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(54) **WEARABLE MULTI-MODAL
PHYSIOLOGICAL SENSING SYSTEM**

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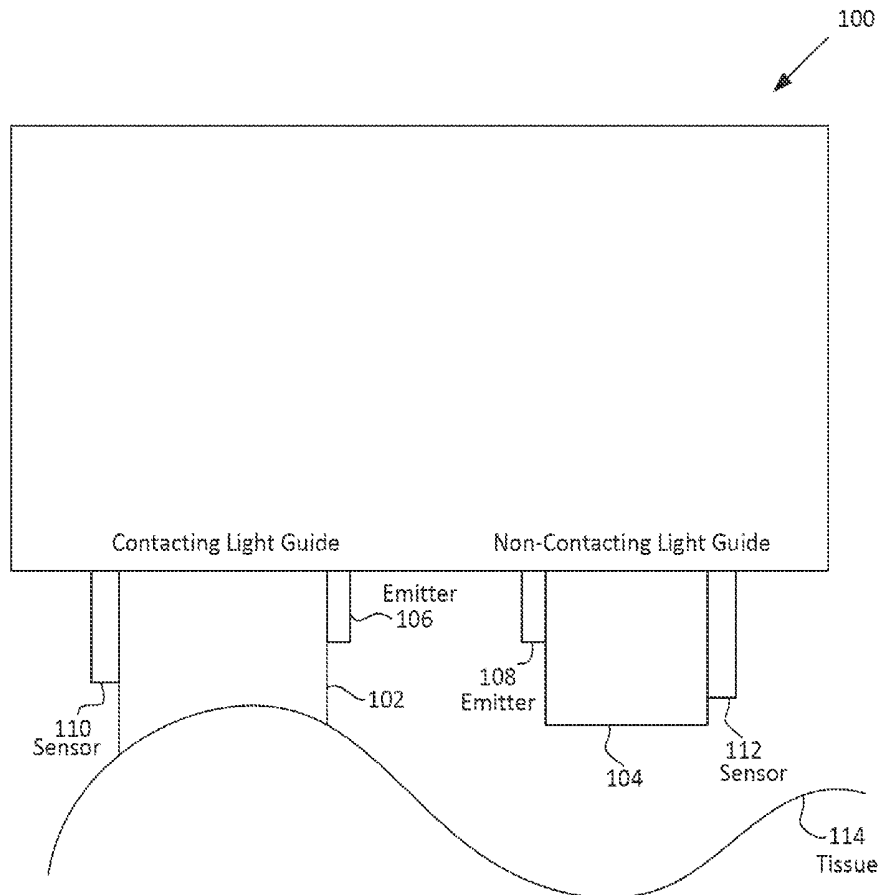
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(57)

ABSTRACT

A PPG signal may be obtained from a pulse oximeter, which employs a light emitter and a light sensor to measure the perfusion of blood to the skin of a user. However, the signal may be compromised by noise due to motion artifacts. To address the presence of motion artifacts, examples of the present disclosure can receive light information from each of two light guides, one in contact with the tissue of the user and one not in contact with the tissue of the user. First light information can be obtained from the first light guide, and second light information can be obtained from the second light guide. A heart rate signal can then be computed from the first and second light information, for example, by using blind source separation and/or cross-correlation.



