conductor of the electrical contact and the skin. For example, an electrical contact could include a flat conductor having a substantially nonconductive dielectric coating configured to be in contact with skin. Additionally or alternatively, an electrical contact could have a textured conductive surface coated in a conformal layer of substantially nonconductive material. Other compositions and configurations of electrodes are anticipated.

A signal conditioner or other electronics of the wearable device **110** could include a variety of components configured in a variety of ways to allow one or more ECG waveforms to be extracted from voltage fluctuations between the first and second **130** electrical contacts when the first and second **130** electrical contacts are contacting appropriate respective skin locations of the wearer **100** and/or to allow other operations and applications. The electronics could include analog and/or digital electronic components to enable analog and/or digital manipulations of electrical signals related to voltage fluctuations between the electrical contacts. Generally, the electronics include components configured to amplify and filter voltage fluctuations between the electrical contacts (e.g., one or more amplifiers, buffers, filters, operational amplifiers, resistors, capacitors, inductors, transistors, rectifiers, or some other linear or nonlinear electronic component or combinations thereof).

For example, the electronics could be configured to generate an electronic signal (e.g., to generate an extracted ECG waveform) that is related to a band-passed version of the voltage fluctuations between the electrical contacts. This could include applying the voltage fluctuations to a band-pass filter having a pass-band between approximately 0.05 Hertz and approximately 150 Hertz. Additionally or alternatively, an electronic signal could be digitally sampled and some digital filtering could be performed (e.g., by a processor of the wearable device **110**) to generate an extracted ECG waveform. The electronics could include fast recovery circuitry configured to determine that one or more elements (e.g., amplifiers, filters) of the electronics are saturated and to responsively control one or more properties of the electronics (e.g., operate an electronic switch to discharge a capacitor, change a corner frequency or other parameter of a filter) to reduce the electronic saturation of the one or more elements of the electronics. Other configurations and applications of electronics of the wearable device **110** are anticipated.

The wearable device **110** and uses thereof illustrated in FIGS. **1**A and **1**B are illustrative examples; a wearable device as described herein could be configured in a variety of ways. Generally, such a wearable device could include at least one electrical contact disposed on or toward an inside surface of the wearable device (e.g., on an inside surface of a housing, strap, or other element of the wearable device) such that the at least one electrical contact is in contact with a first external body surface at a first skin location to which the wearable device is mounted. Generally, such a wearable device could also include at least one electrical contact disposed on or toward an outside surface (i.e., an outside contact) of the wearable device (e.g., on an outside surface of a housing, strap, or other element of the wearable device) such that the at least one electrical contact is not in contact with an external body surface at the first skin location to which the wearable device is mounted. The wearable device could be further configured to prevent electrical contact between the outside contact and an external body surface at the first skin location to which the wearable device is mounted, e.g., by increasing a distance between the outside contact and the external body surface, by disposing the outside contact on an outside surface of the wearable device far from an edge of the outside surface, by providing a non-conductive barrier between the outside contact and the external body surface, or operating or configuring the wearable device in some other way.

A wearable device (e.g., **110**) could include additional sensors. For example, the wearable device could include accelerometers, optical pulse sensors, photoplethysmographic sensors, pulse oximeters, thermometers, acoustical sensors, force sensors, electric field sensors, magnetic field sensors, or some other sensor(s) configured to detect one or more properties of a wearer of the wearable device and/or of the environment of the wearable device. In some examples, information from different sensors of the wearable device could be combined to determine one or more properties of the wearer (e.g., to determine a health or medical state of the wearer).

For example, a wearable device could be configured to extract an ECG waveform from voltage fluctuations between two or more skin locations of a wearer. The wearable device could be further configured to detect a volume of blood in a portion of subsurface vasculature of the wearer at a plurality of points in time (e.g., by illuminating the portion of subsurface vasculature and detecting light responsively received form the portion of subsurface vasculature, i.e., via photoplethysmography) to generate a waveform of the volume of blood in the portion of subsurface vasculature over time. Time differences or other comparisons of features of the extracted ECG waveform and the determined volume waveform (e.g., a time difference between a maximum of the volume waveform and a corresponding QRS complex of the ECG waveform) could be used to determine a flow rate, a pressure wave speed and/or latency, or other information

about the blood in the portion of subsurface vasculature and/or information about the heart and vasculature of the wearer. Further, such determined information could be used to determine a health or medical state of the wearer, e.g., to determine a blood pressure of the wearer, to determine a degree of atherosclerosis of the vasculature of the wearer, etc.

III. Example Wearable Devices

Wearable devices as described herein could be configured in a variety of ways. In some examples, a wearable device could be configured to be mounted to a wrist location of a first arm of the wearer. Further, such a wearable device could include a first electrical contact disposed on a housing (e.g., on an inside surface of the housing) of the wearable device and configured contact skin at wrist location when the wearable device is mounted on the wrist location. Such a wearable device could additionally include a second electrical contact (e.g., disposed on an outside surface of the wearable device) configured to be contacted by skin of a second body surface on a second arm of the wearer such that electronics (e.g., a signal conditioner) of the wearable device could extract an ECG waveform from voltage fluctuations between the first and second electrical contacts when the second electrical contact is contacted by skin of the second body surface and the wearable device is mounted to the wrist location.

As an example, FIG. **3**A illustrates a wearable device **300***a* similar to the wearable device **110** illustrated in FIGS. **1**A and **1**B. The wearable device **300***a* can be configured to extract an ECG waveform from voltage fluctuations between skin at first and second external body surfaces. The term "wearable device," as used in this disclosure, refers to any device that is capable of being worn at, on or in proximity to an external body surface, such as a wrist, ankle, waist, chest, or other body part. A mount **320***a*, such as a belt, wristband, ankle band, etc. can be provided to mount the device at, on or in proximity to the external body surface. In some embodiments, a mount could additionally or alternatively include an adhesive. For example, a mount could include an adhesive and could be configured such that it could be used to mount a wearable device to an external body surface of a wearer without wrapping around a part of the wearer (e.g., a limb). The mount **320***a* may prevent the wearable device **300***a* from moving relative to the body to ensure consistent contact between an electrical contact or other sensor of the wearable device **300***a* and the skin to enable consistent extraction of an ECG waveform and/or measurement of some other property of the wearer. In one example, shown in FIG. **3**, the mount **320***a* takes the form of a strap or band that can be worn around a part of the body.

A housing **310***a* is disposed on the mount **320***a* such that the housing **310***a* can be positioned on a first external surface of a first arm of the body (e.g., a surface of a wrist of the body). The housing **310***a* has an outside surface **312***a* that is away from the first external surface of the body and an inside surface (not shown) that is toward and/or in contact with the first external surface of the body when the housing **310***a* is positioned on the first external surface of the body. Similarly, the mount **320***a* has an inside surface **324***a* and an outside surface **322***a*. A second electrical contact **330***a* is disposed in the middle of the outside surface **312***a* of the housing **310***a* and configured to be contacted by skin of a second external body surface of a second arm of the body (i.e., an arm opposite an arm to which the wearable device **300***a* is mounted). Operated and/or mounted in this way, a first electrical contact (not shown) disposed on the inside surface of the housing **310***a* could contact skin at the first external surface of the body such that an ECG waveform (as measured between the first and second external body surfaces, e.g., between a wrist of a first arm and a finger of a second, opposite, arm) could be extracted from voltage fluctuations between the first and second **330***a* electrical contacts.

The first and second **330***a* electrical contacts could be composed of an electrically conductive material, such as a metal or a combination of metals, or a nonmetal conductor. The first and second **330***a* electrical contacts could be composed of the same material or different materials. The first and second **330***a* electrical contacts could each be composed of a single material or could be composed of multiple materials. For example, the electrical contacts could have a bulk composed of a first material and a surface plating of another material. For example, the electrical contacts could have a bulk composed of copper and a surface composed of gold or of gold alloyed with nickel and/or cobalt. Alternatively, the surface layer could be composed of stainless steel, gold, platinum, silver, silver/silver-chloride, polymers or rubbers containing conductive particles, or other conductive or partially conductive materials. The surface layer could be deposited by a number of methods familiar to one skilled in the art; for example, electroplating. Other compositions are possible, as well. Additionally or alternatively, the electrical contacts could be configured to be substantially capacitively coupled to respective external body surfaces by, e.g., including a flat conductor having a substantially nonconductive dielectric coating configured to be in contact with skin. Other compositions and configurations of electrodes are anticipated. Further, protruding aspects of the electrical contacts could have an inscribed, cast, and/or pressed texture or pattern. Additionally or alternatively, the exposed aspects of the electrical contacts could be roughened mechanically, chemically, or by some other method.

