US 20180317852A1

(19) United States

(12) Patent Application Publication
MacDonald et al.

(10) Pub. No.: US 2018/0317852 A1

(43) Pub. Date: Nov. 8, 2018

(54) OPTICAL MOTION REJECTION

(71) Applicant: **Garmin Switzerland GmbH**, Schaffhausen (CH)

(72) Inventors: **Paul R. MacDonald**, Calgary (CA); **Christopher J. Kulach**, Calgary (CA)

(21) Appl. No.: **15/969,574**

(22) Filed: **May 2, 2018**

Related U.S. Application Data

(60) Provisional application No. 62/501,522, filed on May 4, 2017, provisional application No. 62/571,606, filed on Oct. 12, 2017, provisional application No. 62/580,308, filed on Nov. 1, 2017, provisional application No. 62/580,024, filed on Nov. 1, 2017.

Publication Classification

(51) **Int. Cl.**

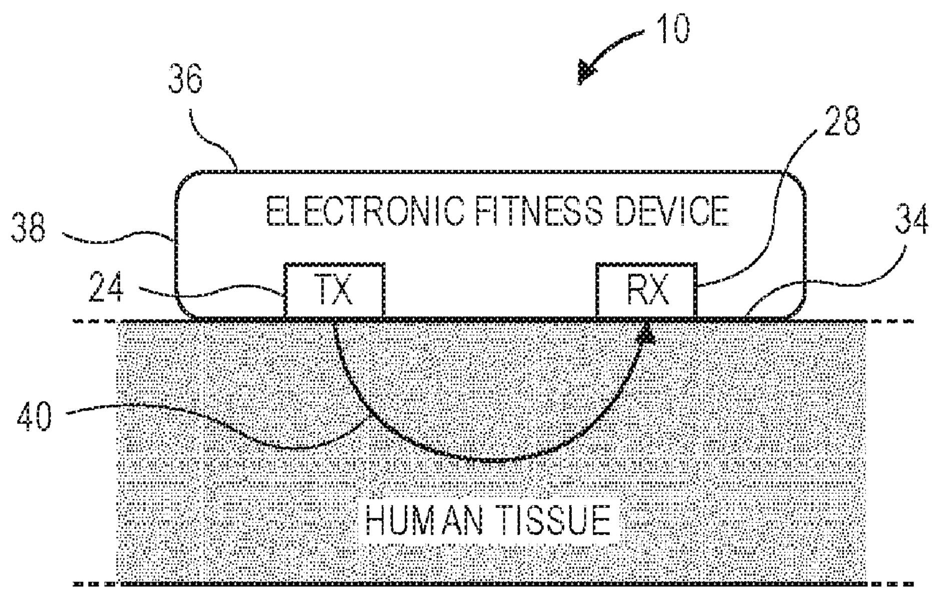
A61B 5/00	(2006.01)
A61B 5/024	(2006.01)

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

CPC ***A61B 5/7214*** (2013.01); ***A61B 5/02427*** (2013.01); ***A61B 5/02438*** (2013.01); *A61B 2562/046* (2013.01); *A61B 2562/0238* (2013.01); *A61B 2562/043* (2013.01); ***A61B 5/681*** (2013.01)

(57) **ABSTRACT**

An electronic fitness device comprises first and second optical transmitters, an optical receiver, and a processing element. The first optical transmitter is configured to transmit a first optical signal having a first wavelength. The second optical transmitter is configured to transmit a first optical signal having a second wavelength. The optical receiver is configured to receive the first and second optical signals and to generate first and second photoplethysmogram (PPG) signals respectively resulting from the received optical signals. The processing element is configured to control the first and second optical transmitters to transmit the first and second optical signals, receive the first and second PPG signals, and utilize the second PPG signal to reduce a noise component from the first PPG signal.



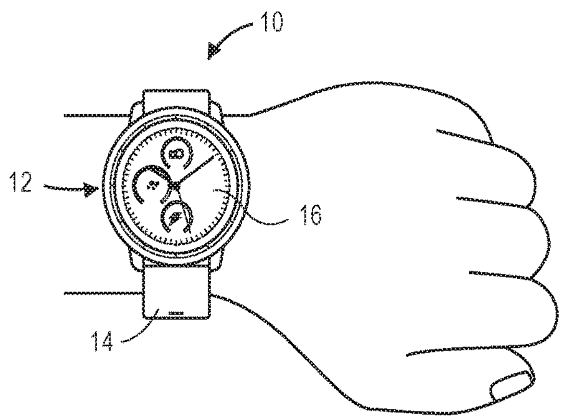

10
12
16
14

FIG. 1

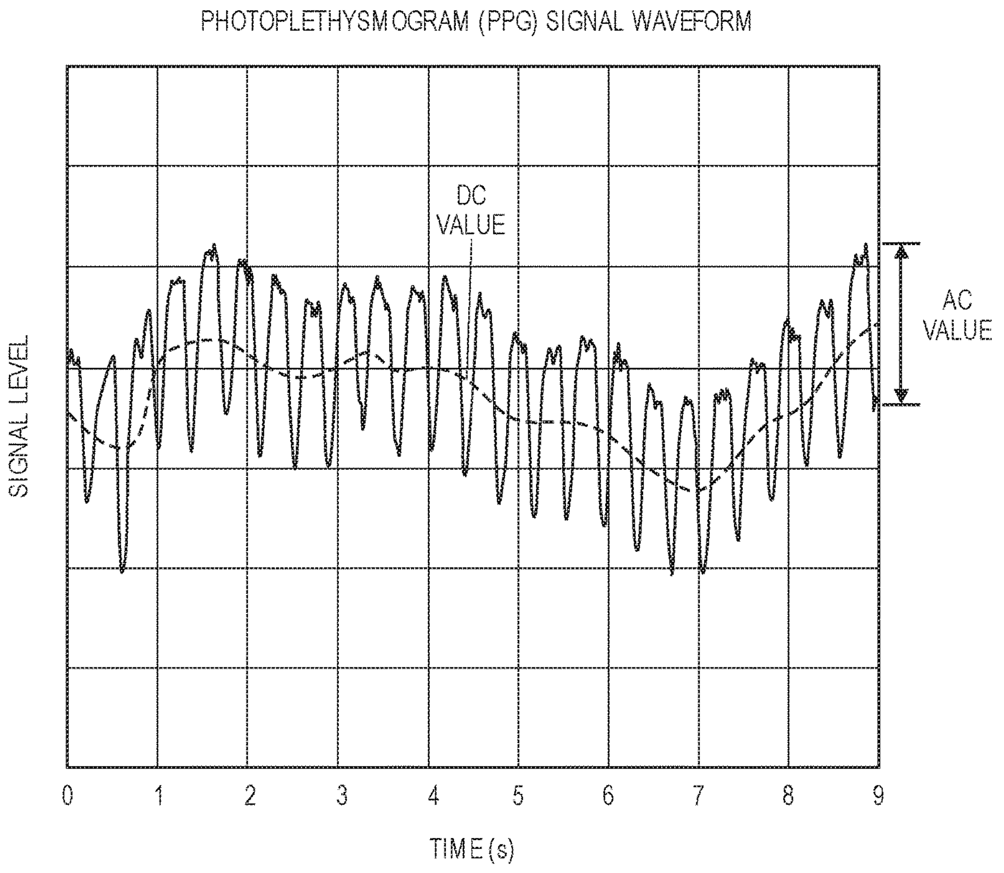

PHOTOPLETHYSMOGRAM (PPG) SIGNAL WAVEFORM
DC VALUE
AC VALUE
SIGNAL LEVEL
0
1
2
3
4
5
6
7
8
9
TIME (s)