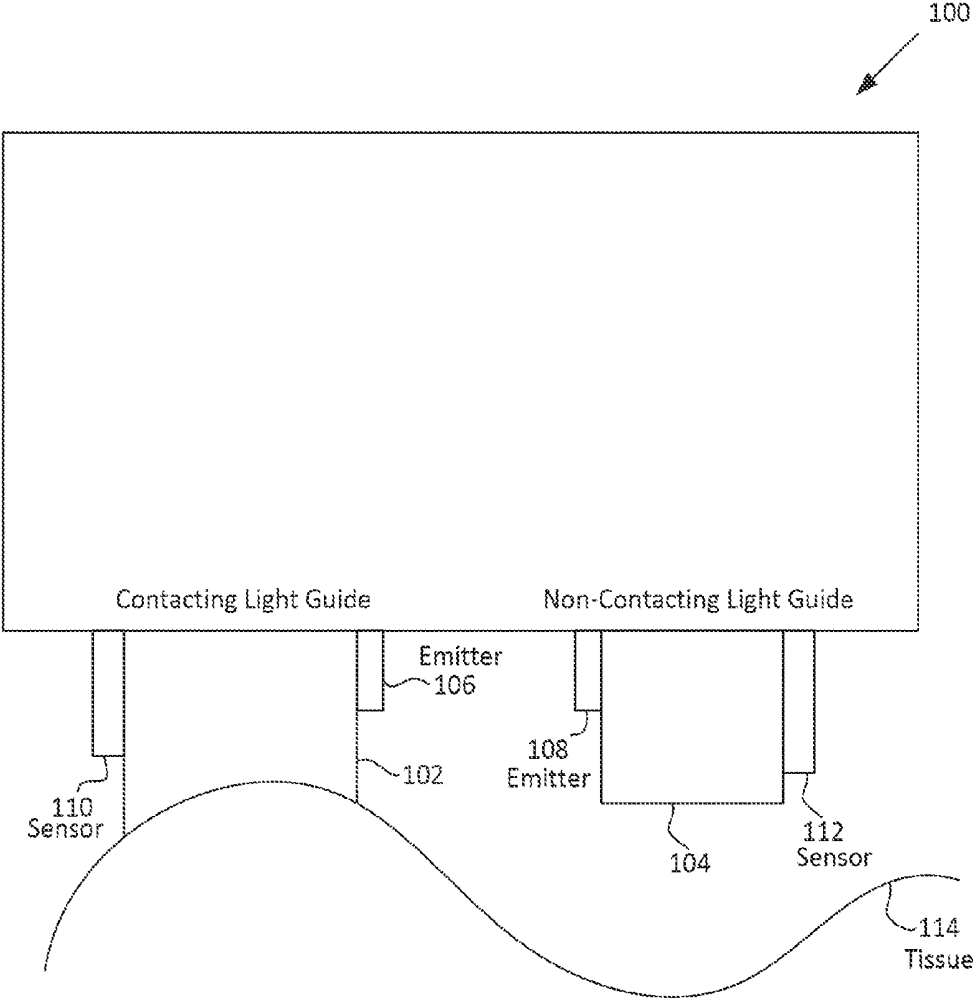


FIG. 1

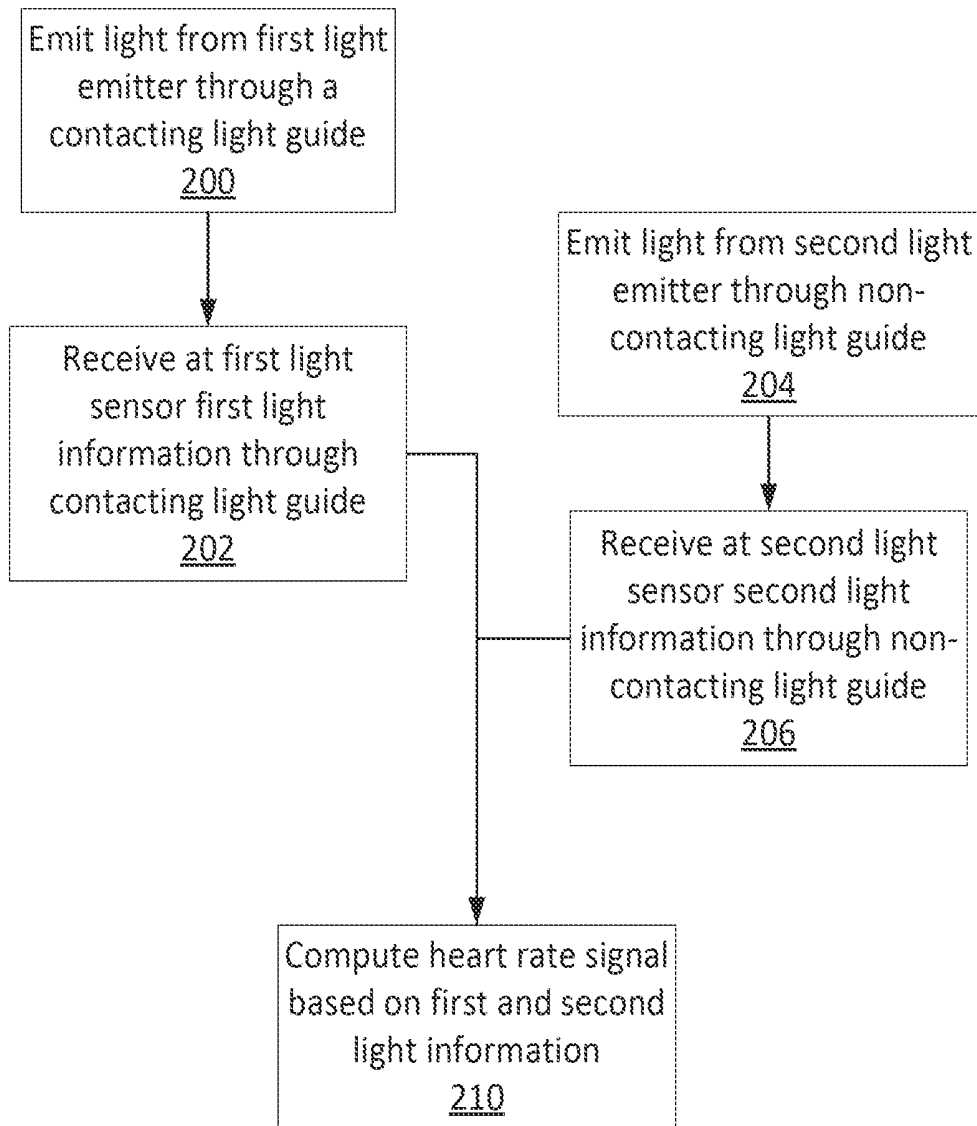


FIG. 2

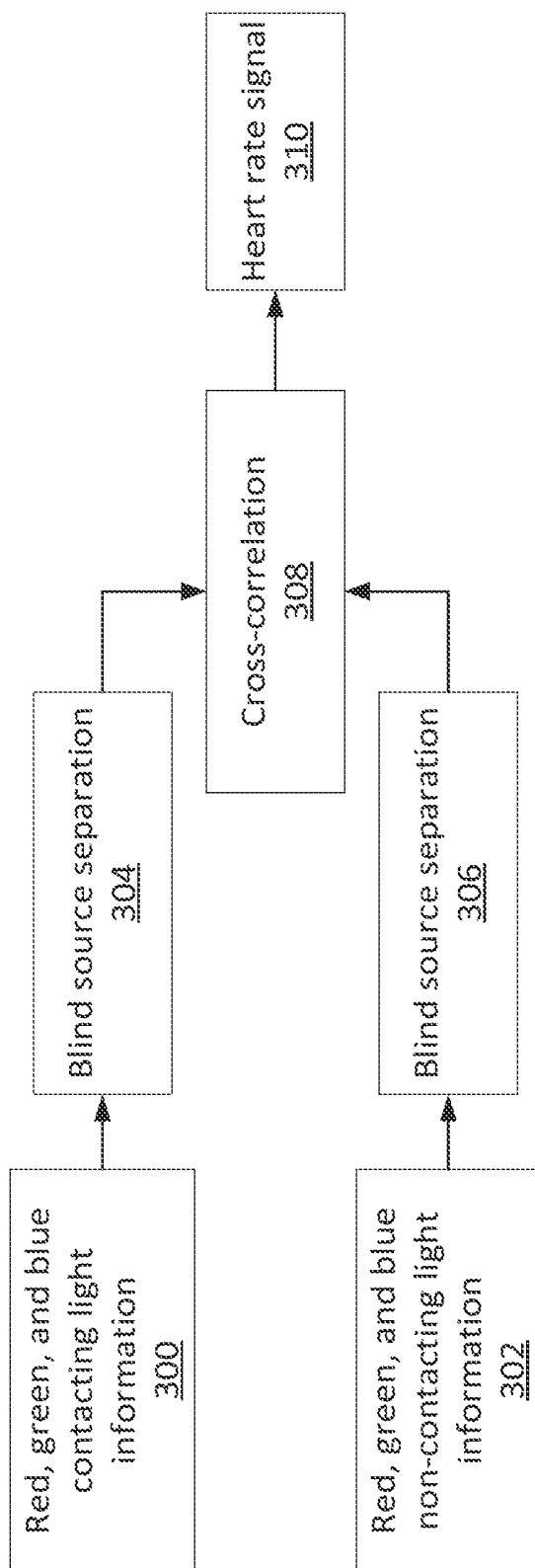


FIG. 3

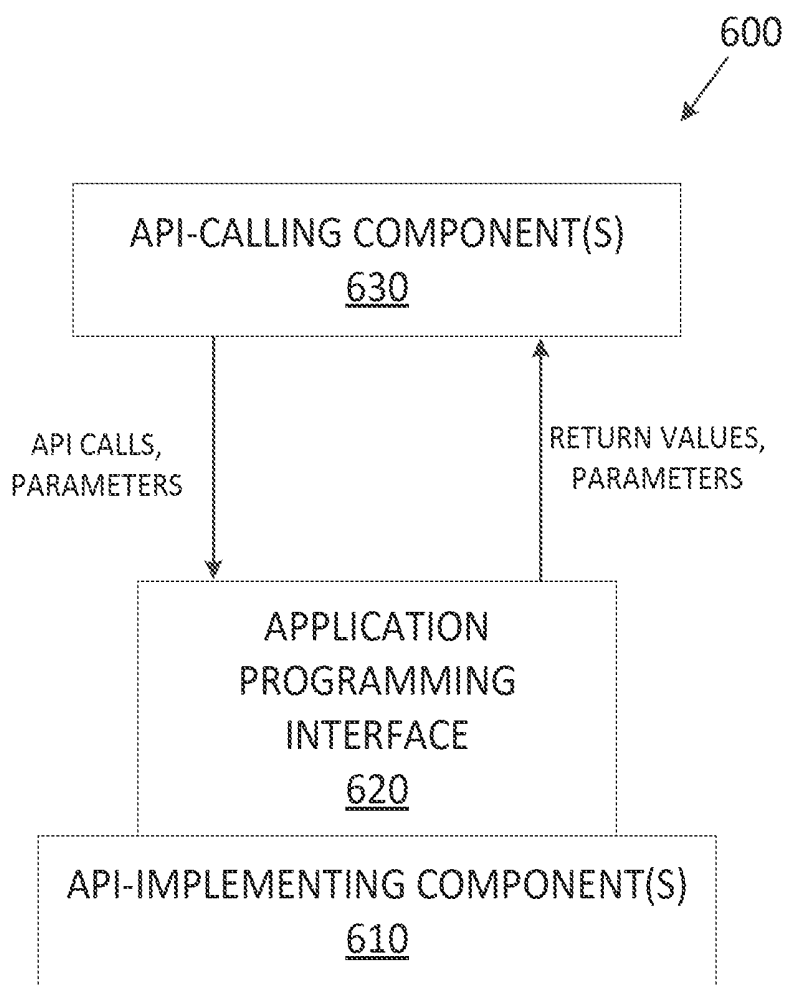


FIG. 4

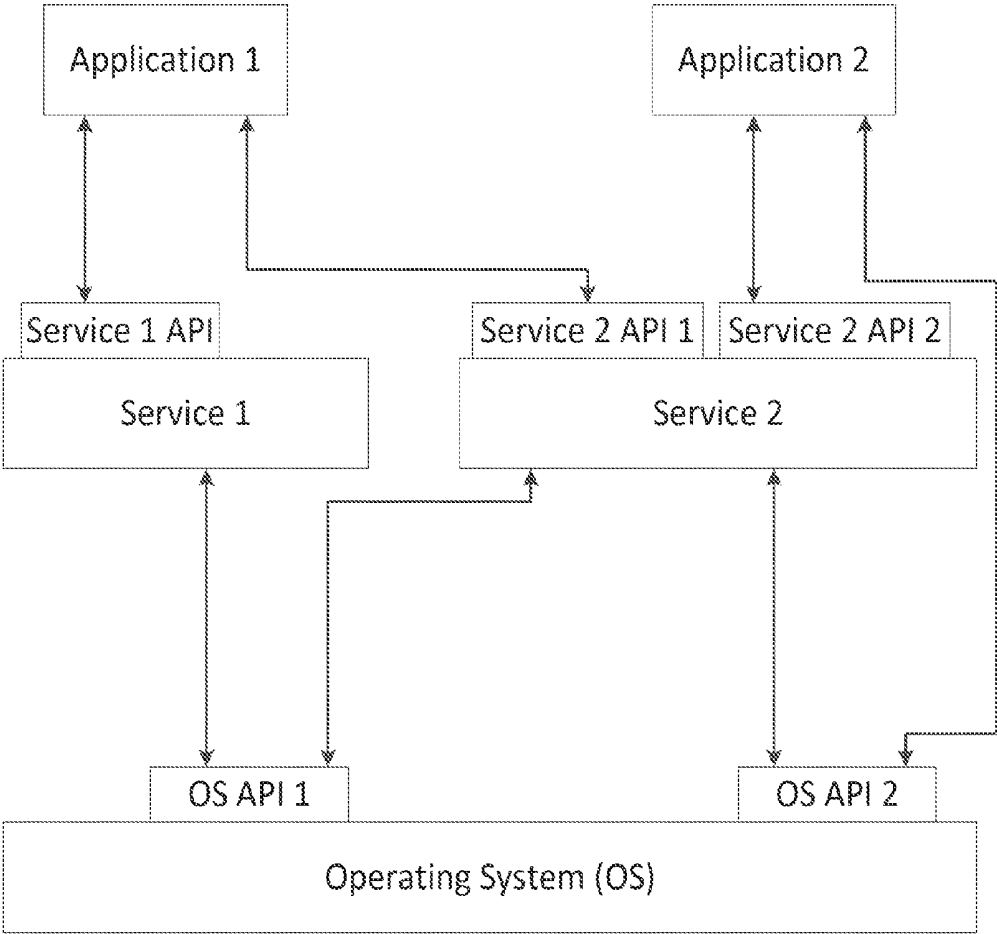


FIG. 5