One or both of the electrical contacts could be spring loaded. That is, the electrical contacts could be configured to include one or more springs or other elements that could be reversibly compressed. The first electrical contact could be spring loaded in a direction perpendicular to an external surface of the body to which the housing **310***a* could be mounted. That is, the first electrical contact could be spring loaded in order to improve and/or make more consistent an electrical connection between the first electrical contact and skin of the first external body surface to which the housing **330***a* is mounted by the mount **320***a*. Alternatively, the first and/or second **330***a* electrical contacts could be fixed relative to housing **310***a*.

The housing **310***a* could be configured to be water-resistant and/or water-proof. That is, the housing could be configured to include sealants, adhesives, gaskets, welds, press-fitted seams, and/or other joints such that the housing **310***a* is resistant to water entering an internal volume or volumes of the housing **310***a* when the housing **310***a* is exposed to water. The housing **310***a* could further be water-proof, i.e., resistant to water entering an internal volume or volumes of the housing **310***a* when the housing **310***a* is submerged in water. For example, the housing **310***a* could be water-proof to a depth of 1 meter, i.e., configured to resist water entering an internal volume or volumes of the housing **310***a* when the housing **310***a* is submerged to a depth of 1 meter. Further, the interface between the housing **310***a* and the first and second **330***a* electrical contacts could be configured such that the combination of the housing **310***a* and the electrical contacts is water-resistant and/or water-proof.

The wearable device **300***a* includes electronics (not shown in FIG. **3**) electronically coupled to the first and second **330***a* electrical contacts. The electronics (e.g., electronics configured as a signal conditioner or otherwise as described herein) are configured to extract an ECG waveform from voltage fluctuations between the first and second **330***a* electrical contacts when the first and second **330***a* electrical contacts are in contact with respective first and second external surfaces of the body.

The wearable device **300***a* could be operated based an ECG waveform extracted as described herein. For example, the wearable device **300***a* could be configured to determine a health or other state of a wearer based on an extracted ECG waveform. Further, the wearable device **300***a* could be configured to determine whether the wearable device **300***a* is mounted to an external body surface of a wearer and/or that an ECG waveform can be extracted using the first and second **330***a* electrical contacts based on a value, a change in value, and/or some other property of a current and/or voltage detected through and/or between the first and second **330***a* electrical contacts (e.g., a current and/or voltage detected while a voltage and/or current is being applied, by electronics of the wearable device **300***a*, through and/or across the first and second **330***a* electrical contacts).

The electronics or other elements of the wearable device **300***a* could be configured to prevent injury of a wearer and/or damage to the wearable device **300***a* due to operation of the device to extract an ECG waveform from voltage fluctuations between two or more external body surfaces using the first and second **330***a* electrical contacts. Clamping diodes and/or associated blocking resistors could be included in the wearable device **300***a* and configured to prevent voltages and/or currents above a certain specified maximum from being applied to the electrical contacts (and thus to the skin of the wearer) and/or to elements of the wearable device **300***a* (e.g., components (e.g., an ADC) of a signal conditioner, components of a recharger coupled to the electrical contacts). A blocking capacitor (i.e., a capacitor having a high specified value of capacitance) could be electrically disposed between one or more or the electrical contacts and electronics of the wearable device **300***a* to prevent the wearable device **300***a* from injuring the skin of the external body surface(s) and/or causing electrochemical damage to the electrical contacts (e.g., by preventing the application of direct current to the skin for a protracted period of time, by ensuring that current injected into the skin through the electrical contacts is essentially balanced). Other operations and configurations of the wearable device **300***a* to prevent injury of a wearer and/or damage to the wearable device **300***a* are anticipated.

The first and second **330***a* electrical contacts, and any additional electrical contacts (not shown) protruding from and or disposed on the housing **310***a* could additionally be used for other purposes. For example, electronics disposed in the wearable device **300***a* could be used to sense a skin resistance, a skin capacitance, a body water content, a body fat content, a Galvanic skin potential (GSP), an electromyographic (EMG) signal, and/or some other physiological signal present at and/or through the electrical contacts. Additionally or alternatively, the electrical contacts could be used to detect the presence of a charging device or some other electronic system electrically connected to the electrical contacts. The electronics could then use the electrical contacts to receive electrical energy from the charging device or other system to recharge a rechargeable battery of the wearable device **300***a* and/or to power the wearable device **300***a*. Such a rechargeable battery could additionally or alternatively be recharged wirelessly using electromagnetic energy received by a coil and other wireless charging circuitry disposed in the wearable device **300***a*.

Alternatively, one or both of the electrical contacts of such a wearable device could be disposed on a band, strap, or other mount of the device. For example, FIG. **3**B illustrates a wearable device **300***b* that can be configured to extract an ECG waveform from voltage fluctuations between skin at first and second external body surfaces. A housing **310***b* is disposed on a mount **320***b* such that the housing **310***b* can be positioned on a first external surface of a first arm of the body (e.g., a surface of a wrist of the body). The housing **310***b* has an outside surface **312***b* that is away from the first external surface of the body and an inside surface (not shown) that is toward and/or in contact with the first external surface of the body when the housing **310***b* is positioned on the first external surface of the body. Similarly, the mount **320***b* has an inside surface **324***b* and an outside surface **322***b*. A second electrical contact **330***b* is disposed on the outside surface **322***b* of the mount **320***b* and configured to be contacted by skin of a second external body surface of a second arm of the body (i.e., an arm opposite an arm to which the wearable device **300***b* is mounted). Operated and/or mounted in this way, a first electrical contact (not shown) disposed on the inside surface of the housing **310***b* could contact skin at the first external surface of the body such that an ECG waveform (as measured between the first and second external body surfaces, e.g., between a wrist of a first arm and a finger of a second, opposite, arm) could be extracted from voltage fluctuations between the first and second **330***b* electrical contacts.

In some examples, such a wearable device could include a user interface configured to present and/or indicate information to a wearer and/or to receive information (e.g., command inputs) from the wearer. For example, FIG. **3**C illustrates a wearable device **300***c* that can be configured to extract an ECG waveform from voltage fluctuations between skin at first and second external body surfaces. A housing **310***c* is disposed on a mount **320***c* such that the housing **310***c* can be positioned on a first external surface of a first arm of the body (e.g., a surface of a wrist of the body). The housing **310***c* has an outside surface **312***c* that is away from the first external surface of the body and an inside surface (not shown) that is toward and/or in contact with the first external surface of the body when the housing **310***c* is positioned on the first external surface of the body. A first electrical contact (not shown) is disposed on the inside surface of the housing **310***c* and a second electrical contact **330***c* is disposed on the outside surface **312***c* of the housing **310***c*. Further, the wearable device **300***c* includes a user interface **340***c* disposed on the outer surface **312***c* of the housing.

A wearer of the device **300***c* may receive one or more recommendations or alerts generated from a remote server or other remote computing device, or from a processor within the device via the user interface **340***c*. The alerts could be any indication that can be noticed by the person wearing the wearable device. For example, the alert could include a visual component (e.g., textual or graphical information on a display), an auditory component (e.g., an alarm sound), and/or tactile component (e.g., a vibration). Further, the user interface **340***c* may be configured and/or operated to provide a visual display **342***c* to provide an indication of a status of the device, a time, an extracted ECG waveform, or an indication of any other measured physiological parameters measured by the device **300***c*. Further, the user interface **340***c* may include one or more buttons and/or be configured as a touch screen for accepting inputs from the

wearer. For example, user interface **340***c* may be configured to change the text or other visual information **342***c* in response to the wearer touching one or more locations of the user interface **340***c*.

To allow for easier and/or more comfortable contact between an outward-facing electrode (e.g., **330***a*, **330***b*, **330***c*) and skin of an external body surface of a wearer (e g, skin of a finger, hand, or other part of a wearer's body) and/or according to some other application, the size, shape, number, and/or disposition of such outward-facing electrode(s) could be different than shown above. For example, an outward-facing electrode could partially or completely encircle a band or strap of a wearable device, cover a larger area of an outside surface of a housing (e.g., completely cover such an outside surface), or be configured and/or disposed in some other way. For example, such an outward facing electrode could completely or partially encircle an outer edge of an outside surface of a housing of a wearable device and/or completely or partially encircle a display or other user interface element disposed on such an outside surface. For example, FIG. **3**D illustrates a wearable device **300***d* that can be configured to extract an ECG waveform from voltage fluctuations between skin at first and second external body surfaces. A housing **310***d* is disposed on a mount **320***d* such that the housing **310***d* can be positioned on a first external surface of a first arm of the body (e.g., a surface of a wrist of the body). The housing **310***d* has an outside surface **312***d* that is away from the first external surface of the body and an inside surface (not shown) that is toward and/or in contact with the first external surface of the body when the housing **310***d* is positioned on the first external surface of the body. A first electrical contact (not shown) is disposed on the inside surface of the housing **310***d*. A user interface **340***d* is disposed on the outside surface **312***d* of the housing **310***d* A second electrical contact **330***d* is disposed along an edge of the outside surface **312***d* of the housing **310***d* completely enclosing the user interface **340***d*.