FIG. 2

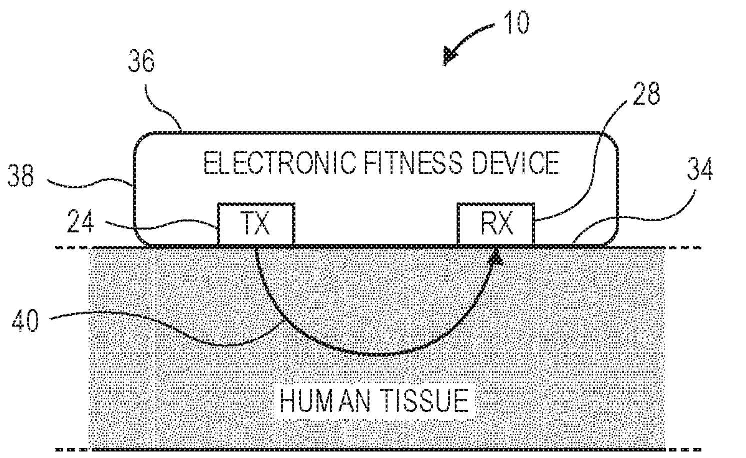

10
36
28
ELECTRONIC FITNESS DEVICE
38
34
24
TX
RX
40
HUMAN TISSUE

FIG. 3

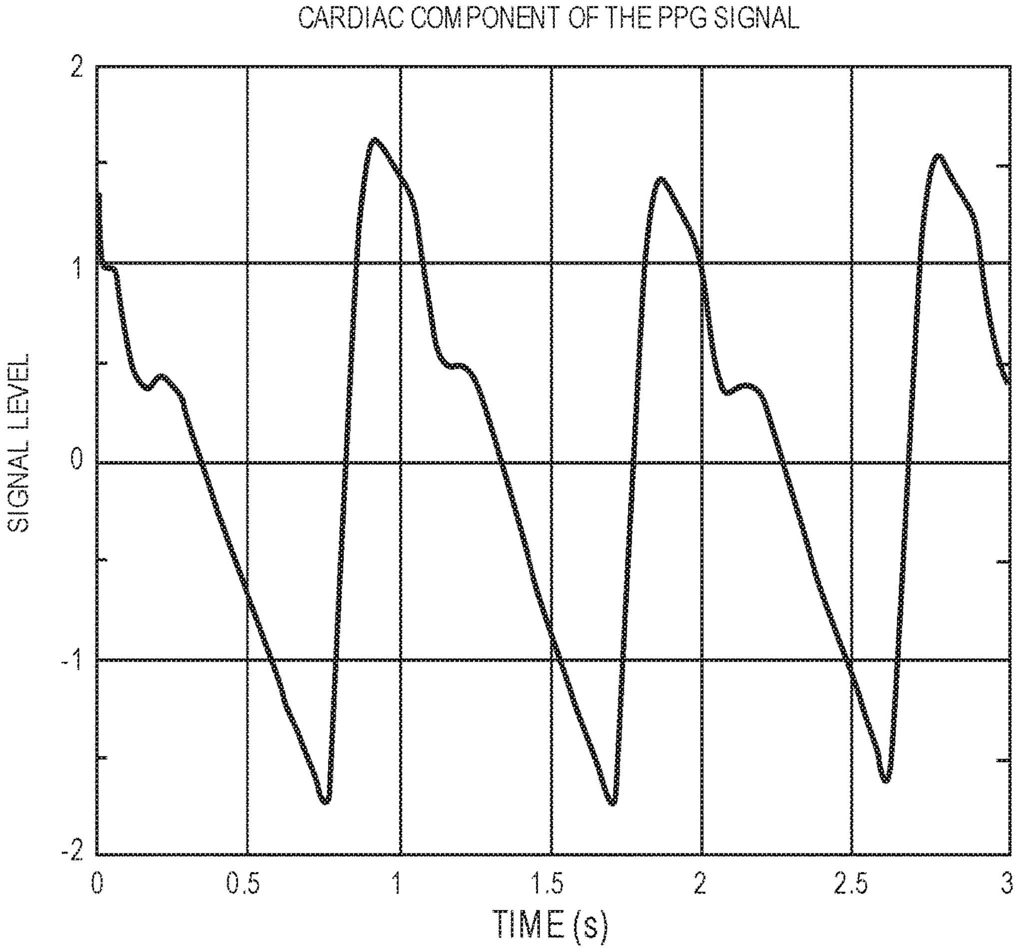

CARDIAC COMPONENT OF THE PPG SIGNAL
SIGNAL LEVEL
2
1
0
-1
-2
0
0.5
1
1.5
2
2.5
3
TIME (s)

FIG. 4

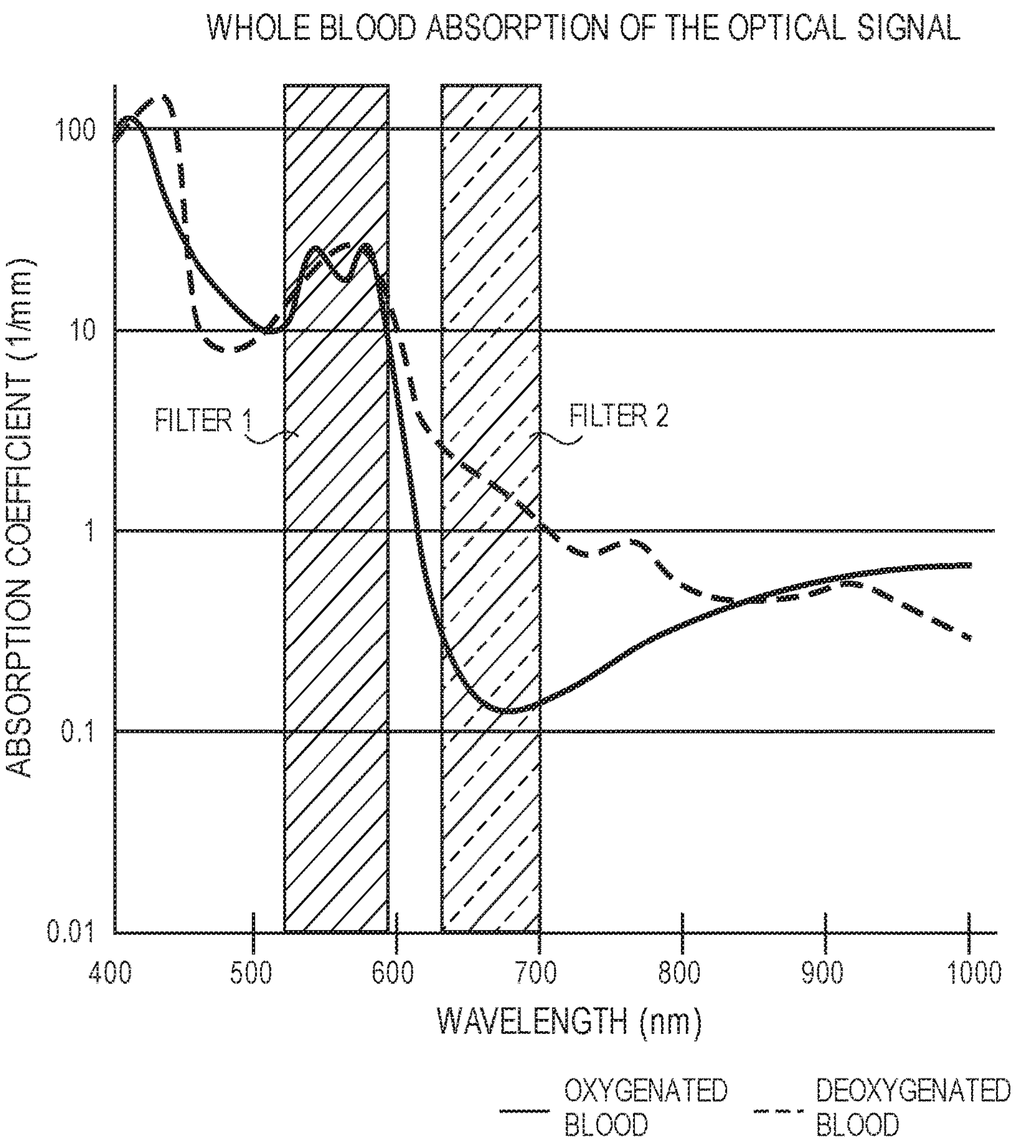

WHOLE BLOOD ABSORPTION OF THE OPTICAL SIGNAL
ABSORPTION COEFFICIENT (1/mm)
100
10
1
0.1
0.01
FILTER 1
FILTER 2
400
500
600
700
800
900
1000
WAVELENGTH (nm)
OXYGENATED BLOOD
DEOXYGENATED BLOOD