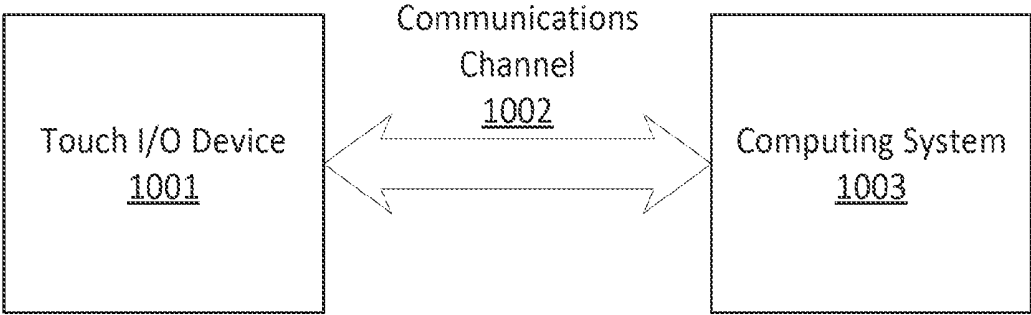


FIG. 6

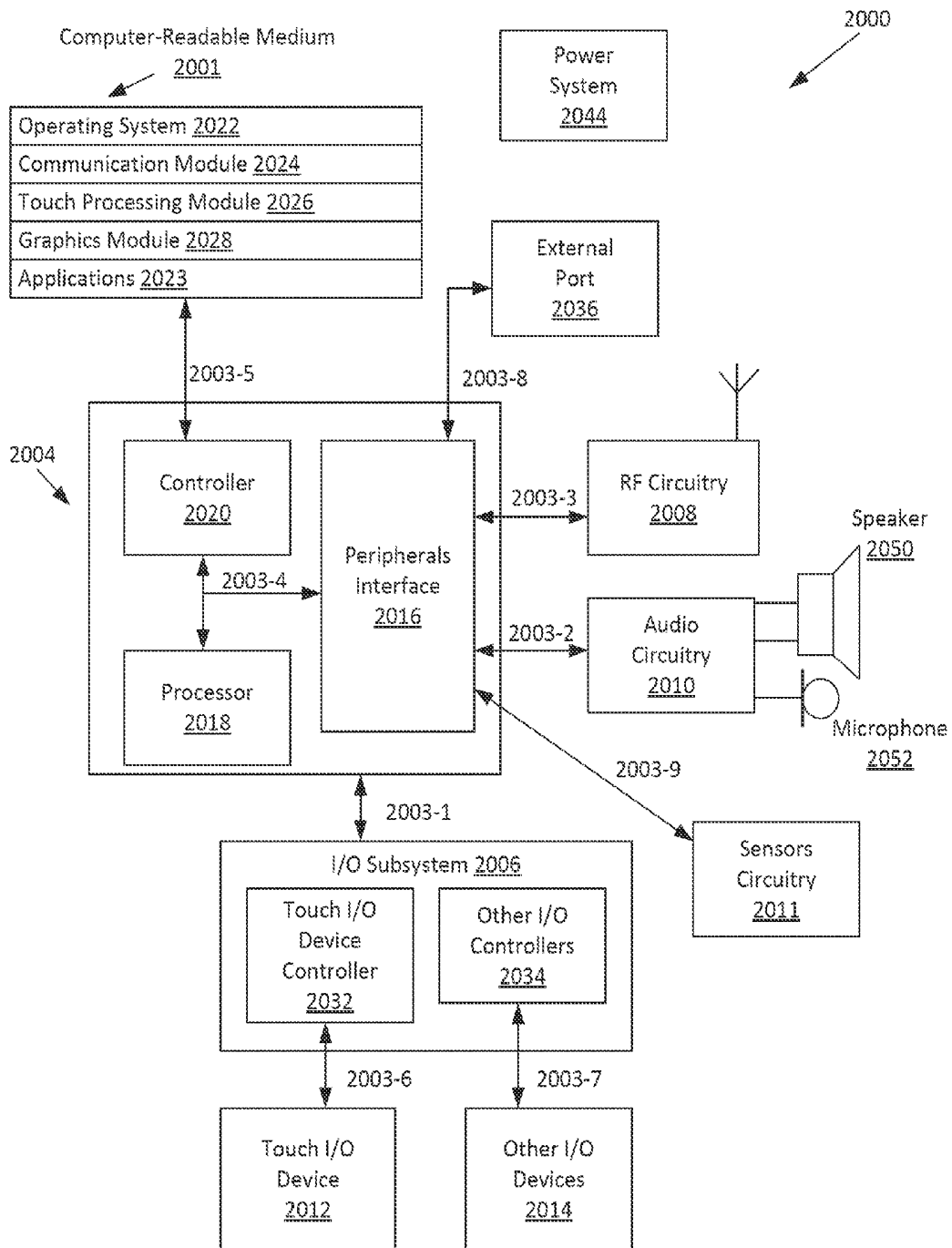


FIG. 7

WEARABLE MULTI-MODAL PHYSIOLOGICAL SENSING SYSTEM

FIELD OF THE DISCLOSURE

[0001] This relates generally to reducing motion artifacts from a physiological signal.