Other configurations of a wearable device configured to extract an EG waveform from two or more skin locations of the body of a wearer are anticipated. Such wearable devices could include more than two electrodes configured to provide additional information to extract additional ECG waveforms, to extract higher-quality (e.g., higher-magnitude, higher signal-to-noise-ratio) ECG waveforms, to detect some other information (e.g., to detect a skin resistance, to detect a Galvanic skin response, to detect an EMG signal (e.g., an EMG signal from muscles in a wrist of a wearer), or to enable some other application. In some examples, an electrical contact could additionally be configured to detect contact with skin (e.g., a finger) of the wearer and the wearable device could operate responsive to such a detection, e.g., to extract an ECG waveform from voltage fluctuations between the electrical contact and some other electrical contact(s). Additionally or alternatively, touch detection by an electrical contact could be used to receive an input from the wearer, e.g., to act as a 'button press' or other indication of a wearer's intent. Further, a wearable device could include multiple such electrical contacts configured to detect skin contact (e.g., to initiate an ECG waveform extraction, to determine user input) and to enable ECG waveform extraction. Additionally or alternatively, such an electrode could form a transparent or semi-transparent layer disposed on a display of the wearable device. For example, a layer of indium-tin-oxide, an array of fine wires or other conductive elements, or some other elements could be disposed on a display and configured to act as an electrical contact. Additionally or alternatively, an electrode of a touchscreen could be configured to capacitively couple with voltage fluctuations of a skin location of a wearer such that an ECG waveform could be extracted from voltage fluctuations between the touchscreen electrode and some other electrical contact(s) of the wearable device.

In some examples, the wearable device (e.g., a housing **310***a*, **310***b*, **310***c*, **310***d* of the wearable device **300***a*, **300***b*, **300***c*, **300***d*) further includes at least one detector for detecting at least one other physiological parameter, which could include any parameters that may relate to the health of the person wearing the wearable device and/or the environment of the wearable device. For example, the detector could be configured to measure acceleration of the wearable device, a magnetic field, an electric field, an ambient light, a respiration rate, a skin temperature, etc. At least one of the detectors could be configured to non-invasively measure a volume of blood circulating in subsurface vasculature proximate to the wearable device. In a non-exhaustive list, the detector may include any one of an optical (e.g., CMOS, CCD, photodiode), acoustic (e.g., piezoelectric, piezoceramic), electrochemical (voltage, impedance), thermal, mechanical (e.g., pressure, strain, acceleration, rotation), magnetic, or electromagnetic (e.g., RF, magnetic resonance) sensor.

For example, a wearable device could be configured to extract an ECG waveform from voltage fluctuations between two or more skin locations of a wearer. The wearable device could be further configured to detect a volume of blood in a portion of subsurface vasculature of the wearer at a plurality of points in time (e.g., by illuminating the portion of subsurface vasculature and detecting light responsively received form the portion of subsurface vasculature, i.e., via photoplethysmography) to generate a waveform of the volume of blood in the portion of subsurface vasculature over time (e.g., a photoplethysmographic signal). Time differences or other comparisons of features of the extracted ECG waveform and the determined volume waveform (e.g., a time difference between a maximum of the volume waveform and a corresponding QRS complex of the ECG waveform) could be used to determine a flow rate, a pressure wave speed and/or latency, or other information about the blood in the portion of subsurface vasculature and/or information about the heart and vasculature of the wearer. Further, such determined information could be used to determine a health or medical state of the wearer, e.g., to determine a blood pressure of the wearer, to determine a degree of atherosclerosis of the vasculature of the wearer, etc.

Further, a wearable device as described herein could be modular. That is, one or more components of such a wearable device could be replaceable, extensible, and/or otherwise reconfigurable to add and/or remove capabilities of the wearable device. For example, a wearable device could include a housing containing a battery, a communications interface, a touchscreen user interface, and general-purpose electronics to enable a variety of applications of a wearable device. The wearable device could further include a modular mount configured to mount the housing to an external body surface and to enable some applications of the wearable device, e.g., by including one or more sensors. For example, a first modular mount could be configured to mount the housing around a wrist of a wearer and to enable extraction of an ECG waveform from voltage fluctuations between the arms of a wearer by providing a second electrical contact on an outside surface of the mount (e.g., an outer surface of a frame encircling the housing) to complement a first electri-

cal contact provided by the housing on an inside surface of the housing. A second modular mount could be configured to mount the housing around the chest of a wearer and to enable detection of breathing patterns of the wearer by providing a strain sensor in a band of the mount that encircles the chest of the wearer.

FIG. **4**A illustrates a top perspective view of an example wearable device **400** including a central housing **410** configured to be removably seated in a frame **450** of a modular mount. The modular mount additionally includes a band (not shown) connected to the frame **450** and configured to mount the central housing **410** to an external body surface (e.g., a wrist) of a wearer. The central housing **410** includes a user interface **420** disposed on an outer surface of the central housing **410** (e.g., a surface opposite the external body surface when the central housing **410** is mounted to the external body surface by the modular mount). The user interface **420** is a touchscreen interface, configured to present visual indications to a wearer (e.g., by spatially modulating an emitted light of the user interface **420** and/or by spatially modulating a reflectivity of the user interface **420**). The frame **450** includes a nonconductive inner portion **470** and a conductive outer portion **460**. The outer portion **460** is configured to act as an electrical contact and to contact skin of an external body surface of the wearer (e.g., skin of a finger of the wearer). The outer portion **460** encircles the user interface **420** when the central housing **410** is seated in the frame **450** (as shown in FIG. **4**A). The inner portion **470** of the frame **450** includes mounting points **475** configured to attach a band, strap, or other means of securing the wearable device **400** to an external body surface (e.g., the mounting points **475** could be configured to attach to a standard watch band, i.e., they could be approximately 26 millimeters apart, 20 millimeters apart, or some other distance apart according to a stand watch band size).

FIG. **4**B illustrates a bottom perspective view of the wearable device **400** illustrating elements disposed on an inside surface of the central housing **410** (i.e., elements disposed toward the external body surface when the central housing **410** is mounted to the external body surface by the modular mount). Electrical contacts **430***a*, **430***b* are disposed on the inside surface of the central housing **410**. The electrical contacts **430***a*, **430***b* could be configured to enable a variety of applications of the wearable device **400**. For example, the electrical contacts **430***a*, **430***b* could be operated to detect a skin resistance, a skin capacitance, a Galvanic skin response, a body water content, a body fat content, or other information by passing a current through and/or applying a voltage to skin proximate to the wearable device and detecting a corresponding voltage across and/or current through the electrical contacts **430***a*, **430***b*. Further, a Galvanic skin voltage, an EMG waveform, or some other electrophysiological voltage signal could be detected through the electrical contacts **430***a*, **430***b*. In some examples, an electro-haptic stimulus could be delivered to a wearer though the electrical contacts **430***a*, **430***b*. In some examples, a temperature sensor could be thermally coupled to one or more of the electrical contacts **430***a*, **430***b* to enable the detection of the temperature of skin proximate to the one or more electrical contacts **430***a*, **430***b*.

Further, an ECG waveform could be extracted from voltage fluctuations between the outer portion **460** of the frame and one or more electrical contacts **430***a*, **430***b* when the central housing **410** is mounted to a first external body surface (e.g., skin of a wrist of a first arm of a wearer) and a second body surface (e.g., skin of a finger of an arm of the wearer opposite the arm to which the wearable device is mounted) is in contact with the outer portion **460** of the frame **450**. Other operation of the wearable device **400** to extract and ECG signal of a wearer, as described herein or otherwise, are anticipated.

In some examples, the outer portion **460** of the frame and one or more electrical contacts **430***a*, **430***b* could be composed of similar materials and/or configured to couple to voltage fluctuations of skin similarly. For example, the outer portion **460** of the frame and one or more electrical contacts **430***a*, **430***b* could all have surfaces composed of silver/silver-chloride and could make ohmic electrical contact with skin. In another example, the outer portion **460** of the frame and one or more electrical contacts **430***a*, **430***b* could all have surfaces composed of a substantially non-conductive dielectric and could make substantially capacitive electrical contact with skin. Further, the outer portion **460** of the frame and one or more electrical contacts **430***a*, **430***b* could be composed of different materials and/or configured to couple to voltage fluctuations of skin differently. For example, the outer portion **460** of the frame could have surfaces composed of silver/silver-chloride and could make ohmic electrical contact with skin, while the electrical contacts **430***a*, **430***b* could have surfaces composed of a substantially non-conductive dielectric and could make substantially capacitive electrical contact with skin. Other combinations of electrode configurations and compositions are anticipated.