FIG. 5

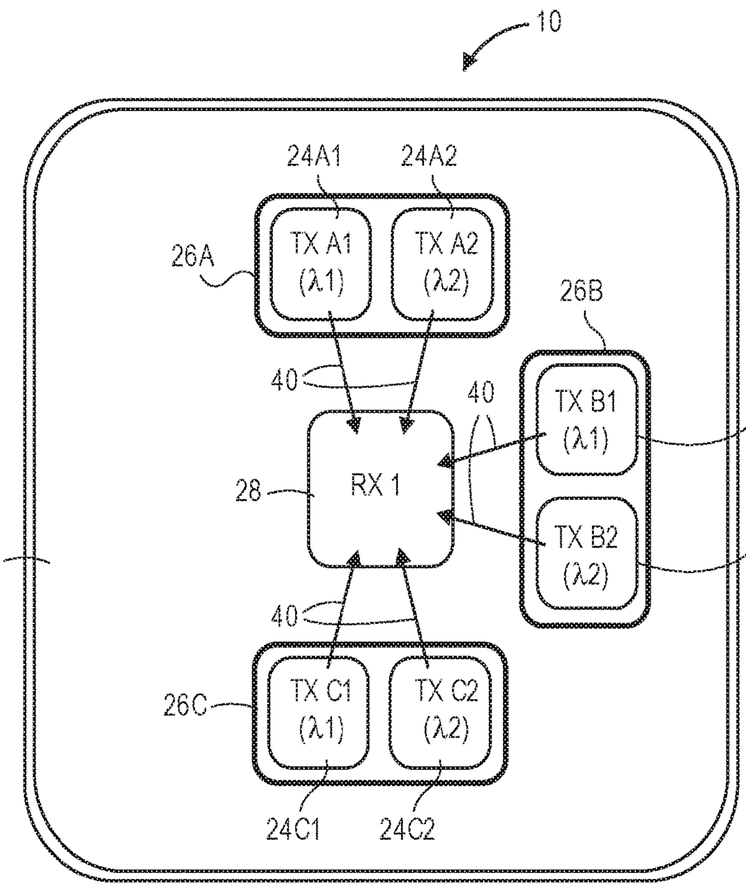

10
24A1
24A2
26A
TX A1 (λ1)
TX A2 (λ2)
26B
40
40
TX B1 (λ1)
24B1
28
RX 1
34
TX B2 (λ2)
24B2
40
26C
TX C1 (λ1)
TX C2 (λ2)
24C1
24C2

FIG. 7

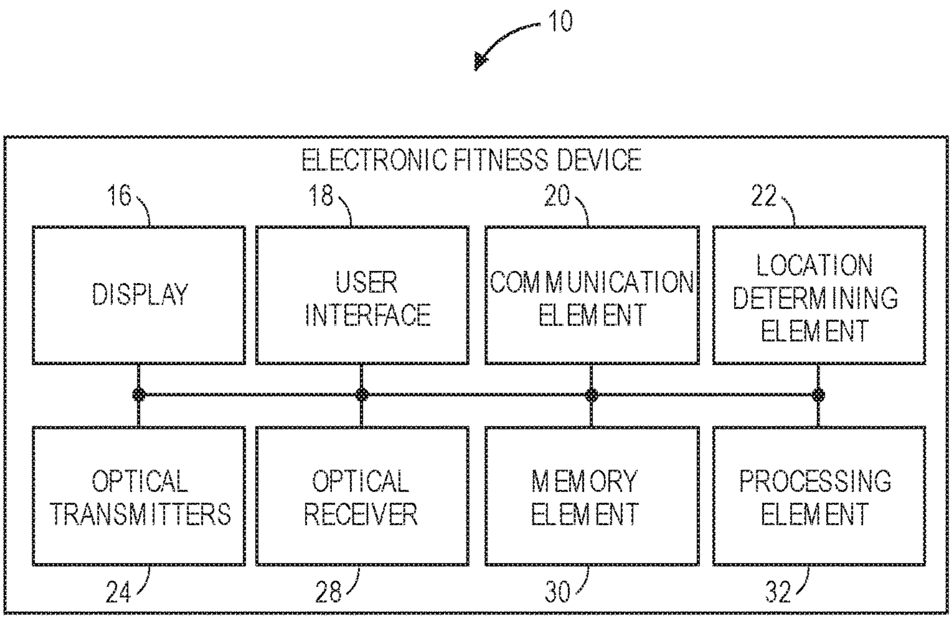

10
ELECTRONIC FITNESS DEVICE
16
18
20
22
DISPLAY
USER INTERFACE
COMMUNICATION ELEMENT
LOCATION DETERMINING ELEMENT
OPTICAL TRANSMITTERS
OPTICAL RECEIVER
MEMORY ELEMENT
PROCESSING ELEMENT
24
28
30
32

FIG. 6

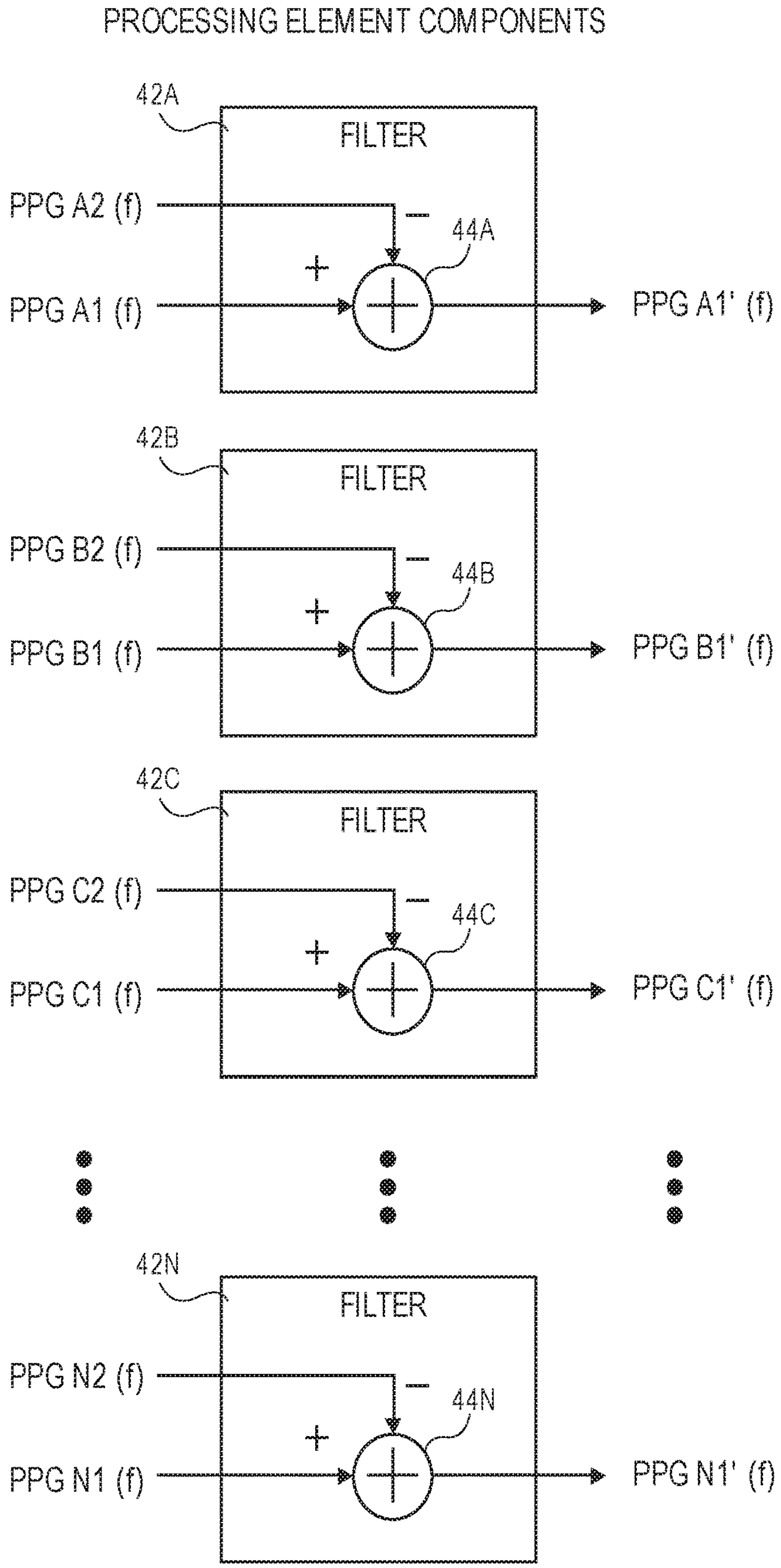

PROCESSING ELEMENT COMPONENTS
42A
FILTER
PPG A2 (f)
−
44A
+
PPG A1 (f)
PPG A1' (f)
42B
FILTER
PPG B2 (f)
−
44B
+
PPG B1 (f)
PPG B1' (f)
42C
FILTER
PPG C2 (f)
−
44C
+
PPG C1 (f)
PPG C1' (f)
42N
FILTER
PPG N2 (f)
−
44N
+
PPG N1 (f)
PPG N1' (f)