BACKGROUND OF THE DISCLOSURE

[0002] A photoplethysmogram (PPG) signal may be obtained from a pulse oximeter, which employs a light emitter and a light sensor to measure the perfusion of blood to the skin of a user. However, the signal may be compromised by noise due to motion artifacts. That is, movement of the body of a user may cause the skin and vasculature to expand and contract, introducing noise to the signal. Further, the device itself may move with respect to the body of the user, introducing further noise. To address the presence of motion artifacts, examples of the present disclosure can receive light information from each of two light guides, one in contact with the tissue of the user and one not in contact with the tissue of the user. First light information can be obtained from the first light guide, and second light information can be obtained from the second light guide. A heart rate signal can then be computed from the first and second light information, for example, by using blind source separation and/or cross-correlation.

SUMMARY OF THE DISCLOSURE

[0003] A photoplethysmogram (PPG) signal may be obtained from a pulse oximeter, which employs a light emitter and a light sensor to measure the perfusion of blood to the skin of a user. However, the signal may be compromised by noise due to motion artifacts. That is, movement of the body of a user may cause the skin and vasculature to expand and contract, introducing noise to the signal. Further, the device itself may move with respect to the body of the user, introducing further noise. To address the presence of motion artifacts, examples of the present disclosure can receive light information from each of two light guides, one in contact with the tissue of the user and one not in contact with the tissue of the user. First light information can be obtained from the first light guide, and second light information can be obtained from the second light guide. A heart rate signal can then be computed from the first and second light information, for example, by using blind source separation and/or cross-correlation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 illustrates an electronic device having light sensors for determining a heart rate signal according to examples of the disclosure.

[0005] FIG. 2 illustrates a method of computing a heart rate signal according to examples of the disclosure.

[0006] FIG. 3 illustrates a method of computing a heart rate signal according to examples of the disclosure.

[0007] FIG. 4 is a block diagram illustrating an exemplary API architecture, which may be used in some examples of the disclosure.

[0008] FIG. 5 illustrates an exemplary software stack of an API according to examples of the disclosure.

[0009] FIG. 6 is a block diagram illustrating exemplary interactions between the touch screen and other components of the device according to examples of the disclosure.

[0010] FIG. 7 is a block diagram illustrating an example of a system architecture that may be embodied within any portable or non-portable device according to examples of the disclosure.

DETAILED DESCRIPTION

[0011] In the following description of examples, reference is made to the accompanying drawings which form a part hereof, and in which it is shown by way of illustration specific examples that can be practiced. It is to be understood that other examples can be used and structural changes can be made without departing from the scope of the disclosed examples.

[0012] A photoplethysmogram (PPG) signal may be obtained from a pulse oximeter, which employs a light emitter and a light sensor to measure the perfusion of blood to the skin of a user. However, the signal may be compromised by noise due to motion artifacts. That is, movement of the body of a user may cause the skin and vasculature to expand and contract, introducing noise to the signal. Further, the device itself may move with respect to the body of the user, introducing further noise. To address the presence of motion artifacts, examples of the present disclosure can receive light information from each of two light guides, one in contact with the tissue of the user and one not in contact with the tissue of the user. First light information can be obtained from the first light guide, and second light information can be obtained from the second light guide. A heart rate signal can then be computed from the first and second light information, for example, by using blind source separation and/or cross-correlation.

[0013] Although examples disclosed herein may be described and illustrated herein primarily in terms of two sensors, emitters, and light guides, it should be understood that the examples are not so limited, but are additionally applicable to devices including any number and configuration of sensors, emitters, and light guides.

[0014] Examples of the disclosure are directed to a system for sensing and measurement of physiological signals that enables a signal decomposition approach to physiological measurements. That is, multiple signals may be obtained, and each signal may contain a physiological signal of interest (e.g., a heart rate signal)—each signal may also contain different noise components, and thus signal decomposition methods may be used to filter the noise and compute the signal of interest. Multiple sensing modalities optimized for the signal decomposition approach may provide robustness against non-signal artifacts commonly induced in wearable sensors, such as motion- or biologically-induced artifacts. Sensing modalities may include detection of physiological signals from optical sensors, force and pressure sensors, temperature sensors, accelerometers, proximity detectors, and/or impedance sensors, among other possibilities. In some examples, sensing modalities may include optical sensors including light guides in contact and not in contact with tissue of a user. Because the signal of interest may be compromised by noise due to motion of the device with respect to the tissue and also by noise due to motion of the tissue itself (e.g., the expansion and contraction of tissue and vasculature), different noise may be captured by sensors corresponding to each of contacting and non-contacting light guides, and signal decomposition methods (e.g., blind source separation) may be employed to separate the signal of interest from the noise.

[0015] FIG. 1 illustrates an electronic device 100 having light sensors for determining a heart rate signal according to examples of the disclosure. A first light sensor 110 may be co-located with a contacting light guide 102 and a first light emitter 106. The contacting light guide 102 may be configured so as to be in contact with tissue 114 of a user, such as skin. For example, the contacting light guide 102 may be curved such that the surface is configured to contact tissue 114 of the user. In some examples, the contacting light guide 102 may jut out from the body of the electronic device 100 such that it is configured to contact tissue 114 of the user. A second light sensor 112 may be co-located with a non-contacting light guide 104 and a second light emitter 108. The non-contacting light guide 104 may be configured so as to not be in contact with tissue 114 of the user. In some examples, the non-contacting light guide 104 may be recessed with respect to the body of the electronic device 100 such that it is configured not to contact tissue 114 of the user.

[0016] The electronic device 100 may be situated such that the sensors 110 and 112, the emitters 106 and 108, and the light guides 102 and 104 are proximate the tissue 114 of the user, so that light from a light emitter may be directed through a light guide and be incident on the tissue. For example, the electronic device 100 may be held in a user's hand or strapped to a user's wrist, among other possibilities. A portion of the light from a light emitter may be absorbed by the skin, vasculature, and/or blood, among other possibilities, and a portion may be reflected back to a light sensor co-located with the light emitter. In some examples, light guides may direct light to tissue and/or back to a light sensor, and some emitters and sensors may direct light to and from tissue without a light guide.

[0017] FIG. 2 illustrates a method of computing a heart rate signal. Light may be emitted from a first light emitter through a contacting light guide (200). First light information may be received at a first light sensor through the contacting light guide (202). Similarly, light may be emitted from a second light emitter through a non-contacting light guide (204), and second light information may be received at a second light sensor through the non-contacting light guide (206). In some examples, a light emitter may emit light, the light may travel to the tissue of a user, and a portion of the light may reflect to a co-located light sensor, and some or all of the travel of the light may be directed by a light guide. Accordingly, the first light information may indicate an amount of light from a first light emitter that has been reflected by the skin, blood, and/or vasculature of the user, among other possibilities. In some examples, the first light information may indicate an amount of light from the first light emitter that has been absorbed by the skin, blood, and/or vasculature of the user.