The central housing **410** additionally includes an optical sensor **440**. The optical sensor **440** includes a photodetector **441** and four light sources **443***a*, **443***b*, **443***c*, **443***d*. The photodetector **441** and light sources **443***a*, **443***b*, **443***c*, **443***d* are disposed behind protective windows **445**. The four light sources **443***a*, **443***b*, **443***c*, **443***d* could be similarly or differently configured. The photodetector could be any element configured to electronically detect one or more properties (e.g., wavelength, spectral profile, amplitude, amplitude within a specified range of wavelengths) of received light (e.g., a photodiode, a phototransistor, a photoresistor, an avalanche photodiode). The four light sources **443***a*, **443***b*, **443***c*, **443***d* could include LEDs, laser, or other elements configured to emit light. Further, the four light sources **443***a*, **443***b*, **443***c*, **443***d* could be configured to emit light having one or more specified properties (e.g., a specified wavelength, a specified amplitude, a specified waveform over time, a specified pulse or other timing). The optical sensor **440** could be configured to illuminate target tissues (e.g., using the light sources **443***a*, **443***b*, **443***c*, **443***d*) and to detect light responsively or otherwise emitted from the target tissue (e.g., using the photodetector **441**) to detect one or more properties of the target tissue.

FIG. **4**C illustrates a bottom perspective view of the wearable device **400** when the central housing **410** has been unseated from the frame **450**. FIG. **4**C illustrates a nonconductive housing **415**, a wired interface **419**, and contact pads **417** of the central housing. The wired interface **419** could be any interface configured to receive one or more conductors configured, e.g., as a connector such that power and electronic signals may be transmitted to and/or received from electronics disposed in the central housing **410**. For example, the wired interface **419** could be a micro-USB interface. The contact pads **417** are configured to allow electrical contacts between electronics of the central housing **410** and electronics or other elements of a modular frame (e.g., the conductive electrical contact formed by the outer portion **460** of the frame **450**). These elements are further illustrated by FIG. **4**D, which illustrates a top perspective view of the central housing **410**.

Note that the contact pads **417** could be electrically connected within the central housing **410** or could be electrically independent. That is, the contact pads **417** could be electrically connected together such that the contact pads **417** cannot be used to transfer different electrical signals. Alternatively, the contact pads **417** could be electrically distinct (e.g., could be connected to separate components of electronics within the central housing **410**) and thus could be used to transfer different electrical signals. For example, the four contact pads **417** could be connected to respective four distinct electrical contacts or electrodes of a modular frame into which the central housing **410** could be removably seated. Additionally or alternatively, a modular frame could electrically connect one or more of the four contact pads **417** together according to some application. For example, a first contact pad could be configured to detect a voltage, a second contact pad could be configured to source and/or sink a specified current, and the modular frame could connect the first and second contact pads to a single electrical contact to enable the determination of a resistance of some target (e.g., of a portion of skin, by determining a voltage across the portion of skin related to the specified current injected into the portion of skin) In some applications, two of the contact pads **417** could be configured to provide power to a component of the modular mount, and the remaining two contact pads **417** could be configured to transmit and/or received data to/from elements of the modular mount (e.g., an active sensor of the modular mount). Additionally or alternatively, such a configuration of the contact pads **417** could be used to facilitate communication between the central housing **410** and some other system, e.g., to facilitate reprogramming of electronics of the central housing **410**, to facilitate data transfer of logged data stored in a data storage of the central housing, or some other application. Additional or alternative configurations and applications of the contact pads **417** and of the central housing **410** are anticipated.

FIGS. **4**E and **4**F show bottom perspective and top perspective exploded views of the frame **450**, respectively. The frame **450** includes four spring-loaded contacts **455** configured to maintain electrical contact between the outer portion **460** of the frame **450** and the contact pads **417** of the central housing **410** when the central housing **410** is seated in the frame **450**. The spring-loaded contacts **455** are disposed within and retained by respective holes **475** formed in the inner portion **470** of the frame **450**. Note that some or all of the spring-loaded contacts **455** could alternatively be disposed as part of the central housing **410**. Further all of the spring-loaded contacts **455** are in electrical contact with each other and with the outer portion **460** (i.e., the electrical contact) of the frame **450**, but individual contacts of the spring-loaded contacts **455** could be in electrical contact with electrically distinct elements (e.g., separate electrical contacts, some other electrical and/or electronic element(s)) of a modular frame.

FIG. **5** is a simplified schematic of a system **500** including one or more wearable devices **510**. The one or more wearable devices **510** may be configured to transmit data via a communication interface **515** over one or more communication networks **520** to a remote server **530**. In one embodiment, the communication interface **515** includes a wireless transceiver for sending and receiving communications (e.g., indications of a measured skin resistance and/or capacitance) to and from the server **530**. In further embodiments, the communication interface **515** may include any means for the transfer of data, including both wired and wireless communications. For example, the communication interface **515** may include a universal serial bus (USB) interface or a secure digital (SD) card interface. Communication networks **520** may include any of: a plain old telephone service (POTS) network, a cellular network, a fiber network and a data network. The server **530** may include any type of remote computing device or remote cloud computing network. Further, communication network **520** may include one or more intermediaries, including, for example wherein the wearable device **510** transmits data to a mobile phone or other personal computing device, which in turn transmits the data to the server **530**.

In addition to receiving communications from the wearable device **510**, such as data regarding health and/or affect state as input by the user or extracted electrocardiographic (ECG) waveforms, the server may also be configured to gather and/or receive either from the wearable device **510** or from some other source, information regarding a wearer's overall medical history, environmental factors and geographical data. For example, a user account may be established on the server for every wearer that contains the wearer's medical history. Moreover, in some examples, the server **530** may be configured to regularly receive information from sources of environmental data, such as viral illness or food poisoning outbreak data from the Centers for Disease Control (CDC) and weather, pollution and allergen data from the National Weather Service. Further, the server may be configured to receive data regarding a wearer's health state from a hospital or physician. Such information may be used in the server's decision-making process, such as recognizing correlations and in generating clinical protocols.

Additionally, the server may be configured to gather and/or receive the date, time of day and geographical location of each wearer of the device during each measurement period. If measuring physiological parameters of the user (e.g., extracted ECG waveforms), such information may be used to detect and monitor spatial and temporal spreading of diseases. As such, the wearable device may be configured to determine and/or provide an indication of its own location. For example, a wearable device may include a GPS system so that it can include GPS location information (e.g., GPS coordinates) in a communication to the server. As another example, a wearable device may use a technique that involves triangulation (e.g., between base stations in a cellular network) to determine its location. Other location-determination techniques are also possible.

Further, some embodiments of the system may include privacy controls which may be automatically implemented or controlled by the wearer of the device. For example, where a wearer's collected data are uploaded to a cloud computing network for analysis by a clinician, the data may be treated in one or more ways before it is stored or used, so that personally identifiable information is removed. For example, a user's identity may be treated so that no personally identifiable information can be determined for the user, or a user's geographic location may be generalized where location information is obtained (such as to a city, ZIP code, or state level), so that a particular location of a user cannot be determined.

Additionally or alternatively, wearers of a device may be provided with an opportunity to control whether or how the device collects information about the wearer (e.g., information about a user's medical history, social actions or activities, profession, a user's preferences, or a user's current location), or to control how such information may be used. Thus, the wearer may have control over how information is collected about him or her and used by a clinician or physician or other user of the data. For example, a wearer may elect that data, such as health state and physiological

parameters, collected from his or her device may only be used for generating an individual baseline and recommendations in response to collection and comparison of his or her own data and may not be used in generating a population baseline or for use in population correlation studies.

IV. Example Electronics Disposed in a Wearable Device

FIG. **6** is a simplified block diagram illustrating the components of a wearable device **600**, according to an example embodiment. Wearable device **600** may take the form of or be similar to one of wearable device **110**, **210**, **300***a*, **300***b*, **300***c*, **300***d*, and **400** shown in FIGS. **1**A-B, **2**, **3**A-D, and **4**A-**4**F. However, wearable device **600** may also take other forms, for example, an ankle, waist, or chest-mounted device.