FIG. 8

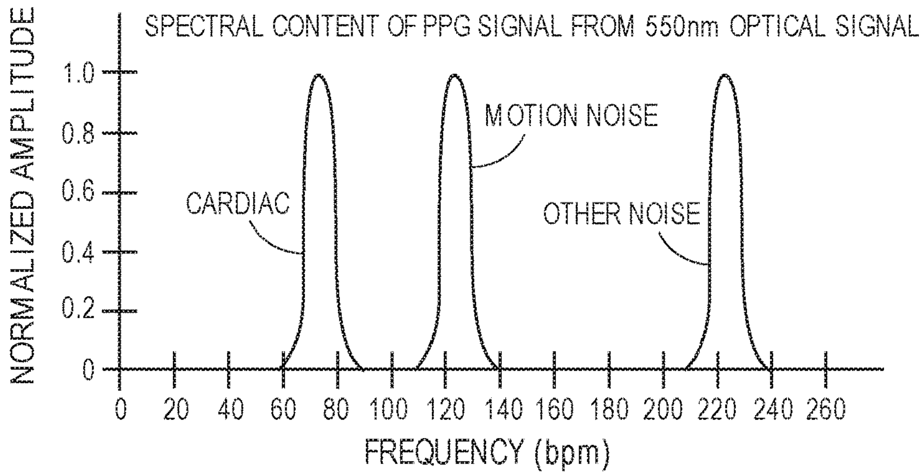


FIG. 9

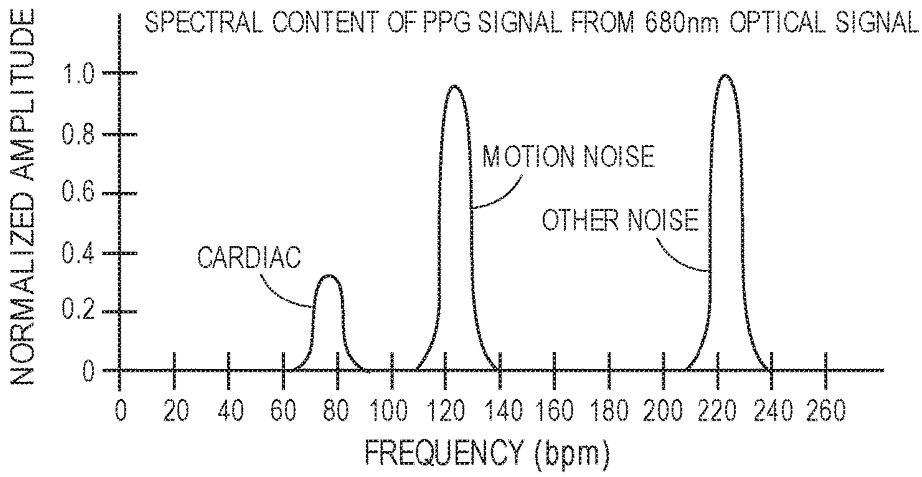


FIG. 10

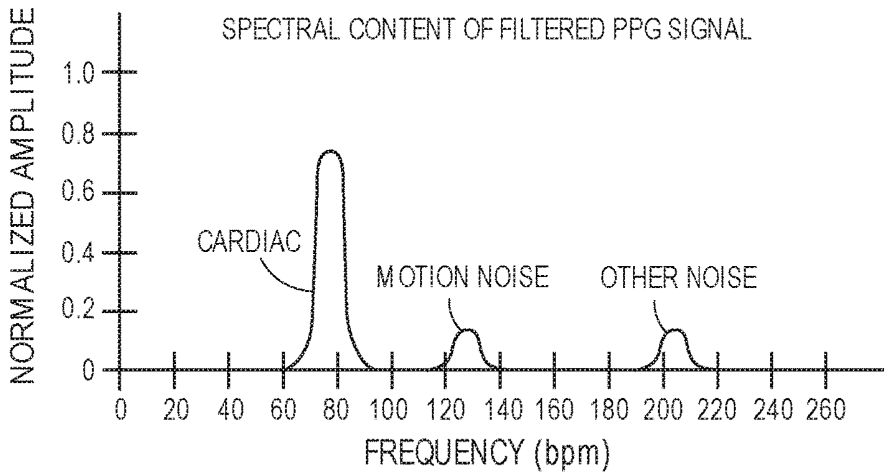


FIG. 11

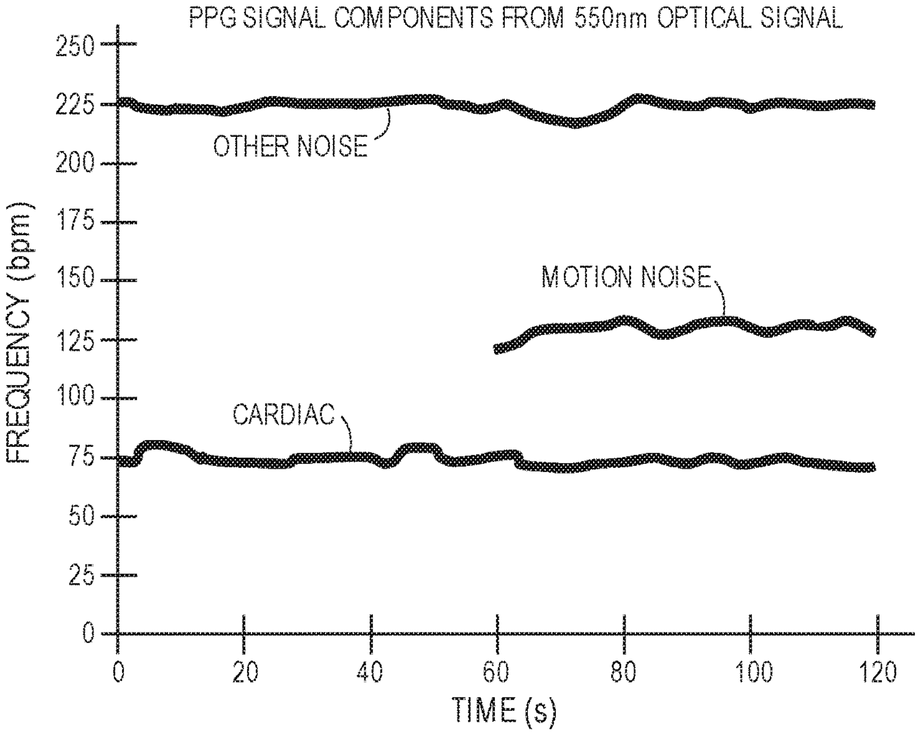

PPG SIGNAL COMPONENTS FROM 550nm OPTICAL SIGNAL
FREQUENCY (bpm)
250
225
200
175
150
125
100
75
50
25
0
OTHER NOISE
MOTION NOISE
CARDIAC
0
20
40
60
80
100
120
TIME (s)

FIG. 12

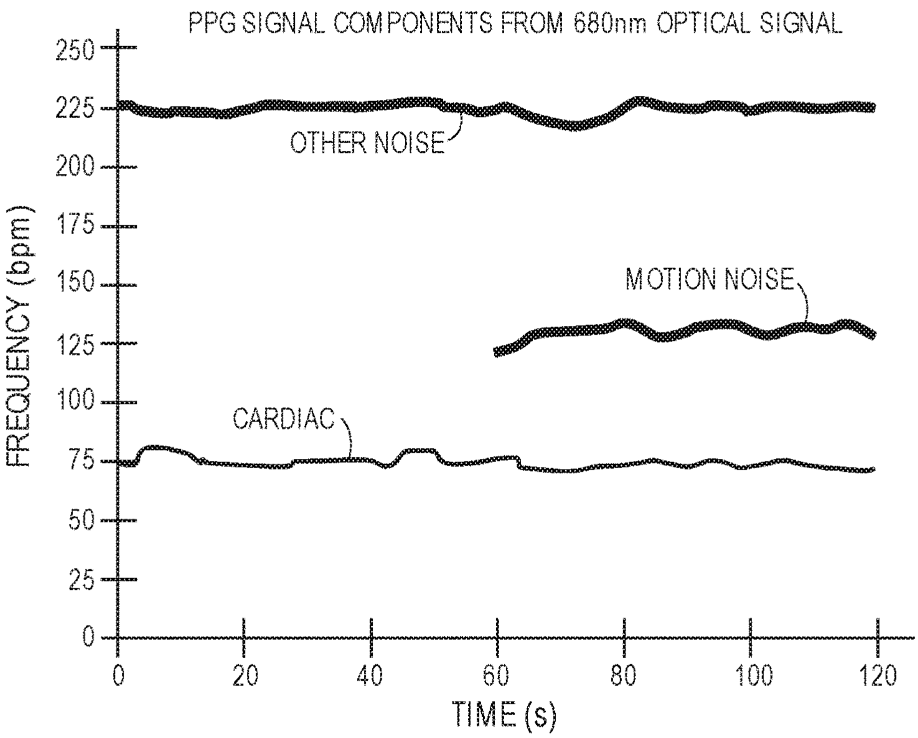

PPG SIGNAL COMPONENTS FROM 680nm OPTICAL SIGNAL
FREQUENCY (bpm)
250
225
200
175
150
125
100
75
50
25
0
OTHER NOISE
MOTION NOISE
CARDIAC
0
20
40
60
80
100
120
TIME (s)