[0018] The light emitters may produce light in ranges corresponding to infrared (IR), green, amber, blue, and/or red light, among other possibilities. Additionally, the light sensors may be configured to sense light having certain wavelengths more easily than light having other wavelengths. For example, if the first light emitter emits light having a wavelength in the IR range, then the first light sensor may be configured to sense light in the IR range more powerfully than light in the green range. That is, the incidence of light in the IR range may produce a stronger response in the first light sensor than the incidence of light in the green range. In this way, the first light sensor can be

configured so as to sense the light produced by the first light emitter more powerfully than the light produced by the second light emitter, for example. In some examples, each light emitter may produce light in the same wavelength.

[0019] In some examples, a light emitter may be a light emitting diode (LED) and a light sensor may be a photodiode. The light information may include information produced by the photodiode. For example, the light information may include a voltage reading that corresponds to light absorbed by the photodiode. In some examples, the light information may include some transformation of raw signal produced by the photodiode, such as through filtering, scaling, or other signal processing.

[0020] Based on the first and second light information, a heart rate signal may be computed (206). For example, the first and second light information may be processed through blind source separation and/or cross-correlation methods. For example, the first and second light information may be processed with principal component analysis (one example method of blind source separation), to separate out a plurality of linearly uncorrelated component signals. Those components may then be further processed with a cross-correlation method, serving as a second filter, to compute a heart rate signal. In some examples, the first light information may include light information of red, green, and blue wavelengths, and the second light information may also include light information of red, green, and blue wavelengths, although any number and combination of wavelengths is possible. In some examples, the computed heart rate signal may include one or more additional signals, such as residual noise and/or a signal corresponding to a respiratory rate of a user, among other possibilities.

[0021] FIG. 3 illustrates a method of computing a heart rate signal based on multiple wavelengths of contacting and non-contacting light information. Red, green, and blue contacting light information (300) may be processed with blind source separation (e.g., principal component analysis, among other possibilities) (304). Further, red, green, and blue non-contacting light information (302) may be processed with blind source separation (306). The results of the contacting and non-contacting blind source separation processes may be cross-correlated (308), and the result may be a heart rate signal with reduced noise (310).

[0022] The examples discussed above can be implemented in one or more Application Programming Interfaces (APIs). An API is an interface implemented by a program code component or hardware component (hereinafter "API-implementing component") that allows a different program code component or hardware component (hereinafter "API-calling component") to access and use one or more functions, methods, procedures, data structures, classes, and/or other services provided by the API-implementing component. An API can define one or more parameters that are passed between the API-calling component and the API-implementing component.

[0023] The above-described features can be implemented as part of an application program interface (API) that can allow it to be incorporated into different applications (e.g., spreadsheet apps) utilizing touch input as an input mechanism. An API can allow a developer of an API-calling component (which may be a third party developer) to leverage specified features, such as those described above, provided by an API-implementing component. There may be one API-calling component or there may be more than

one such component. An API can be a source code interface that a computer system or program library provides in order to support requests for services from an application. An operating system (OS) can have multiple APIs to allow applications running on the OS to call one or more of those APIs, and a service (such as a program library) can have multiple APIs to allow an application that uses the service to call one or more of those APIs. An API can be specified in terms of a programming language that can be interpreted or compiled when an application is built.

[0024] In some examples, the API-implementing component may provide more than one API, each providing a different view of the functionality implemented by the API-implementing component, or with different aspects that access different aspects of the functionality implemented by the API-implementing component. For example, one API of an API-implementing component can provide a first set of functions and can be exposed to third party developers, and another API of the API-implementing component can be hidden (not exposed) and provide a subset of the first set of functions and also provide another set of functions, such as testing or debugging functions which are not in the first set of functions. In other examples the API-implementing component may itself call one or more other components via an underlying API and thus be both an API-calling component and an API-implementing component.

[0025] An API defines the language and parameters that API-calling components use when accessing and using specified features of the API-implementing component. For example, an API-calling component accesses the specified features of the API-implementing component through one or more API calls or invocations (embodied for example by function or method calls) exposed by the API and passes data and control information using parameters via the API calls or invocations. The API-implementing component may return a value through the API in response to an API call from an API-calling component. While the API defines the syntax and result of an API call (e.g., how to invoke the API call and what the API call does), the API may not reveal how the API call accomplishes the function specified by the API call. Various API calls are transferred via the one or more application programming interfaces between the calling (API-calling component) and an API-implementing component. Transferring the API calls may include issuing, initiating, invoking, calling, receiving, returning, or responding to the function calls or messages; in other words, transferring can describe actions by either of the API-calling component or the API-implementing component. The function calls or other invocations of the API may send or receive one or more parameters through a parameter list or other structure. A parameter can be a constant, key, data structure, object, object class, variable, data type, pointer, array, list or a pointer to a function or method or another way to reference a data or other item to be passed via the API.

[0026] Furthermore, data types or classes may be provided by the API and implemented by the API-implementing component. Thus, the API-calling component may declare variables, use pointers to, use or instantiate constant values of such types or classes by using definitions provided in the API.

[0027] Generally, an API can be used to access a service or data provided by the API-implementing component or to initiate performance of an operation or computation provided by the API-implementing component. By way of

example, the API-implementing component and the API-calling component may each be any one of an operating system, a library, a device driver, an API, an application program, or other module (it should be understood that the API-implementing component and the API-calling component may be the same or different type of module from each other). API-implementing components may in some cases be embodied at least in part in firmware, microcode, or other hardware logic. In some examples, an API may allow a client program to use the services provided by a Software Development Kit (SDK) library. In other examples an application or other client program may use an API provided by an Application Framework. In these examples the application or client program may incorporate calls to functions or methods provided by the SDK and provided by the API or use data types or objects defined in the SDK and provided by the API. An Application Framework may in these examples provide a main event loop for a program that responds to various events defined by the Framework. The API allows the application to specify the events and the responses to the events using the Application Framework. In some implementations, an API call can report to an application the capabilities or state of a hardware device, including those related to aspects such as input capabilities and state, output capabilities and state, processing capability, power state, storage capacity and state, communications capability, etc., and the API may be implemented in part by firmware, microcode, or other low level logic that executes in part on the hardware component.

[0028] The API-calling component may be a local component (i.e., on the same data processing system as the API-implementing component) or a remote component (i.e., on a different data processing system from the API-implementing component) that communicates with the API-implementing component through the API over a network. It should be understood that an API-implementing component may also act as an API-calling component (i.e., it may make API calls to an API exposed by a different API-implementing component) and an API-calling component may also act as an API-implementing component by implementing an API that is exposed to a different API-calling component.

[0029] The API may allow multiple API-calling components written in different programming languages to communicate with the API-implementing component (thus the API may include features for translating calls and returns between the API-implementing component and the API-calling component); however the API may be implemented in terms of a specific programming language. An API-calling component can, in one example, call APIs from different providers such as a set of APIs from an OS provider and another set of APIs from a plug-in provider and another set of APIs from another provider (e.g. the provider of a software library) or creator of the another set of APIs.

[0030] FIG. 4 is a block diagram illustrating an exemplary API architecture, which may be used in some examples of the disclosure. As shown in FIG. 4, the API architecture 600 includes the API-implementing component 610 (e.g., an operating system, a library, a device driver, an API, an application program, software or other module) that implements the API 620. The API 620 specifies one or more functions, methods, classes, objects, protocols, data structures, formats and/or other features of the API-implementing component that may be used by the API-calling component 630. The API 620 can specify at least one calling convention

that specifies how a function in the API-implementing component receives parameters from the API-calling component and how the function returns a result to the API-calling component. The API-calling component 630 (e.g., an operating system, a library, a device driver, an API, an application program, software or other module), makes API calls through the API 620 to access and use the features of the API-implementing component 610 that are specified by the API 620. The API-implementing component 610 may return a value through the API 620 to the API-calling component 630 in response to an API call.