In particular, FIG. **6** shows an example of a wearable device **610** having a signal conditioner **330** for extracting an electrocardiographic (ECG) waveform from voltage fluctuations between two skin locations proximate to the wearable device **610**, a rechargeable battery **635**, a user interface **680**, communication interface **690** for transmitting data to a server, a temperature sensor **644**, and processor(s) **650**. The components of the wearable device **600** may be disposed on or within a mount and/or housing for mounting the wearable device and components thereof to an external body surface, e.g., one of the two skin locations from which the signal conditioner **330** is configured to extract an ECG waveform. The wearable device **610** also includes a first electrical contact **640** and a second electrical contact **645** operatively coupled to the signal conditioner **630**. The signal conditioner **630** uses the first and second electrical contacts **640**, **645** to extract an ECG waveform from voltage fluctuations between first and second skin locations proximate to respective first and second electrical contacts **640**, **645**. The signal conditioner **630** could be configured to perform other functions using the first and second electrical contacts **640**, **645** and/or further electrical contacts of the wearable device **600**. For example, the signal conditioner **630** could be configured to interface with a charger or other external device or system to power the electronics and to recharge the rechargeable battery **635**, to determine that the first and second electrical contacts **640**, **645** are in contact with skin and/or that an ECG waveform can be extracted from voltage fluctuations between them **640**, **645**, to determine a skin resistance and/or capacitance between the electrical contacts **640**, **645** and/or some other electrical contacts, or some other function (s). Additionally or alternatively, the rechargeable battery **635** could be charged wirelessly using a coil and/or other components of the wearable device **600** (not shown). Additionally, the temperature sensor **644** is thermally coupled to the first electrical contact **640** such that the temperature sensor **644** can be used to obtain a measurement related to the temperature of skin proximate to the first electrical contact **640**.

Processor **650** may be a general-purpose processor or a special purpose processor (e.g., digital signal processors, application specific integrated circuits, etc.). The one or more processors **650** can be configured to execute computer-readable program instructions **672** that are stored in a computer readable medium **660** (i.e., data storage) and are executable to provide the functionality of a wearable device **600** described herein.

The computer readable medium **660** may include or take the form of one or more non-transitory, computer-readable data storage media that can be read or accessed by at least one processor **650**. The one or more computer-readable storage media can include volatile and/or non-volatile storage components, such as optical, magnetic, organic or other memory or disc storage, which can be integrated in whole or in part with at least one of the one or more processors **650**. In some embodiments, the computer readable medium **660** can be implemented using a single physical device (e.g., one optical, magnetic, organic or other memory or disc storage unit), while in other embodiments, the computer readable medium **660** can be implemented using two or more physical devices.

The signal conditioner **630** could include a variety of components configured in a variety of ways to allow one or more ECG waveforms to be extracted from voltage fluctuations between the electrical contacts **640**, **645** when the electrical contacts **640**, **645** are contacting appropriate respective skin locations of a wearer and/or to allow other operations and applications. The signal conditioner **630** could include analog and/or digital electronic components to enable analog and/or digital manipulations of electrical signals related to voltage fluctuations between the electrical contacts **640**, **645**. In some examples, the signal conditioner **630** could include one or more analog electronic components (e.g., amplifiers, transistors, op-amps, analog filters) assembled into an analog front-end and configured to amplify, buffer, filter, or otherwise act on voltage fluctuations between the electrical contacts **640**, **645** and to present one or more analog electronic outputs to digital components of the signal conditioner **630** and/or other elements of the wearable device **600** (e.g., to an ADC or other component of the processor **650**).

Generally, the signal conditioner **630** includes components configured to amplify and filter voltage fluctuations between the electrical contacts **640**, **645**. The signal conditioner **630** could include one or more amplifiers, buffers, filters, operational amplifiers, resistors, capacitors, inductors, transistors, rectifiers, or some other linear or nonlinear electronic component or combinations thereof. Such components could be formed as a number of discrete signal processing blocks (e.g., discrete sets of components configured to perform some operation(s) on electronic input(s) to form electronic output(s)) that are connected together (e.g., the output(s) of a first block form the input(s) of one or more other blocks).

In some embodiments, the signal conditioner **630** could be configured to generate an electronic signal (e.g., to generate an extracted ECG waveform) that is related to a band-passed version of the voltage fluctuations between the electrical contacts **640**, **645**. This could include applying the voltage fluctuations to a band-pass filter having a pass-band between approximately 0.05 Hertz and approximately 150 Hertz. The signal conditioner **630** could additionally apply a notch filter (at, e.g., approximately 60 Hertz) to remove some narrow-band signal from the voltage fluctuations (e.g., to remove approximately 60 Hertz noise emitted by power mains in the environment of the wearable device **600**). Additionally or alternatively, an electronic signal could be digitally sampled and some digital filtering could be performed (e.g., by the processor **650**) to generate an extracted ECG waveform. In such examples, the processor **650** and elements thereof (e.g., an ADC of the processor) could be considered part of an overall signal conditioner configured to extract an ECG waveform from voltage fluctuations between the electrical contacts **640**, **645**.

The signal conditioner **630** could include a fast response circuit or other circuitry or components configured to allow the signal conditioner **630** to extract an ECG waveform after

the voltage fluctuations between the electrical contacts **640**, **645** exhibit a large change (e.g., a change in baseline voltage level, a spike or other transient related to an electrostatic discharge, a skin location coming into contact with one of the electrical contacts, and/or a skin location moving relative to one or both of the electrical contacts **640**, **645**). For example, the signal conditioner **630** could be configured to determine that one or more elements (e.g., amplifiers, op-amps, signal processing blocks) of the signal conditioner **630** are electronically saturated (i.e., outputting a maximal and/or minimal signal level, or having an internal signal that has a maximal or minimal value) and to responsively control one or more properties of the signal conditioner **630** to reduce the electronic saturation of the one or more elements of the signal conditioner **630**.

Determining that one or more elements of the signal conditioner are electronically saturated could include sampling an output or other electronic signal of the signal conditioner **630** using an ADC and making a determination related to one or more digital outputs of the ADC, applying an output or other electronic signal of the signal conditioner **630** to a comparator, Schmitt trigger, or other digital component, or some other determination. Further, controlling one or more properties of the signal conditioner **630** to reduce the electronic saturation of the one or more elements of the signal conditioner **630** could include discharging a capacitor, switching in and/or out one or more signal-processing blocks of the signal conditioner **630**, and/or changing a corner frequency, pass-band, or other parameter(s) of a filter (e.g., increasing a corner frequency of a high-pass filter to allow the output of the filter to more quickly reduce from a saturation level). These methods of control could be implemented by operating one or more electronic switches, transistors, or other elements.

Additionally or alternatively, fast response or other circuitry of the signal conditioner **630** could prevent electronic saturation of one or more elements of the signal conditioner **630** by having a nonlinear property; for example, a metal-oxide varistor or other electronic elements or combinations thereof having a nonlinear current-voltage characteristic (e.g., having a lower resistance and/or impedance at higher voltages than at lower voltages) could be included in the signal conditioner **630** (e.g., could be connected across a filtering or other capacitor, could be connected between a signal line and a ground plane). Fast response or other circuitry of the signal conditioner **630** configured to prevent electronic saturation of one or more elements of the signal conditioner **630** could exhibit hysteresis. For example, fast response circuitry could include a Schmitt trigger configured to close a capacitor-discharging switch when the voltage across the capacitor exceeds a first specified level and to subsequently open the capacitor-discharging switch when the voltage across the capacitor falls below a second specified level.

The signal conditioner **630** could include circuitry or other elements configured to detect and/or determine whether the first and second electrical contacts **640**, **645** are in contact with skin and/or that an ECG waveform can be extracted from voltage fluctuations between them **640**, **645**. The signal conditioner **630** could include circuitry (e.g., voltage dividers, relaxation oscillators, current injectors) configured to actively or passively detect an effective resistance and/or capacitance between the first and second electrical contacts **640**, **645** that could be used to determine that the first and second electrical contacts **640**, **645** are in contact with skin and/or that an ECG waveform can be extracted therefrom. Such circuitry could additionally be configured and/or operated to detect other properties of a wearer, e.g., a body water content, a body fat content. Additionally or alternatively, the signal conditioner **630** could include circuitry (e.g., comparators, Schmitt triggers, overvoltage sensors, differentiators, fast response circuitry) configured to detect electrostatic discharges, voltage transients, changes in voltage offsets, or other properties of voltage fluctuations between the first and second electrical contacts **640**, **645** that are related to the electrical contacts **640**, **645** coming into and/or leaving contact with skin of a wearer.

A voltage sensor of the signal conditioner **630** (and/or of the processor **650**) could include one or more comparators, Schmitt triggers, direct-conversion ADCs, successive-approximation ADCs, sigma-delta ADCs, or some other type(s) of ADC. The voltage sensor could include an amplifier, a filter, a sample-and-hold, and/or some other components. Further, individual elements of the signal conditioner **630** could be embodied as respective discrete components. Additionally or alternatively, one or more elements of the signal conditioner **630** could be incorporated into one or more integrated circuits (e.g., an integrated circuit that includes elements of the processor **650**, the communication interface(s) **690**, and/or elements of the wearable device **600**. In examples where the signal conditioner **630** are included in a wearable device composed of multiple housings or other subassemblies, the elements of the signal conditioner **630** could all be disposed in a single housing or subassembly or elements of the signal conditioner **630** could be disposed in multiple housings or subassemblies and connected using wires, cables, or other means passing between housings or subassemblies.