FIG. 13

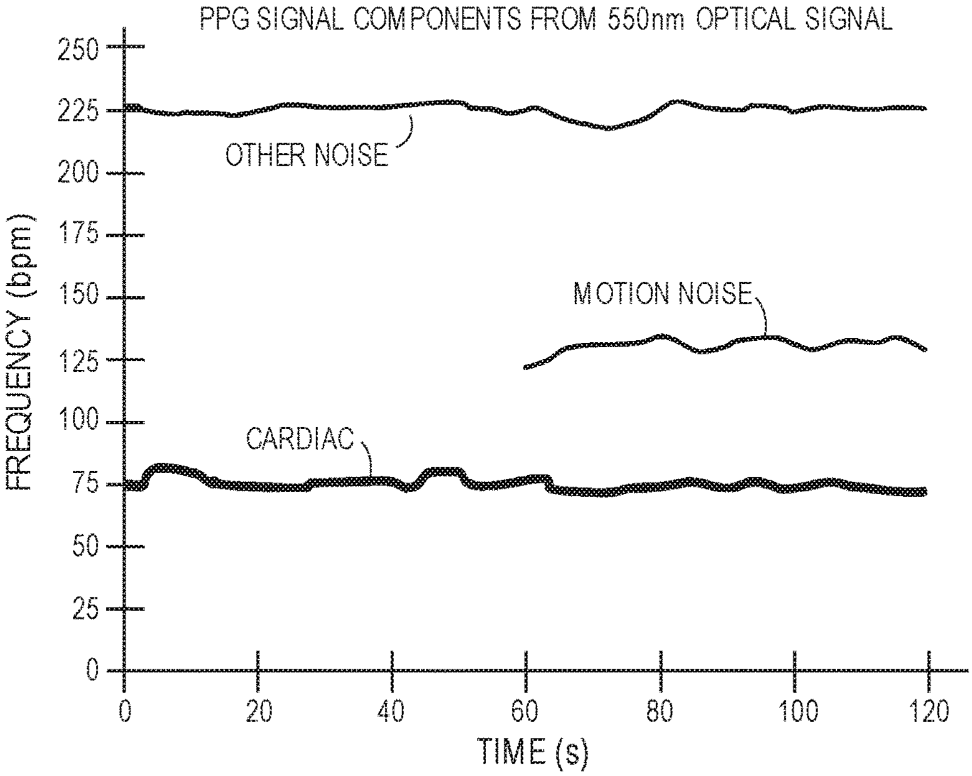

PPG SIGNAL COMPONENTS FROM 550nm OPTICAL SIGNAL
FREQUENCY (bpm)
250
225
200
175
150
125
100
75
50
25
0
OTHER NOISE
MOTION NOISE
CARDIAC
0
20
40
60
80
100
120
TIME (s)

FIG. 14

OPTICAL MOTION REJECTION

RELATED APPLICATIONS

[0001] The present application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application Ser. No. 62/501,522, entitled "Improved SNR of Components in PPG Signal," filed May 4, 2017, Provisional Application Ser. No. 62/571,606, entitled "Improved Optical Cardiac Monitor," filed Oct. 12, 2017, Provisional Application Ser. No. 62/580,308, entitled "Improved Optical Cardiac Monitor," filed Nov. 1, 2017, and Provisional Application Ser. No. 62/580,024, entitled "User Body Hydration," filed Nov. 1, 2017. The above-referenced Provisional Applications are herein incorporated by reference in their entireties.

BACKGROUND

[0002] An electronic fitness device may provide optical cardiac monitoring of a user of the device. The user (wearer) may be any individual who wears the electronic device such that a housing of the electronic device is located proximate to skin of the individual (e.g., worn against the person's wrist, abdomen, leg, etc.). The cardiac monitoring may include physiological metrics and information such as a user's heart rate. The electronic fitness device may utilize a photoplethysmogram (PPG) signal to determine the cardiac monitoring information. The PPG signal is typically output by a photodiode and is commonly utilized to identify changes in the volume of blood in the skin proximate to the photodiode and is collected over a period of time encompassing a plurality of heart beats. The electronic fitness device may include optical devices, such as an optical transmitter, which emits an optical signal (light) into the user's skin, and an optical receiver, which receives reflections of the optical signal (light) from the skin and generates a PPG signal corresponding to the intensity of the received light. Typically, the electronic fitness device includes a housing and straps enabling it to be worn on the user's wrist, arm, leg, or torso, and the optical devices are positioned on the back, or bottom wall, of the housing to orient the optical devices to output and receive light from the user's skin when the device is worn.

SUMMARY

[0003] PPG signals include a cardiac component along with noise components from various sources and noise resulting from motion of the user. The cardiac metrics and information generally require identification and analysis of the cardiac component of the PPG signal. However, the noise components also included in the PPG signal make deriving the desired information more difficult. Embodiments of the present technology provide an electronic fitness device which filters the noise components. An embodiment of the electronic fitness device broadly comprises a housing, a first optical transmitter, a second optical transmitter, an optical receiver, and a processing element. The housing generally retains the other components and includes a bottom wall. The first optical transmitter is positioned along the bottom wall and is configured to transmit a first optical signal having a first wavelength such that the first optical signal is directed into the skin of a user. The second optical transmitter is positioned along the bottom wall and is configured to transmit a second optical signal having a second wavelength such that the second optical signal is directed into the skin of the user. The optical receiver is positioned along the bottom wall and is configured to receive the first and second optical signals modulated by the skin of the user and to generate a first photoplethysmogram (PPG) signal resulting from the received first optical signal and a second PPG signal resulting from the received second optical signal. The processing element is in electronic communication with the first optical transmitter, the second optical transmitter, and the optical receiver. The processing element is configured to control the first optical transmitter to transmit the first optical signal during a first period of time, control the second optical transmitter to transmit the second optical signal during a second period of time, receive the first and second PPG signals from the optical receiver, and utilize the second PPG signal to reduce a motion noise component from the first PPG signal.

[0004] Another embodiment of the present technology provides an electronic fitness device broadly comprising a housing, a first optical transmitter, a second optical transmitter, an optical receiver, a processing element including a filter. The housing generally retains the other components and includes a bottom wall. The first optical transmitter is positioned along the bottom wall and is configured to transmit a first optical signal having a first wavelength such that the first optical signal is directed into the skin of a user. The second optical transmitter is positioned along the bottom wall and is configured to transmit a second optical signal having a second wavelength such that the second optical signal is directed into the skin of the user. The optical receiver is positioned along the bottom wall and is configured to receive the first and second optical signals modulated by the skin of the user and to generate a first photoplethysmogram (PPG) signal resulting from the received first optical signal and a second PPG signal resulting from the received second optical signal. The processing element is in electronic communication with the first optical transmitter, the second optical transmitter, and the optical receiver. The processing element is configured to control the first optical transmitter to transmit the first optical signal during a first period of time, control the second optical transmitter to transmit the second optical signal during a second period of time, receive the first and second PPG signals from the optical receiver, and convert the first PPG signal and the second PPG signal from the time domain to the frequency domain. The filter is configured to receive the first frequency domain PPG signal and the second frequency domain PPG signal and filter noise components from the first and second frequency domain PPG signals to generate a filtered frequency domain PPG signal.

[0005] Yet another embodiment of the present technology provides an electronic fitness device broadly comprising a housing, a first optical transmitter, a second optical transmitter, an optical receiver, a processing element, and a filter. The housing generally retains the other components and includes a bottom wall. The first optical transmitter is positioned along the bottom wall and is configured to transmit a first optical signal having a first wavelength such that the first optical signal is directed into the skin of a user. The second optical transmitter is positioned along the bottom wall and is configured to transmit a second optical signal having a second wavelength such that the second optical signal is directed into the skin of the user. The optical receiver is positioned along the bottom wall and is configured to receive the first and second optical signals modulated by the skin of the user and to generate a first photoplethysmogram (PPG) signal resulting from the received first optical signal and a second PPG signal resulting from the received second optical signal. The processing element is configured to control the first optical transmitter to transmit the first optical signal during a first period of time, control the second optical transmitter to transmit the second optical signal during a second period of time, receive the first and second PPG signals from the optical receiver, and convert the first PPG signal and the second PPG signal from the time domain to the frequency domain. The filter is configured to receive the first frequency domain PPG signal and the second frequency domain PPG signal and subtract the first frequency domain PPG signal from the second frequency domain PPG signal to generate a filtered frequency domain PPG signal.