[0031] It will be appreciated that the API-implementing component 610 may include additional functions, methods, classes, data structures, and/or other features that are not specified through the API 620 and are not available to the API-calling component 630. It should be understood that the API-calling component 630 may be on the same system as the API-implementing component 610 or may be located remotely and accesses the API-implementing component 610 using the API 620 over a network. While FIG. 4 illustrates a single API-calling component 630 interacting with the API 620, it should be understood that other API-calling components, which may be written in different languages (or the same language) than the API-calling component 630, may use the API 620.

[0032] The API-implementing component 610, the API 620, and the API-calling component 630 may be stored in a non-transitory machine-readable storage medium, which includes any mechanism for storing information in a form readable by a machine (e.g., a computer or other data processing system). For example, a machine-readable medium includes magnetic disks, optical disks, random access memory; read only memory, flash memory devices, etc.

[0033] In the exemplary software stack shown in FIG. 5, applications can make calls to Services A or B using several Service APIs and to Operating System (OS) using several OS APIs. Services A and B can make calls to OS using several OS APIs.

[0034] Note that the Service 2 has two APIs, one of which (Service 2 API 1) receives calls from and returns values to Application 1 and the other (Service 2 API 2) receives calls from and returns values to Application 2. Service 1 (which can be, for example, a software library) makes calls to and receives returned values from OS API 1, and Service 2 (which can be, for example, a software library) makes calls to and receives returned values from both OS API 1 and OS API 2. Application 2 makes calls to and receives returned values from OS API 2.

[0035] FIG. 6 is a block diagram illustrating exemplary interactions between the touch screen and the other components of the device. Described examples may include touch I/O device 1001 that can receive touch input for interacting with computing system 1003 via wired or wireless communication channel 1002. Touch I/O device 1001 may be used to provide user input to computing system 1003 in lieu of or in combination with other input devices such as a keyboard, mouse, etc. One or more touch I/O devices 1001 may be used for providing user input to computing system 1003. Touch I/O device 1001 may be an integral part of computing system 1003 (e.g., touch screen on a smartphone or a tablet PC) or may be separate from computing system 1003.

[0036] Touch I/O device 1001 may include a touch sensing panel which is wholly or partially transparent, semi-

transparent, non-transparent, opaque or any combination thereof. Touch I/O device 1001 may be embodied as a touch screen, touch pad, a touch screen functioning as a touch pad (e.g., a touch screen replacing the touchpad of a laptop), a touch screen or touchpad combined or incorporated with any other input device (e.g., a touch screen or touchpad disposed on a keyboard) or any multi-dimensional object having a touch sensing surface for receiving touch input.

[0037] In one example, touch I/O device 1001 embodied as a touch screen may include a transparent and/or semi-transparent touch sensing panel partially or wholly positioned over at least a portion of a display. According to this example, touch I/O device 1001 functions to display graphical data transmitted from computing system 1003 (and/or another source) and also functions to receive user input. In other examples, touch I/O device 1001 may be embodied as an integrated touch screen where touch sensing components/devices are integral with display components/devices. In still other examples a touch screen may be used as a supplemental or additional display screen for displaying supplemental or the same graphical data as a primary display and to receive touch input.

[0038] Touch I/O device 1001 may be configured to detect the location of one or more touches or near touches on device 1001 based on capacitive, resistive, optical, acoustic, inductive, mechanical, chemical measurements, or any phenomena that can be measured with respect to the occurrences of the one or more touches or near touches in proximity to device 1001. Software, hardware, firmware or any combination thereof may be used to process the measurements of the detected touches to identify and track one or more gestures. A gesture may correspond to stationary or non-stationary, single or multiple, touches or near touches on touch I/O device 1001. A gesture may be performed by moving one or more fingers or other objects in a particular manner on touch I/O device 1001 such as tapping, pressing, rocking, scrubbing, twisting, changing orientation, pressing with varying pressure and the like at essentially the same time, contiguously, or consecutively. A gesture may be characterized by, but is not limited to a pinching, sliding, swiping, rotating, flexing, dragging, or tapping motion between or with any other finger or fingers. A single gesture may be performed with one or more hands, by one or more users, or any combination thereof.

[0039] Computing system 1003 may drive a display with graphical data to display a graphical user interface (GUI). The GUI may be configured to receive touch input via touch I/O device 1001. Embodied as a touch screen, touch I/O device 1001 may display the GUI. Alternatively, the GUI may be displayed on a display separate from touch I/O device 1001. The GUI may include graphical elements displayed at particular locations within the interface. Graphical elements may include but are not limited to a variety of displayed virtual input devices including virtual scroll wheels, a virtual keyboard, virtual knobs, virtual buttons, any virtual UI, and the like. A user may perform gestures at one or more particular locations on touch I/O device 1001 which may be associated with the graphical elements of the GUI. In other examples, the user may perform gestures at one or more locations that are independent of the locations of graphical elements of the GUI. Gestures performed on touch I/O device 1001 may directly or indirectly manipulate, control, modify, move, actuate, initiate or generally affect graphical elements such as cur-

sors, icons, media files, lists, text, all or portions of images, or the like within the GUI. For instance, in the case of a touch screen, a user may directly interact with a graphical element by performing a gesture over the graphical element on the touch screen. Alternatively, a touch pad generally provides indirect interaction. Gestures may also affect non-displayed GUI elements (e.g., causing user interfaces to appear) or may affect other actions within computing system **1003** (e.g., affect a state or mode of a GUI, application, or operating system). Gestures may or may not be performed on touch I/O device **1001** in conjunction with a displayed cursor. For instance, in the case in which gestures are performed on a touchpad, a cursor (or pointer) may be displayed on a display screen or touch screen and the cursor may be controlled via touch input on the touchpad to interact with graphical objects on the display screen. In other examples in which gestures are performed directly on a touch screen, a user may interact directly with objects on the touch screen, with or without a cursor or pointer being displayed on the touch screen.

[**0040**] Feedback may be provided to the user via communication channel **1002** in response to or based on the touch or near touches on touch I/O device **1001**. Feedback may be transmitted optically, mechanically, electrically, olfactory, acoustically, or the like or any combination thereof and in a variable or non-variable manner.

[**0041**] Attention is now directed towards examples of a system architecture that may be embodied within any portable or non-portable device including but not limited to a communication device (e.g. mobile phone, smart phone), a multi-media device (e.g., MP3 player, TV, radio), a portable or handheld computer (e.g., tablet, netbook, laptop), a desktop computer, an All-In-One desktop, a peripheral device, or any other system or device adaptable to the inclusion of system architecture **2000**, including combinations of two or more of these types of devices. FIG. 7 is a block diagram of one example of system **2000** that generally includes one or more computer-readable mediums **2001**, processing system **2004**, I/O subsystem **2006**, radio frequency (RF) circuitry **2008**, audio circuitry **2010**, and sensors circuitry **2011**. These components may be coupled by one or more communication buses or signal lines **2003**.

[**0042**] It should be apparent that the architecture shown in FIG. 7 is only one example architecture of system **2000**, and that system **2000** could have more or fewer components than shown, or a different configuration of components. The various components shown in FIG. 7 can be implemented in hardware, software, firmware or any combination thereof, including one or more signal processing and/or application specific integrated circuits.