In some examples, voltage sources, electronic switches, amplifiers, filters, op-amps, voltage sensors (e.g., ADCs, comparators, Schmitt triggers), and/or other elements of the signal conditioner **630** could be elements of a microprocessor (e.g., of **650**) that are electronically coupled to a pin of the microprocessor (e.g., logic gates, capacitors, high-impedance electrical switches (e.g., CMOS FETs), or other microelectronics). For example, a voltage source of the signal conditioner **630** could be an internal voltage supply of the microprocessor, and a voltage source switch of the signal conditioner **630** could be a gate of the microprocessor configured to electrically connect the internal voltage supply and/or an internal ground of the microprocessor to a pin of the microprocessor and to appear as a high impedance element when not connecting the pin to the internal voltage supply and/or the internal ground (e.g., to provide a 'three-state' digital output to the pin). An ADC of the microprocessor could additionally be configured to electrically connect to the pin and to act as a voltage sensor of the signal conditioner **630**.

In some examples, the signal conditioner **630** could include circuitry to protect elements of the wearable device **600** (e.g., to protect amplifiers, filters, voltage sensors, or other elements of the signal conditioner **630**) from high voltages and/or currents present across and/or through the electrical contacts **640**, **645**. For example, the signal conditioner **630** could include clamping diodes, blocking resistors, blocking capacitors, electronic switches, or other elements configured to prevent components of the signal conditioner **630** from being damaged by voltages and/or currents at/through the electrical contacts **640**, **645**. These elements of the signal conditioner **630** could be configured to protect the wearable device **600** from electrostatic discharges from the environment of the wearable device **600**.

The signal conditioner **630** could include additional components. In some examples, the signal conditioner **630** could include a recharger configured to recharge the rechargeable battery **635** and to be powered through the electrical contacts **640**, **645** and/or some additional electrical contact(s). In some examples, the wearable device **600** could be configured to be mounted on an external charger. The external charger could be configured to apply a voltage and/or current to the electrical contacts (e.g., **640**, **645**) sufficient to power the recharger to recharge the rechargeable battery **635**. The signal conditioner **630** could include rectifiers, capacitors, or other elements disposed electrically between the recharger and the electrical contacts (e.g., **640**, **645**). The rectifiers or other elements could be configured to reduce electrical interference in ECG waveform measurements made using the electrical contacts **640**, **645** when the wearable device **600** is mounted to an external surface of a wearer and not mounted to an external charger. Additionally or alternatively, the wearable device **600** could include a coil and other components configured to receive electromagnetic energy (e.g., from a wireless charger) and to recharge the rechargeable battery **635** using the received electromagnetic energy. The signal conditioner **630** could include components configured to detect an EMG, a skin resistance, a skin capacitance, a body water content, a body fat content, a Galvanic skin response, or some other electrical signal using the electrical contacts **640**, **645** and/or some additional electrical contact(s). The signal conditioner **630** could include components to operate some other sensors (e.g., accelerometers, optical pulse sensors, photoplethysmographic sensors, pulse oximeters, thermometers, the temperature sensor **644**) configured to detect one or more properties of a wearer of the wearable device **600** and/or of the environment of the wearable device **600**.

Note that, while the signal conditioner **630**, processor(s) **650**, rechargeable battery **635**, and other components are sometimes described herein as being disposed on or within a single housing, other configurations are anticipated. In some examples, a wearable device could include multiple housings, and the components of the wearable device **600** could be distributed amongst the multiple housings. For example, a first housing could contain some elements of the signal conditioner **630** (for example, ECG waveform extraction electronics, temperature sensing electronics) and the electrical contacts **640**, **645** could protrude from the first housing. A second housing could include the recharger electronics and the rechargeable battery **635** and elements disposed in the second housing could be electrically connected to elements disposed in the first housing. In some examples, the wearable device **600** could include a modular mount and a housing configured to be removably seated in a frame of the modular mount. The first electrical contact **640**, elements of the signal conditioner **630**, and/or other elements of the wearable device **600** (e.g., **650**, **660**, **680**, **690**, **635**) could be disposed on or within the housing. The second electrical contact **645** (and other elements) could be disposed on or within the modular mount (e.g., on an outside surface of the frame, on an outside surface of a band of the modular mount) and maintained in electrical contact with elements of the housing (e.g., **630**) via spring-loaded contact(s) or some other means. Other numbers of housings, configurations of housings, and dispositions of components within multiple housings are anticipated.

The program instructions **672** stored on the computer readable medium **660** may include instructions to perform or facilitate some or all of the device functionality described herein. For instance, program instructions **672** could include instructions to operate the signal conditioner **630** to extract an ECG waveform from voltage fluctuations between the electrical contacts **640**, **645**. The program instructions **672** could additionally include instructions to operate other elements of the signal conditioner **630** (e.g., switches, circuit breakers, FETs) to protect other elements of the wearable device **600** that are electrically coupled to the electrical contacts **640**, **645** (e.g., an amplifier and/or voltage sensor of the signal conditioner **630**) from being damaged. The program instructions **672** could include instructions to operate based on parameter and user data **674** stored in the computer readable medium **660** and/or modify the parameters and user data **674**. For example, the parameters and user data **674** could include calibration data for the wearable device **600** and/or stored ECG waveforms (and/or features thereof, e.g., Q-T intervals, QRS complex parameters) extracted using the wearable device **600**.

The program instructions **672** stored on the computer readable medium **660** could include instructions for operating the signal conditioner **630** to extract an ECG waveform from voltage fluctuations between the electrical contacts **640**, **645**. The instructions could include instructions to activate and/or set a value of a current source, a voltage source, a programmable resistor, an ADC, one or more electronic switches, and/or some other component(s) of the signal conditioner **630**. The instructions could include instructions to set a gain, bandwidth, corner frequency, notch frequency, or other property of an amplifier and/or filter of the signal conditioner **630**. The instructions could include instructions to operate a voltage or current sensor to make one or more measurements relating to the voltage between the electrical contacts **640**, **645**. The instructions could include instructions to operate a voltage or current sensor to make a series of measurements during a respective series of regularly spaced periods of time relating to the voltage between the electrical contacts **640**, **645**.

The instructions could include instructions to determine whether the first and second electrical contacts **640**, **645** are in contact with skin and/or that an ECG waveform can be extracted from voltage fluctuations between electrical contacts **640**, **645** and to responsively extract an ECG waveform. This could include analyzing voltage fluctuations between the electrical contacts **640**, **645** to determine whether the voltage fluctuations contain ECG waveforms. Additionally or alternatively, this could include actively or passively sensing an effective resistance and/or capacitance between the electrical contacts **640**, **645** and further determining that the sensed resistance and/or capacitance corresponds to the electrical contacts **640**, **645** being in contact with skin. In some examples, the instructions could include instructions to extract an ECG waveform in response to a user input (e.g., in response to a user depressing a button of the wearable device **600** to indicate that the wearer is contacting the first and second electrical contacts **640**, **645** to skin at appropriate respective first and second skin locations).

Other instructions in the program instructions **672** relating to the use of the signal conditioner **630** to extract one or more ECG waveforms from voltage fluctuations between the electrical contacts **640**, **645** are anticipated. The program instructions **672** could include instructions to extract a plurality of ECG waveforms during a plurality of periods of time using the signal conditioner **630**. The program instructions **672** could include instructions to log or otherwise store data related to the extracted ECG waveform(s) in the parameters and user data **874** and/or some other data storage.

The instructions could include instructions to operate the wearable device **600** based on an extracted ECG waveform(s) and or information related to extracted ECG waveform(s). For example, the instructions could describe how to determine a health or other state of a wearer based on extracted ECG waveform(s) (e.g., based on a determined heart rate, a determine pulse timing variability, a determined Q-T interval, determined QRS complex parameters, or some other determined property or feature of one or more extracted ECG waveforms). The instructions could describe how to determine whether the first and second electrical contacts **640**, **645** are in contact with skin and/or that an ECG waveform can be extracted from voltage fluctuations between them **640**, **645**. The instructions could further describe how to operate the wearable device **600** relative to such a determination. For example, one or more elements (e.g., a voltage or current sensor, an amplifier) of the signal conditioner **630** and/or of the wearable device **600** could be disabled and/or operated in a low-power state when the wearable device **600** determines that the first and second electrical contacts **640**, **645** are not in contact with skin and/or that an ECG waveform cannot be extracted from voltage fluctuations between them **640**, **645**. Other operations relative to such a determination are anticipated and could be described by the program instructions **672**.