[0006] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Other aspects and advantages of the present technology will be apparent from the following detailed description of the embodiments and the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0007] Embodiments of the present technology are described in detail below with reference to the attached drawing figures, wherein:

[0008] FIG. **1** is a top view of an electronic fitness device, constructed in accordance with various embodiments of the present technology, worn on a user's wrist;

[0009] FIG. **2** is a plot of a photoplethysmogram (PPG) signal waveform that may be generated by the electronic fitness device over a period of time;

[0010] FIG. **3** is a schematic side sectional view of the electronic fitness device and a user's wrist depicting transmission of an optical signal through the skin and tissue of the user;

[0011] FIG. **4** is a plot of a cardiac component of the PPG signal resulting from the PPG signal being filtered;

[0012] FIG. **5** is a plot of an absorption coefficient, or level, of the optical signal versus a wavelength of the optical signal, wherein the optical signal may be absorbed by various components of blood, such as oxygenated blood and deoxygenated blood;

[0013] FIG. **6** is a schematic block diagram of various electronic components of the electronic fitness device;

[0014] FIG. **7** is a schematic view of the bottom wall of the electronic fitness device illustrating a plurality of pairs of optical transmitters in proximity to an optical receiver;

[0015] FIG. **8** is a schematic block diagram of components of a processing element of the electronic fitness device, the components including a plurality of filters;

[0016] FIG. **9** is a plot of a spectral content of a PPG signal resulting from an optical signal having a wavelength of approximately 550 nanometers (nm);

[0017] FIG. **10** is a plot of a spectral content of a PPG signal resulting from an optical signal having a wavelength of approximately 680 nm;

[0018] FIG. **11** is a plot of a spectral content of a filtered PPG signal;

[0019] FIG. **12** is a plot of frequency versus time for PPG signal components resulting from an optical signal having a wavelength of approximately 550 nm;

[0020] FIG. **13** is a plot of frequency versus time for PPG signal components resulting from an optical signal having a wavelength of approximately 680 nm; and

[0021] FIG. **14** is a plot of frequency versus time for a filtered PPG signal.

[0022] The drawing figures do not limit the present technology to the specific embodiments disclosed and described herein. While the drawings do not necessarily provide exact dimensions or tolerances for the illustrated components or structures, the drawings are to scale as examples of certain embodiments with respect to the relationships between the components of the structures illustrated in the drawings.

DETAILED DESCRIPTION

[0023] The following detailed description of the technology references the accompanying drawings that illustrate specific embodiments in which the technology can be practiced. The embodiments are intended to describe aspects of the technology in sufficient detail to enable those skilled in the art to practice the technology. Other embodiments can be utilized and changes can be made without departing from the scope of the present technology. The following detailed description is, therefore, not to be taken in a limiting sense. The scope of the present technology is defined only by the appended claims, along with the full scope of equivalents to which such claims are entitled.

[0024] In this description, references to "one embodiment", "an embodiment", or "embodiments" mean that the feature or features being referred to are included in at least one embodiment of the technology. Separate references to "one embodiment", "an embodiment", or "embodiments" in this description do not necessarily refer to the same embodiment and are also not mutually exclusive unless so stated and/or except as will be readily apparent to those skilled in the art from the description. For example, a feature, structure, act, etc. described in one embodiment may also be included in other embodiments, but is not necessarily included. Thus, the present technology can include a variety of combinations and/or integrations of the embodiments described herein.

[0025] Embodiments of the present technology provide an electronic fitness device that may be worn on a user's wrist, such as the electronic fitness device shown in FIG. **1**, and provides optical cardiac monitoring by generating and utilizing photoplethysmogram (PPG) signals, such as the PPG signal shown as a waveform in FIG. **2**. Cardiac monitoring may include determining information such as the user's pulse or heart rate, a pulse oximetry ("Pulse Ox") level (also known as a level of blood oxygen saturation, or SpO2), an estimated stress level, a maximum rate of oxygen consumption (VO2 max), or the like. Referring to FIG. **3**, a PPG signal is based on an optical signal (light) emitted from an optical transmitter (TX) into the user's skin (human tissue) proximate to the optical transmitter (TX). The user (wearer) may be any individual who wears the electronic device such that a housing of the electronic device is located proximate to skin of the individual (e.g., worn against the person's wrist, abdomen, leg, etc.). The emitted optical signal penetrates the user's skin to a depth that ranging from tens of microns to several millimeters depending on a variety of criteria, such as the wavelength of transmitted light, presence of blood vessels and composition of the user's skin layers. A portion of the optical signal is reflected, or otherwise transferred, from the skin to an optical receiver (RX), typically a photodiode, that generates the PPG signal. The magnitude of the PPG signal is associated with an intensity of the received optical signal (light). The optical signal may be modulated, or otherwise modified, by the flow of blood through the vessels in the path of the optical signal. Specifically, the optical signal is modulated by the blood flow response to the beating of the user's heart, or the cardiac cycle. Thus, the optical signal received by the optical receiver (RX) has been modulated to include a cardiac component corresponding to the user's cardiac characteristics, which are associated with the user's heartbeat. In turn, the PPG signal generated by the optical receiver (RX) includes the cardiac component corresponding to the user's heartbeat. In addition to the cardiac component, the PPG signal includes undesirable components, such as a motion noise component resulting from motion of the user, and other noise components resulting from operation of the device and/or electronic circuitry of the optical receiver (RX), etc.

[0026] Generally, as shown in FIG. **2**, the PPG signal waveform includes an AC component and a DC component. The AC component of the PPG signal waveform oscillates between a local maximum and a local minimum over successive short periods of time. The DC component of the PPG signal waveform may be a moving average of the local maximum and the local minimum over successive short periods of time. In some implementations, a processing element may control a low-pass filter to isolate the DC component or a substantial portion of the DC component.

[0027] Referring to FIG. **4**, the cardiac component of the PPG signal is typically a periodic, substantially sinusoidal waveform. Use of optical signals and active motion of the user, particularly the part of the body where the electronic fitness device is worn, typically generates the motion noise and other noise components. Motion noise and other noise components may exist at frequencies less than a few hundred bpm (beats per minute), as seen in FIGS. **9-14**, and such undesired noise may distort the cardiac component and thereby reduce a signal to noise ratio of the cardiac component. Accordingly, the noise components of the PPG signal may make it difficult to isolate and identify the cardiac component of the PPG signal.

[0028] Conventional electronic fitness devices have a housing enclosing an accelerometer, gyroscope, and other motion sensors to detect motion of the housing and generate a motion electronic signal corresponding to the motion. In such conventional electronic devices, the motion electronic signal may be utilized by a (signal) processing element to filter the motion noise component from a PPG signal generated at approximately the same time as the motion electronic signal. There are at least three drawbacks to use of this conventional approach. A first drawback is that the accelerometer may detect motion or movement of the electronic fitness device housing when there is a lower magnitude or no motion noise component included in the PPG signal. Such motion or movement of the housing may be detected when the user is substantially sedentary or inactive, such as when the user is changing wrist orientation with respect to gravity. A second drawback is that the accelerometer detecting movement of the electronic fitness devices housing may not detect subtle, active motion of the user that introduces motion noise and other noise components into a PPG signal. For example, the user may be typing at a keyboard with his forearms and wrist in a substantially stationary position while typing. In such environments, the accelerometer of the conventional electronic device worn on a user's wrist may detect very little motion of the housing. However, the user is moving his fingers and thumbs, which results from various movements of the user's ligaments and tendons under the conventional electronic device housing. This motion may generate a motion noise component in the PPG signal that cannot be adequately detected by the accelerometer of the conventional electronic device because such motion may not cause significant movement of the housing. A third drawback is that a motion electronic signal, such as one generated by an accelerometer detecting the motion of the housing does not relate to any specific optical path, but rather to the entire device housing. Thus, in implementations of conventional products that output optical signals traveling along different paths to generate a plurality of PPG signals, use of a motion signal output by an accelerometer limits any motion filtering to use of only a single, common motion electronic signal associated with the movement or motion of the entire device housing. Such conventional motion signals do not account for substantially different motion noise components along each of the paths traveled by the optical signals. This conventional approach of motion noise filtering may result in poor performance of removing motion noise components from each of the multiple PPG signals by using a single motion electronic signal associated with movement of the device housing. As a result, conventional motion sensors may not generate a motion electronic signal, associated with each path traveled by an optical signal, that could be used to identify a motion noise component by applying optical motion sensing techniques.