[**0043**] RF circuitry **2008** can be used to send and receive information over a wireless link or network to one or more other devices and includes well-known circuitry for performing this function. RF circuitry **2008** and audio circuitry **2010** can be coupled to processing system **2004** via peripherals interface **2016**. Interface **2016** can include various known components for establishing and maintaining communication between peripherals and processing system **2004**. Audio circuitry **2010** can be coupled to audio speaker **2050** and microphone **2052** and can include known circuitry for processing voice signals received from interface **2016** to enable a user to communicate in real-time with other users. In some examples, audio circuitry **2010** can include a headphone jack (not shown). Sensors circuitry **2011** can be

coupled to various sensors including, but not limited to, one or more Light Emitting Diodes (LEDs) or other light emitters, one or more photodiodes or other light sensors, one or more photothermal sensors, a magnetometer, an accelerometer, a gyroscope, a barometer, a compass, a proximity sensor, a camera, an ambient light sensor, a thermometer, a GPS sensor, and various system sensors which can sense remaining battery life, power consumption, processor speed, CPU load, and the like.

[**0044**] Peripherals interface **2016** can couple the input and output peripherals of the system to processor **2018** and computer-readable medium **2001**. One or more processors **2018** communicate with one or more computer-readable mediums **2001** via controller **2020**. Computer-readable medium **2001** can be any device or medium that can store code and/or data for use by one or more processors **2018**. In some examples, medium **2001** can be a non-transitory computer-readable storage medium. Medium **2001** can include a memory hierarchy, including but not limited to cache, main memory and secondary memory. The memory hierarchy can be implemented using any combination of RAM (e.g., SRAM, DRAM, DDRAM), ROM, FLASH, magnetic and/or optical storage devices, such as disk drives, magnetic tape, CDs (compact disks) and DVDs (digital video discs). Medium **2001** may also include a transmission medium for carrying information-bearing signals indicative of computer instructions or data (with or without a carrier wave upon which the signals are modulated). For example, the transmission medium may include a communications network, including but not limited to the Internet (also referred to as the World Wide Web), intranet(s), Local Area Networks (LANs), Wide Local Area Networks (WLANs), Storage Area Networks (SANs), Metropolitan Area Networks (MAN) and the like.

[**0045**] One or more processors **2018** can run various software components stored in medium **2001** to perform various functions for system **2000**. In some examples, the software components can include operating system **2022**, communication module (or set of instructions) **2024**, touch processing module (or set of instructions) **2026**, graphics module (or set of instructions) **2028**, and one or more applications (or set of instructions) **2030**. Each of these modules and above noted applications can correspond to a set of instructions for performing one or more functions described above and the methods described in this application (e.g., the computer-implemented methods and other information processing methods described herein). These modules (i.e., sets of instructions) need not be implemented as separate software programs, procedures or modules, and thus various subsets of these modules may be combined or otherwise re-arranged in various examples. In some examples, medium **2001** may store a subset of the modules and data structures identified above. Furthermore, medium **2001** may store additional modules and data structures not described above.

[**0046**] Operating system **2022** can include various procedures, sets of instructions, software components and/or drivers for controlling and managing general system tasks (e.g., memory management, storage device control, power management, etc.) and facilitates communication between various hardware and software components.

[**0047**] Communication module **2024** can facilitate communication with other devices over one or more external ports **2036** or via RF circuitry **2008** and can include various

software components for handling data received from RF circuitry **2008** and/or external port **2036**.

[**0048**] Graphics module **2028** can include various known software components for rendering, animating and displaying graphical objects on a display surface. In examples in which touch I/O device **2012** is a touch sensing display (e.g., touch screen), graphics module **2028** can include components for rendering, displaying, and animating objects on the touch sensing display.

[**0049**] One or more applications **2030** can include any applications installed on system **2000**, including without limitation, a browser, address book, contact list, email, instant messaging, word processing, keyboard emulation, widgets, JAVA-enabled applications, encryption, digital rights management, voice recognition, voice replication, location determination capability (such as that provided by the global positioning system (GPS)), a music player, etc.

[**0050**] Touch processing module **2026** can include various software components for performing various tasks associated with touch I/O device **2012** including but not limited to receiving and processing touch input received from I/O device **2012** via touch I/O device controller **2032**.

[**0051**] I/O subsystem **2006** can be coupled to touch I/O device **2012** and one or more other I/O devices **2014** for controlling or performing various functions. Touch I/O device **2012** can communicate with processing system **2004** via touch I/O device controller **2032**, which can include various components for processing user touch input (e.g., scanning hardware). One or more other input controllers **2034** can receive/send electrical signals from/to other I/O devices **2014**. Other I/O devices **2014** may include physical buttons, dials, slider switches, sticks, keyboards, touch pads, additional display screens, or any combination thereof.

[**0052**] If embodied as a touch screen, touch I/O device **2012** can display visual output to the user in a GUI. The visual output may include text, graphics, video, and any combination thereof. Some or all of the visual output may correspond to user-interface objects. Touch I/O device **2012** can form a touch sensing surface that accepts touch input from the user. Touch I/O device **2012** and touch screen controller **2032** (along with any associated modules and/or sets of instructions in medium **2001**) can detect and track touches or near touches (and any movement or release of the touch) on touch I/O device **2012** and can convert the detected touch input into interaction with graphical objects, such as one or more user-interface objects. In the case in which device **2012** is embodied as a touch screen, the user can directly interact with graphical objects that are displayed on the touch screen. Alternatively, in the case in which device **2012** is embodied as a touch device other than a touch screen (e.g., a touch pad), the user may indirectly interact with graphical objects that are displayed on a separate display screen embodied as I/O device **2014**.

[**0053**] Touch I/O device **2012** may be analogous to the multi-touch sensing surface described in the following U.S. Pat. No. 6,323,846 (Westerman et al.), U.S. Pat. No. 6,570,557 (Westerman et al.), and/or U.S. Pat. No. 6,677,932 (Westerman), and/or U.S. Patent Publication 2002/0015024A1, each of which is hereby incorporated by reference.

[**0054**] In examples for which touch I/O device **2012** is a touch screen, the touch screen may use LCD (liquid crystal display) technology, LPD (light emitting polymer display)

technology, OLED (organic LED), or OEL (organic electro luminescence), although other display technologies may be used in other examples.

[**0055**] Feedback may be provided by touch I/O device **2012** based on the user's touch input as well as a state or states of what is being displayed and/or of the computing system. Feedback may be transmitted optically (e.g., light signal or displayed image), mechanically (e.g., haptic feedback, touch feedback, force feedback, or the like), electrically (e.g., electrical stimulation), olfactory, acoustically (e.g., beep or the like), or the like or any combination thereof and in a variable or non-variable manner.

[**0056**] System **2000** can also include power system **2044** for powering the various hardware components and may include a power management system, one or more power sources, a recharging system, a power failure detection circuit, a power converter or inverter, a power status indicator and any other components typically associated with the generation, management and distribution of power in portable devices.

[**0057**] In some examples, peripherals interface **2016**, one or more processors **2018**, and memory controller **2020** may be implemented on a single chip, such as processing system **2004**. In some other examples, they may be implemented on separate chips.

[**0058**] Examples of the disclosure can be advantageous in allowing for an electronic device to obtain a heart rate signal with reduced noise due to motion artifacts, making for a more accurate reading of heart rate.