The program instructions **672** stored on the computer readable medium **660** could include instructions for operating components of the wearable device **600** (e.g., the signal conditioner **630**) to recharge the rechargeable battery **635** and/or to power the wearable device **600** using the rechargeable battery **635**. For example, the instructions could include instructions for operating switches or other electrical components to gate power from the electrical contacts **640**, **645** to the recharger and/or from the recharger to the rechargeable battery **635**. Additionally or alternatively, the instructions could include instructions to operate a voltage or current sensor (possibly a sensor of the signal conditioner **630**) to detect the presence of an external charger in electrical contact with the electrical contacts **640**, **645** and/or to detect a charge state of the rechargeable battery **635**. A recharger and/or rectifier elements of the signal conditioner **630** or of other electronics of the wearable device **600** could be passive, that is, they could be configured to recharge the rechargeable battery **635** and/or power the wearable device **600** without direct operation by the processor(s) **650** or other elements of the wearable device **600** (other than the electrical contacts **640**, **645**) when the wearable device **600** is mounted to an external charger or other appropriately configured power source. Additionally or alternatively, a coil and other components of a wireless charger of the wearable device **600** could be configured to receive electromagnetic energy and to charge the rechargeable battery **635** using the received electromagnetic energy.

The program instructions **672** can include instructions for operating the user interface(s) **680**. For example, the program instructions **672** could include instructions for displaying data about the wearable device **600**, for displaying an extracted ECG waveform or other information generated by the wearable device **600** (e.g., a heart rate, a variability of extracted ECG waveforms), or for displaying one or more alerts generated by the wearable device **600** and/or received from an external system. Further, program instructions **672** may include instructions to execute certain functions based on inputs accepted by the user interface(s) **680**, such as inputs accepted by one or more buttons disposed on the user interface(s) **680**.

Communication interface **690** may also be operated by instructions within the program instructions **672**, such as instructions for sending and/or receiving information via an antenna, which may be disposed on or in the wearable device **600**. For example, the program instructions **672** could include instructions to operate the communication interface **690** to transmit an extracted ECG waveform and/or information related to an extracted ECG waveform using the communication interface **690** (e.g., using a wireless transmitter of the communication interface **690**). The communication interface **690** can optionally include one or more oscillators, mixers, frequency injectors, etc. to modulate and/or demodulate information on a carrier frequency to be transmitted and/or received by the antenna. In some examples, the wearable device **600** is configured to indicate an output from the processor **650** by modulating an impedance of the antenna in a manner that is perceivable by a remote server or other remote computing device.

In some examples, the communication interface(s) **690** could be operably coupled to the electrical contacts **640**, **645** and could be configured to communicate with an external system by using the electrical contacts **640**, **645**. In some examples, this includes sending and/or receiving voltage and/or current signals transmitted through the electrical contacts **640**, **645** when the wearable device **600** is mounted onto an external system such that the electrical contacts **640**, **645** are in electrical contact with components of the external system.

In some examples, extracted ECG waveforms, temperature measurements, wearer profiles, history of wearable device use, health state information input by device wearers and generated recommendations and clinical protocols may additionally be input to a cloud network and be made available for download by a wearer's physician. Trend and other analyses may also be performed on the collected data, such as physiological parameter data and health state information, in the cloud computing network and be made available for download by physicians or clinicians.

Further, extracted ECG waveforms and/or health state data from individuals or populations of device wearers may be used by physicians or clinicians in monitoring efficacy of a drug or other treatment. For example, high-density, real-time data may be collected from a population of device wearers who are participating in a clinical study to assess the safety and efficacy of a developmental drug or therapy. Such data may also be used on an individual level to assess a particular wearer's response to a drug or therapy. Based on this data, a physician or clinician may be able to tailor a drug treatment to suit an individual's needs.

In response to a determination by instructions contained in the program instructions **672** that a medical condition is indicated, the wearable device **600** may generate an alert via the user interface **680**. The alert may include a visual component, such as textual or graphical information displayed on a display, an auditory component (e.g., an alarm sound), a tactile component (e.g., a vibration), and/or an electro-haptic component (e.g., an electro-haptic stimulus delivered using the electrical contacts **640**, **645**). The textual information may include one or more recommendations, such as a recommendation that the wearer of the device contact a medical professional, seek immediate medical attention, or administer a medication.

V. Illustrative Methods for Operating a Wearable Device

FIG. **7** is a flowchart of a method **700** for operating a wearable device. The operated wearable device includes (i)

a housing, (ii) a mount configured to mount the housing to a wrist location of a first arm of a wearer, (iii) a first electrical contact disposed on the housing and configured to contact skin at a first external body surface when the housing is mounted on the first external body surface, (iv) a second electrical contact that is configured to be contacted by skin of a second body surface located on a second arm of the wearer, (v) a signal conditioner connected to the first and second electrical contacts and configured to extract an electrocardiographic (ECG) waveform form voltage fluctuations between the first and second electrical contacts.

The method **700** includes mounting the wearable device to the wrist location of the first arm of the wearer such that skin of the first external body surface of the wrist location is in contact with the first electrical contact (**710**). This could include encircling the wrist of the wearer with a band, strap, or other encircling element of the mount. This could include operating a clasp, snap, or other securing elements of the mount such that the wearable device is mounted to the wrist location (e.g., securing two halves of a flexible strap of the mount together around the wrist of the wearer). In some examples, the mount includes an adhesive, and mounting the wearable device to the wrist location (**710**) includes activating, applying, and/or exposing the adhesive and adhering the wearable device to the wrist location.

The method **700** also includes placing skin of the second external body surface of a second arm of the wearer in contact with the second electrical contact (**720**). This could include the wearer contacting the second electrical contact with skin of one or more of a finger, hand, wrist, or forearm of the second arm. Placing skin of the second external body surface in contact with the second electrical contact (**720**) could occur at the initiative of the wearer, e.g., in response to the wearer having performed and/or being about to perform a strenuous task (e.g., exercise), experiencing some symptoms (e.g., fatigue, nausea, vertigo, heart palpitations, orthostatic hypertension), having received and/or being about to receive a drug (e.g., having taken nitroglycerin). Additionally or alternatively, placing skin of the second external body surface in contact with the second electrical contact (**720**) could occur in response to an indication (e.g., a vibration, a sound, a visual indication on a display of the wearable device, an indication through some other device in communication with the wearable device) that the wearer should perform such an action to enable the extraction of an ECG waveform by the wearable device.

The method **700** also includes using the signal conditioner of the wearable device to extract an ECG waveform from voltage fluctuations between the first and second electrical contacts (**730**). This could include sampling (e.g., using an ADC or other discrete-time device) a voltage between the first and second electrical contacts a plurality of time during a plurality of respective points in time. This could include amplifying, filtering, level-shifting, inverting, and/or performing some other operation on the voltage between the first and second electrical contacts using, e.g., one or more amplifiers, filters, op-amps, resistors, inductors, capacitors, other electronic element(s), and/or combinations thereof.

The method **700** for operating a wearable device could include additional steps relating to an extracted ECG waveform. In some examples, the method **700** could include indicating the extracted ECG waveform and/or information related to the ECG waveform using a display disposed in the wearable device. In some examples, the method **700** could include wirelessly transmitting the extracted ECG waveform and/or information related to the ECG waveform using a wireless transmitter disposed in the wearable device. For example, the wearable device could transmit an extracted ECG waveform to a remote system (e.g., a server or cloud service accessible to a healthcare provider). In some examples, the method **700** could include logging or otherwise storing the extracted ECG waveform and/or information related to the ECG waveform using a data storage disposed in the wearable device. In some examples, the method **700** could include operating the wearable device based on the extracted ECG waveform and/or information related to the ECG waveform. For example, the wearable device could be operated to generate an alert, send a transmission to a remote system, or some other action in response to the extracted ECG waveform and/or information related to the ECG waveform (e.g., if a Q-T interval of the extracted ECG waveform exceeds a threshold).

In another example, the method **700** could include determining whether the first and second electrical contacts are in contact with skin at the first and second external body surfaces, respectively. For example, the method could include determining that electrical contacts are contacting respective skin locations based on a detected capacitance and/or resistance between the electrical contacts being within a specified range and/or increasing or decreasing at a specified rate. The method could further include operating the wearable device relative to such a determination. For example, extracting an ECG waveform using the signal conditioner (**730**) could be performed in response to the determination that the first and second electrical contacts are in contact with respective first and second external body surfaces. Other applications of a determined resistance and/or capacitance are anticipated.

In some examples, the wearable device could include means for optically detecting the volume of blood in a portion of subsurface vasculature of the wearer at a plurality of points in time, and generating a blood volume waveform over time (i.e., a photoplethysmographic waveform) based on the plurality of detected volumes of blood. An individual such blood volume detection could include operating a light source of the wearable device to emit light into the portion of subsurface vasculature through overlying skin and operating a light sensor of the wearable device to receive light responsively reflected, scattered, or otherwise emitted from the portion of subsurface vasculature through the overlying skin. The method **700** could further include using the generated blood volume waveform, in combination with the extracted ECG waveform, to determine a blood pressure of the wearer, a degree of atherosclerosis of the vasculature of the wearer, or some other health or medical state of the wearer. This could include determining time differences or other comparisons of features of the extracted ECG waveform and the generated blood volume waveform (e.g., a time difference between a maximum of the volume waveform and a corresponding QRS complex of the ECG waveform) to determine a flow rate, a pressure wave speed and/or latency, or other information about the blood in the portion of subsurface vasculature and/or information about the heart and vasculature of the wearer.