[0029] Embodiments of the present technology implement a solution to the problems discussed above using an electronic fitness device. It is generally known that a level of absorption of an optical signal transmitted by an optical transmitter into a user's skin and surrounding tissue varies according to a wavelength of the optical signal and according to a level of oxygen in the skin and surrounding tissue. In the visible to near infrared (NIR) regions of light spectrum, the absorption substantially relates to the absorption of the optical signal by the blood vessels. Typically, the greater the absorption, the greater the modulation of the optical signal by the flow of blood, which yields a greater magnitude and signal to noise ratio of the cardiac component in the resulting PPG signal. Conversely, a lower absorption of the optical signal leads to a lower magnitude and signal to noise ratio of the cardiac component. A plot of the absorption of oxygenated and deoxygenated blood versus wavelength of an optical signal is shown in FIG. **5**. The plot illustrates that not only is there a difference in absorption between oxygenated blood and deoxygenated blood but also the level of absorption varies greatly with wavelength—particularly for oxygenated blood. In addition, as shown in FIGS. **9-10** and **12-13**, the magnitudes of certain components of the PPG signal, such as the motion noise and other noise components, may remain roughly the same for at least some bands of wavelength, such as 550 nm and 680 nm.

[0030] One filtration technique applied in embodiments of the present technology to filter the noise components from the PPG signal utilizes the differing magnitudes of the cardiac component between two wavelengths of the optical signal for which the magnitudes of the noise components remain the approximately the same. In embodiments, a signal filter may include a signal mixer or adder that adds a first signal to a negative of a second signal—effectively subtracting the second signal from the first signal to generate a filtered output signal that is the difference of the two input signals. In embodiments, the subtracted signal is pre-scaled to substantially match magnitude of noise components between the two signals. With this type of filter, the components common to both signals having approximately the same magnitude are removed from (subtracted) or at least greatly reduced in the resulting filtered signal, while the components common to both signals having different magnitudes remain or at least partially remain in the resulting filtered signal. Therefore, a processing element of the electronic fitness device may produce a PPG signal having a substantially preserved cardiac component while the noise components are substantially removed (filtered out) by inputting two PPG signals to the signal filter wherein the magnitude of the cardiac component differs between the two signals but the noise components are roughly the same.

[0031] In embodiments, the two optical signals that result in the two PPG signals being generated by an optical receiver may have two wavelengths for which the difference in the blood absorption is the greatest. As seen in the plot of FIG. **5**, two ranges of wavelengths provide a significant difference in the blood absorption of the optical signal. Specifically, a first range of wavelengths, labeled "Filter **1**", may range from approximately 520 nm to approximately 590 nm and may have an absorption coefficient for oxygenated blood of approximately 30/mm and a second range of wavelengths, labeled "Filter **2**", may range from approximately 620 nm to approximately 700 nm and may have an absorption coefficient for oxygenated blood of approximately 0.15/mm to approximately 0.40/mm. The blood absorption of the optical signal is much greater for oxygenated blood at a wavelength within the Filter **1** range than within the Filter **2** range. Similarly, the blood absorption is greater for deoxygenated blood at a wavelength within the Filter **1** range than within the Filter **2** range, but the extent of the difference is not as significant as the absorption differences for oxygenated blood. Human blood, particularly on the arterial (pulsatile) side of the cardiovascular system is substantially oxygenated. Accordingly, a PPG signal resulting from an optical signal having a wavelength in the Filter **1** range typically has a greater signal-to-noise ratio (SNR) than a SNR of a PPG signal resulting from an optical signal having a wavelength in the Filter **2** range.

[0032] The electronic fitness device of the present technology includes at least two optical transmitters and an optical receiver. A first optical transmitter is configured to transmit a first optical signal having a wavelength in the Filter **1** range and a second optical transmitter is configured to transmit a second optical signal having a wavelength in the Filter **2** range. The optical receiver receives the optical signals (after the optical signals have passed through the user's skin and tissue) and generates a first PPG signal resulting from the first optical signal and a second PPG signal resulting from the second optical signal. In addition, the electronic fitness device includes a filter that receives the two PPG signals, performs a filtering function (e.g., subtraction of the second PPG signal from the first PPG signal), and outputs a filtered PPG signal including a cardiac component and a substantially reduced (filtered) noise components. The present technology solves the problems of conventional electronic fitness devices because it does not rely on sensor devices that detect a motion or movement of a housing worn on or against a user's body. Instead, the present technology utilizes optical signals of different wavelengths to substantially remove (filter out) noise caused by motion and other noise sources from one of the PPG signals.

[0033] Embodiments of the present technology will now be described in more detail with reference to the drawing figures. Referring initially to FIGS. **1**, **3**, **6**, and **7**, an electronic fitness device **10** configured to implement the disclosed filtering techniques to substantially reduce various noise components of a PPG signal is illustrated. An exemplary electronic fitness device **10** may be embodied by a smart watch or a fitness band that is typically worn on a user's wrist, but may also be embodied by bands or belts worn on the user's arm, leg, or torso. Other examples of the electronic fitness device **10** may include smartphones, personal data assistants, or the like which include a surface, operable to retain optical devices, that can be pressed against the user's skin. The electronic fitness device **10** may broadly comprise a housing **12**, a wrist band **14**, a display **16**, a user interface **18**, a communication element **20**, a location determining element **22**, a plurality of optical transmitters **24**, a plurality of lenses **26**, an optical receiver **28**, a memory element **30**, and a processing element **32**.

[0034] The housing **12** generally houses or retains other components of the electronic fitness device **10** and may include or be coupled to the wrist band **14**. As seen in FIG. **3**, the housing **12** may include a bottom wall **34**, an upper surface **36**, and at least one side wall **38** that bound an internal cavity (not shown in the figures). The bottom wall **34** may include a lower, outer surface that contacts the user's wrist while the user is wearing the electronic fitness device **10**. The upper surface **36** opposes the bottom wall **34**. In various embodiments, the upper surface **36** may further include an opening that extends from the upper surface to the internal cavity. In some embodiments, such as the exemplary embodiments shown in the figures, the bottom wall **34** of the housing **12** may have a round, circular, or oval shape, with a single circumferential side wall **38**. In other embodiments, the bottom wall **34** may have a four-sided shape, such as a square or rectangle, or other polygonal shape, with the housing **12** including four or more sidewalls. The bottom wall **34** includes one or more openings through which the optical transmitters **24** emit or transmit an optical signal **40** and the optical receiver **28** receives reflections of the optical signal **40** from the user's skin. The one or more openings within the bottom wall **34** may be covered by one or more lenses **26** through which the optical signal **40** may be transmitted and received.

[0035] The display **16** generally presents the information mentioned above, such as time of day, current location, and the like. The display **16** may be implemented in one of the following technologies: light-emitting diode (LED), organic LED (OLED), Light Emitting Polymer (LEP) or Polymer LED (PLED), liquid crystal display (LCD), thin film transistor (TFT) LCD, LED side-lit or back-lit LCD, or the like, or combinations thereof. In some embodiments, the display **16** may have a round, circular, or oval shape. In other embodiments, the display **16** may possess a square or a rectangular aspect ratio which may be viewed in either a landscape or a portrait orientation.

[0036] The user interface **18** generally allows the user to directly interact with the electronic fitness device **10** and may include pushbuttons, rotating knobs, or the like. In various embodiments, the display **16** may also include a touch screen occupying the entire display **16** or a portion thereof so that the display **16** functions as at least a portion of the user interface **18**. The touch screen may allow the user to interact with the electronic fitness device **10** by physically touching, swiping, or gesturing on areas of the display **16**.

[0037] The communication element **20** generally allows communication with external systems or devices. The communication element **20** may include signal and/or data transmitting and receiving circuits, such as antennas, amplifiers, filters, mixers, oscillators, digital signal processors (DSPs), and the like. The communication element **20** may establish communication wirelessly by utilizing radio frequency (RF) signals and/or data that comply with communication standards such as cellular 2G, 3G, 4G, LTE, or 5G, Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard such as Wi-Fi, IEEE 802.16 standard such as WiMAX, Bluetooth™, or combinations thereof. In addition, the communication element **20** may utilize communication standards such as ANT, ANT+, Bluetooth™ low energy (BLE), the industrial, scientific, and medical (ISM) band at 2.4 gigahertz (GHz), or the like. Alternatively, or in addition, the communication element **20** may establish communication through connectors or couplers that receive metal conductor wires or cables which are compatible with networking technologies such as Ethernet. In certain embodiments, the communication element **20** may also couple with optical fiber cables. The communication element **20** may be in electronic communication with the memory element **30** and the processing element **32**.