[**0059**] In some examples, a method of an electronic device including a plurality of light emitters, a plurality of light sensors, and a plurality of light guides is disclosed. The method may include: emitting light from each of the plurality of light emitters through respective light guides, wherein a contacting light guide may be configured to contact tissue of a user and a non-contacting light may be configured not to contact tissue of the user; receiving first light information from the contacting light guide; receiving second light information from the non-contacting light guide; and computing a heart rate signal based on the first and second light information. Additionally or alternatively to one or more of the above examples, a surface of the contacting light guide may be curved such that the surface is configured to contact tissue of the user. Additionally or alternatively to one or more of the above examples, the non-contacting light guide may be recessed with respect to the electronic device such that the non-contacting light guide may be configured not to contact tissue of the user. Additionally or alternatively to one or more of the above examples, computing the heart rate signal based on the first and second light information may include performing blind source separation on the first and second light information. Additionally or alternatively to one or more of the above examples, emitting light through the contacting light guide may include emitting light of a plurality of wavelengths through the contacting light guide; and wherein computing the heart rate signal may include performing blind source separation on light information of the plurality of wavelengths. Additionally or alternatively to one or more of the above examples, the plurality of wavelengths may include

wavelengths of red, green, and blue light. Additionally or alternatively to one or more of the above examples, one or more of the plurality of light sensors may be in contact with respective light guides through which light is sensed, and one or more of the plurality of light sensors may be not in contact with respective light guides through which light is sensed.

[0060] In some examples, a non-transitory computer readable medium is disclosed. The non-transitory computer readable medium may contain instructions that, when executed, perform a method of an electronic device including a plurality of light emitters, a plurality of light sensors, and a plurality of light guides. The method may include: emitting light from each of the plurality of light emitters through respective light guides, wherein a contacting light guide may be configured to contact tissue of a user and a non-contacting light may be configured not to contact tissue of the user; receiving first light information from the contacting light guide; receiving second light information from the non-contacting light guide; and computing a heart rate signal based on the first and second light information. Additionally or alternatively to one or more of the above examples, a surface of the contacting light guide may be curved such that the surface is configured to contact tissue of the user. Additionally or alternatively to one or more of the above examples, the non-contacting light guide may be recessed with respect to the electronic device such that the non-contacting light guide may be configured not to contact tissue of the user. Additionally or alternatively to one or more of the above examples, computing the heart rate signal based on the first and second light information may include performing blind source separation on the first and second light information. Additionally or alternatively to one or more of the above examples, computing the heart rate signal based on the first and second light information may include performing cross-correlation on the first and second light information. Additionally or alternatively to one or more of the above examples, emitting light through the contacting light guide may include emitting light of a plurality of wavelengths through the contacting light guide; and wherein computing the heart rate signal may include performing blind source separation on light information of the plurality of wavelengths. Additionally or alternatively to one or more of the above examples, the plurality of wavelengths may include wavelengths of red, green, and blue light. Additionally or alternatively to one or more of the above examples, one or more of the plurality of light sensors may be in contact with respective light guides through which light is sensed, and one or more of the plurality of light sensors may be not in contact with respective light guides through which light is sensed.

[0061] In some examples, an electronic device is disclosed. The electronic device may include: a processor to execute instructions; a plurality of light emitters; a plurality of light sensors; a plurality of light guides; and a memory coupled with the processor to store instructions, which when executed by the processor, may cause the processor to perform operations to generate an application programming interface (API) that allows an API-calling component to perform a method. The method may include: emitting light from each of the plurality of light emitters through respective light guides, wherein a contacting light guide may be configured to contact tissue of a user and a non-contacting light may be configured not to contact tissue of the user;

receiving first light information from the contacting light guide; receiving second light information from the non-contacting light guide; and computing a heart rate signal based on the first and second light information. Additionally or alternatively to one or more of the above examples, a surface of the contacting light guide may be curved such that the surface is configured to contact tissue of the user. Additionally or alternatively to one or more of the above examples, the non-contacting light guide may be recessed with respect to the electronic device such that the non-contacting light guide may be configured not to contact tissue of the user. Additionally or alternatively to one or more of the above examples, computing the heart rate signal based on the first and second light information may include performing blind source separation on the first and second light information. Additionally or alternatively to one or more of the above examples, computing the heart rate signal based on the first and second light information may include performing cross-correlation on the first and second light information. Additionally or alternatively to one or more of the above examples, emitting light through the contacting light guide may include emitting light of a plurality of wavelengths through the contacting light guide; and wherein computing the heart rate signal may include performing blind source separation on light information of the plurality of wavelengths. Additionally or alternatively to one or more of the above examples, the plurality of wavelengths may include wavelengths of red, green, and blue light. Additionally or alternatively to one or more of the above examples, one or more of the plurality of light sensors may be in contact with respective light guides through which light is sensed, and one or more of the plurality of light sensors may be not in contact with respective light guides through which light is sensed.

[0062] Although the disclosed examples have been fully described with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of the disclosed examples as defined by the appended claims.

1. A method of an electronic device including a plurality of light emitters, a plurality of light sensors, and a plurality of light guides, the method comprising:

emitting light from a first light emitter through a first light guide, wherein the first light emitter is located a first distance away from a tissue of a user;

receiving first light information from the first light guide; emitting light from a second light emitter through a second light guide, wherein the second light emitter is located a second distance, greater than the first distance, away from the tissue of the user;

receiving second light information from the second light guide; and

computing a heart rate signal based on the first and second light information.

2. The method of claim 1, wherein a surface of the first light guide is curved such that the surface is configured to contact the tissue of the user.

3. The method of claim 1, wherein the second light guide is recessed with respect to the electronic device such that the second light guide is configured not to contact the tissue of the user.

4. The method of claim 1, wherein computing the heart rate signal based on the first and second light information includes performing blind source separation on the first and second light information.

5. The method of claim 1, wherein computing the heart rate signal based on the first and second light information includes performing cross-correlation on the first and second light information.

6. The method of claim 1, wherein emitting light through the first light guide includes emitting light of a plurality of wavelengths through the first light guide; and

wherein computing the heart rate signal includes performing blind source separation on light information of the plurality of wavelengths.

7. The method of claim 6, wherein the plurality of wavelengths include wavelengths of red, green, and blue light.

8. The method of claim 1, wherein one or more of the plurality of light sensors are in contact with respective light guides through which light is sensed, and one or more of the plurality of light sensors are not in contact with respective light guides through which light is sensed.

9-16. (canceled)

17. An electronic device, comprising:

a first light guide;

a first light emitter configured to emit light through the first light guide;

a first light sensor configured to receive first light information from the first light guide;

a second light guide;

a second light emitter configured to emit light through the second light guide;

a second light sensor configured to receive second light information from the second light guide; and

processor configured to:

compute a heart rate signal based on the first and second light information.

18. The electronic device of claim 17, wherein a surface of the first light guide is curved such that the surface is configured to contact a tissue of a user.

19. The electronic device of claim 17, wherein the second light guide is recessed with respect to the electronic device such that the second light guide is configured not to contact a tissue of a user.

20. The electronic device of claim 17, wherein computing the heart rate signal based on the first and second light information includes performing blind source separation on the first and second light information.

21. The electronic device of claim 17, wherein computing the heart rate signal based on the first and second light information includes performing cross-correlation on the first and second light information.

22. The electronic device of claim 17, wherein the first light emitter is configured to emit a plurality of wavelengths through the first light guide; and

further wherein computing the heart rate signal includes performing blind source separation on light information of the plurality of wavelengths.

23. The electronic device of claim 22, wherein the plurality of wavelengths include wavelengths of red, green, and blue light.

24. The electronic device of claim 17, wherein one or more of the plurality of light sensors are in contact with respective light guides through which light is sensed, and one or more of the plurality of light sensors are not in contact with respective light guides through which light is sensed.

25. The electronic device of claim 17, where the first light guide protrudes with respect to the electronic device.

26. The electronic device of claim 17, wherein at least one of the first light sensor and the second light is configured to be more sensitive to light of a first wavelength than light of a second wavelength.

27. The electronic device of claim 23, wherein the second light emitter is configured to emit a plurality of second wavelengths through the second light guide, the plurality of second wavelengths including wavelengths of red, green, and blue light, and

further wherein computing the heart rate signal includes performing blind source separation on light information of the plurality of second wavelengths.

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摘要(译)

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