The example method **700** illustrated in FIG. **7** is meant as an illustrative, non-limiting example. Additional or alternative elements of the method and additional or alternative components of the wearable device are anticipated, as will be obvious to one skilled in the art.

IV. Conclusion

Where example embodiments involve information related to a person or a device of a person, the embodiments should

be understood to include privacy controls. Such privacy controls include, at least, anonymization of device identifiers, transparency and user controls, including functionality that would enable users to modify or delete information relating to the user's use of a product.

Further, in situations in where embodiments discussed herein collect personal information about users, or may make use of personal information, the users may be provided with an opportunity to control whether programs or features collect user information (e.g., information about a user's medical history, social network, social actions or activities, profession, a user's preferences, or a user's current location), or to control whether and/or how to receive content from the content server that may be more relevant to the user. In addition, certain data may be treated in one or more ways before it is stored or used, so that personally identifiable information is removed. For example, a user's identity may be treated so that no personally identifiable information can be determined for the user, or a user's geographic location may be generalized where location information is obtained (such as to a city, ZIP code, or state level), so that a particular location of a user cannot be determined. Thus, the user may have control over how information is collected about the user and used by a content server.

The particular arrangements shown in the Figures should not be viewed as limiting. It should be understood that other embodiments may include more or less of each element shown in a given Figure. Further, some of the illustrated elements may be combined or omitted. Yet further, an exemplary embodiment may include elements that are not illustrated in the Figures.

Additionally, while various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are contemplated herein.

What is claimed is:

1. A wearable device, comprising:

a housing;

a modular mount for mounting the housing to a first external body surface, wherein the first external body surface is a wrist location of a first arm of a wearer, wherein the modular mount comprises a band and a frame, wherein the housing is removably seated in the frame, and wherein the band can encircle a wrist of the first arm of the wearer;

a first electrical contact disposed on the housing, wherein the first electrical contact contacts skin at the first external body surface when the housing is mounted on the first external body surface;

a second electrical contact disposed on an outside surface of the modular mount, wherein the second electrical contact can be contacted by skin of a second external body surface, wherein the second external body surface is a location of a second arm of the wearer; and

a signal conditioner disposed in the housing and electrically connected to the first and second electrical contacts, wherein the signal conditioner extracts an electrocardiographic waveform from voltage fluctuations between the first electrical contact and the second electrical contact;

wherein the signal conditioner is in electrical contact with the second electrical contact when the housing is seated in the frame, and wherein unseating the housing from the frame removes electrical contact between the signal conditioner and the second electrical contact.

2. The wearable device of claim **1**, wherein the signal conditioner is in electrical contact with the second electrical contact via at least one spring-loaded contact, wherein the spring loaded contact is disposed in the wearable device such that it is compressed when the housing is seated in the frame.

3. The wearable device of claim **1**, further comprising a display, wherein the display is disposed on an outside surface of the housing, and wherein the second electrical contact is disposed proximate to a peripheral edge of the display and at least partially encircles the display.

4. The wearable device of claim **1**, wherein the second electrical contact is disposed on an outside surface of the band.

5. The device of claim **1**, wherein at least one of the first and second electrical contacts has a surface comprising silver/silver-chloride.

6. The device of claim **1**, wherein at least one of the first and second electrical contacts capacitively couples to skin at the first and second locations, respectively.

7. The device of claim **1**, further comprising a wireless transmitter that transmits data related to the extracted electrocardiographic waveform.

8. The device of claim **1**, further comprising a data storage that logs data related to the extracted electrocardiographic waveform.

9. The device of claim **1**, wherein the signal conditioner comprises at least one amplifier, at least one high-pass filter, and at least one low-pass filter.

10. The device of claim **9**, wherein the signal conditioner comprises fast recovery circuitry, wherein the fast recovery circuitry detects when the signal conditioner is electronically saturated and responsively controls one or more properties of the signal conditioner to reduce the electronic saturation of the signal conditioner.

11. The device of claim **1**, further comprising a further sensor.

12. The device of claim **11**, wherein the further sensor comprises a light source and a light sensor, and wherein the further sensor detects a volume of blood in subsurface vasculature by emitting light into the subsurface vasculature through an overlying skin location and receiving light from the subsurface vasculature through the overlying skin location.

13. The device of claim **1**, wherein the signal conditioner determines whether the first and second electrical contacts are in contact with skin at the first and second external body surfaces, respectively.

14. A method comprising:

mounting a wearable device to a wrist of a first arm of a wearer, wherein the device comprises:

a housing;

a modular mount, wherein the modular mount comprises a band and a frame, wherein mounting the wearable device to the wrist comprises removably seating the housing in the frame and encircling the band around the wrist;

a first electrical contact disposed on the housing, wherein the first electrical contact contacts skin at a first external body surface when the wearable device is mounted to the wrist;

a second electrical contact disposed on an outside surface of the modular mount, wherein the second electrical contact can be contacted by skin of a second external body surface, wherein the second external body surface is a location of a second arm of the wearer; and

a signal conditioner disposed in the housing and electrically connected to the first and second electrical contacts, wherein the signal conditioner extracts an electrocardiographic waveform from voltage fluctuations between the first electrical contact and the second electrical contact;

wherein removably seating the housing in the frame causes the signal conditioner to be in electrical contact with the second electrical contact, and wherein unseating the housing from the frame removes electrical contact between the signal conditioner and the second electrical contact;

while the wearable device is mounted to the wrist location of the first arm of the wearer such that the first electrical contact is in contact with skin at the first external body surface, placing skin of the second external body surface in contact with the second electrical contact; and

while the first electrical contact is in contact with skin at the first external body surface and the second electrical contact is in contact with skin of the second external body surface, using the signal conditioner to extract the electrocardiographic waveform.

15. The method of claim **14**, further comprising indicating information related to the extracted electrocardiographic waveform using a display disposed in the wearable device.

16. The method of claim **14**, wherein the device further comprises a wireless transmitter, and further comprising:

transmitting data related to the extracted electrocardiographic waveform using the wireless transmitter.

17. The device of claim **14**, wherein the device further comprises a data storage, and further comprising:

logging data related to the extracted electrocardiographic waveform using the data storage.

18. The method of claim **14**, wherein the device further comprises a light source and a light sensor, and further comprising:

operating the light source to emit light into subsurface vasculature of the wearer through an overlying skin location of the wearer;

operating the light sensor to receive light from the subsurface vasculature through the overlying skin location;

determining a photoplethysmographic signal related to the volume of blood in the subsurface vasculature based at least on the light received from the subsurface vasculature by the light sensor; and

determining a blood pressure of the wearer based at least on the determined photoplethysmographic signal and the extracted electrocardiographic waveform.

19. The method of claim **14**, wherein the signal conditioner can further determine whether the first and second electrical contacts are in contact with skin at the first and second external body surfaces, respectively, and further comprising:

determining, using the signal conditioner, that the first and second electrical contacts are in contact with skin at the first and second external body surfaces, respectively.

20. The method of claim **14**, wherein removably seating the housing in the frame causes the signal conditioner to be in electrical contact with the second electrical contact via at least one spring-loaded contact, wherein the spring loaded contact is disposed in the wearable device such that it is compressed when the housing is seated in the frame.

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专利名称(译)	手腕式心电图设备		
公开(公告)号	US9526433	公开(公告)日	2016-12-27
申请号	US14/485392	申请日	2014-09-12
[标]申请(专利权)人(译)	谷歌公司		
申请(专利权)人(译)	GOOGLE INC.		
当前申请(专利权)人(译)	实实在在的生命科学LLC GOOGLE LLC		
[标]发明人	LAPETINA JOHN MIROV RUSSELL NORMAN		
发明人	LAPETINA, JOHN MIROV, RUSSELL NORMAN		
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外部链接	Espacenet USPTO		

摘要(译)

本文描述了可穿戴设备，其包括壳体和安装件，所述安装件构造成将壳体安装到佩戴者的手腕上。可穿戴设备还包括第一和第二电触头，其被配置成使得当可穿戴设备如此安装时，第一电触头与手腕附近的皮肤接触。第二电触点设置在可穿戴设备的远离手腕的表面上，使得当佩戴者用手指或与手腕相对的手臂的其他元件接触第二电触点时，可以提取佩戴者的心电图波形。来自第一和第二电极之间的电压波动。这种可穿戴设备可用于周期性记录或佩戴者的心电图波形的其他应用。这种记录的心电图波形可用于确定佩戴者的医疗或健康状态。