[0038] The location determining element **22** generally determines a current geolocation of the electronic fitness device **10** and may receive and process radio frequency (RF) signals from a global navigation satellite system (GNSS) such as the global positioning system (GPS) primarily used in the United States, the GLONASS system primarily used in the Soviet Union, or the Galileo system primarily used in Europe. The location determining element **22** may accompany or include an antenna to assist in receiving the satellite signals. The antenna may be a patch antenna, a linear antenna, or any other type of antenna that can be used with location or navigation devices. The location determining element **22** may include satellite navigation receivers, processors, controllers, other computing devices, or combinations thereof, and memory. The location determining element **22** may process a signal, referred to herein as a "location signal", from one or more satellites that includes data from which geographic information such as the current geolocation is derived. The current geolocation may include coordinates, such as the latitude and longitude, of the current location of the electronic fitness device **10**. The location determining element **22** may communicate the current geolocation to the processing element **32**, the memory element **30**, or both.

[0039] Although embodiments of the location determining element **22** may include a satellite navigation receiver, it will be appreciated that other location-determining technology may be used. For example, cellular towers or any customized transmitting radio frequency towers can be used instead of satellites may be used to determine the location of the electronic fitness device **10** by receiving data from at least three transmitting locations and then performing basic triangulation calculations to determine the relative position of the device with respect to the transmitting locations. With such a configuration, any standard geometric triangulation algorithm can be used to determine the location of the electronic fitness device **10**. The location determining element **22** may also include or be coupled with a pedometer, accelerometer, compass, or other dead-reckoning components which allow it to determine the location of the device **10**. The location determining element **22** may determine the current geographic location through a communications network, such as by using Assisted GPS (A-GPS), or from another electronic fitness device. The location determining element **22** may even receive location data directly from a user.

[0040] Each optical transmitter **24** may include a photonic generator, such as a light-emitting diode (LED), a modulator, a top emitter, an edge emitter, or the like. The photonic generator receives an electrical input signal from the processing element **32** that may be a control signal, such as an electric voltage or electric current that is analog or digital, or data, either of which is indicative of activating or energizing the optical transmitter **24** to transmit (emit) an optical signal **40** having a desired amplitude, frequency, and duration. The photonic generator of each optical transmitter **24** transmits electromagnetic radiation having a particular wavelength (the optical signal **40**) in the visible light spectrum, which is typically between approximately 400 nanometers (nm) to 700 nm, or in the infrared spectrum, which is typically between approximately 700 nm to 1 millimeter (mm). However, in some embodiments, the photonic generator transmits electromagnetic radiation in wavelength range of 1000 nm to 1500 nm. The wavelength of the optical signal **40** is generally determined by, or varies according to, the material from which the photonic generator of each optical transmitter **24** is formed. The optical signal **40** may comprise a sequence of pulses, a periodic or non-periodic waveform, a constant level for a given period of time, or the like, or combinations thereof.

[0041] In various embodiments, each optical transmitter **24** may include a driver circuit, with electronic circuitry such as amplifier and an optional filter, electrically coupled to the photonic generator. The driver circuit may receive the electrical input signal (control signal) from the processing element **32** and the driver circuit may generate an electric voltage or electric current to the photonic generator, which in turn, transmits (emits) the optical signal **40**.

[0042] In exemplary embodiments as shown in FIG. **7**, the electronic fitness device **10** includes six optical transmitters **24** (labeled "TX" in the figure) positioned along the bottom wall **34** of the housing **12**. The optical transmitters **24** may be divided into separate pairs of optical transmitters **24**. For example, each pair of optical transmitters **24** may include a first optical transmitter **24** configured to transmit the optical signal **40** with a first wavelength ($\lambda 1$) and a second optical transmitter **24** configured to transmit the optical signal **40** with a second wavelength ($\lambda 2$). The optical signals **40** originating from both the first optical transmitter **24** and the second optical transmitter **24** of each pair travel along the same or a substantially similar path through the user's skin and tissue to the optical receiver **28**. Such a configuration enables the processing element **32** to utilize two optical signals **40** having different wavelengths that have both traveled the same or substantially similar path has many benefits. For instance, use of different paths from optical transmitters **24** to the optical receiver **28** causes the optical signals **40** to pass through or past different ligaments and tendons, thereby embodying any motion resulting therefrom, and possibly resulting in substantially uncorrelated motion noise. The first wavelength λ**1** has a value (wavelength) in the Filter **1** range of wavelengths, while the second wavelength λ**2** has a value (wavelength) in the Filter **2** range of wavelengths.

[0043] Still referring to FIG. **7**, the electronic fitness device **10** may include three pairs of optical transmitters **24**. For example, a first pair of optical transmitters **24A1**, **24A2** may be positioned at a 12 o'clock position (using a clock face analogy), a second pair of optical transmitters **24B1**, **24B2** may be positioned a 3 o'clock position, and a third pair of optical transmitters **24C1**, **24C2** may be positioned at a 6 o'clock position. The optical receiver may be centrally positioned along the bottom wall **34** of the housing **12** (a center of a clock face using the clock face analogy). As described above, such configurations allow for the optical signals **40** generated by the optical transmitters **24** to travel to the optical receiver **28** by passing along different signal paths and to arrive at the optical receiver **28** from different directions, which provides signal path diversity. Other configurations, orientations, or relative positions, are contemplated and possible. It is also possible to include additional optical receivers **28** and optical transmitters **24**. As seen in FIG. **7**, a first path traveled by the optical signals **40** output by the first and second optical transmitters **24A1**, **24A2** is substantially different from a second path traveled by the optical signals **40** output by the third and fourth optical transmitters **24B1**, **24B2**. Additionally, optical receiver **28** is equidistant to the first pair of optical transmitters **24A1**, **24A2** as well as the second pair of optical transmitters **24B1**, **24B2**. Optical receiver **28** is also equidistant to optical transmitter **24A1** and optical transmitters **24B1**, from which the optical signals resulting in PPG signals from which the motion and other noise components may be removed.

[0044] Each lens **26** may be constructed from glass, polymers, or the like and may be configured, operable, shaped, or formed to provide focusing, collimation, refraction, diffraction, and so forth. In addition, each lens **26** may provide cover or mechanical protection for the optical transmitters **24**. In exemplary embodiments as shown in FIG. **7**, the electronic fitness device **10** includes three lenses **26** with a first lens **26**A positioned over the first pair of optical transmitters **24A1**, **24A2**, a second lens **26**B positioned over the second pair of optical transmitters **24B1**, **24B2**, and a third lens **26**C positioned over the third pair of optical transmitters **24C1**, **24C2**. Each lens **26** may be coupled or attached to the bottom wall **34**. Additionally, a lens **26** may be positioned over optical receiver **28**.

[0045] The optical receiver **28** may include a photodetector, such as a photodiode, a phototransistor, a photoresistor, a phototube, or the like. The photodetector receives electromagnetic radiation having multiple wavelengths (typically any of the wavelengths generated by the photonic generators) and in response, generates the PPG signal, comprising an electric current, an electric voltage, or other electrical parameter, that corresponds to the intensity of the modulated optical signal in amplitude and frequency that is transmitted by one of the optical transmitters **24** and reflected from the user's skin. Given that the optical receiver **28** may receive multiple optical signals **40**, each having a particular wavelength, each PPG signal generated by the optical receiver **28** may be a particular wavelength-related PPG signal because it includes characteristics or components resulting from, or related to, the particular wavelength of the optical signal **40** transmitted (emitted) by one of the optical transmitters **24**.

[0046] In various embodiments, the optical receiver **28** may include the photodetector electrically coupled to an amplifier circuit followed by an analog-to-digital converter (ADC). The photodetector may receive electromagnetic radiation having multiple wavelengths and in response, may generate an output signal, comprising an electric current, an electric voltage, or other electrical parameter that corresponds to the intensity of the modulated optical signal in amplitude and frequency that is transmitted by one of the optical transmitters **24** and reflected from the user's skin. The amplifier circuit may receive the output signal from the photodetector and amplify it to produce an amplified output signal that is analog and communicated to the ADC. The ADC may sample the amplified output signal and output a PPG signal, which is converted into a corresponding stream of digital data.

[0047] In an exemplary embodiment shown in FIG. **7**, the optical receiver **28** is positioned in an opening roughly at the center of the bottom wall **34** of the housing **12**. In embodiments, the optical receiver **28** may be equidistant from each pair of optical transmitters **24**. The first pair of optical transmitters **24A1**, **24A2** is positioned in a first direction from the optical receiver **28**. The second pair of optical transmitters **24B1**, **24B2** is positioned in a second direction from the optical receiver **28**—the second direction being offset roughly 90 degrees from the first direction. The third pair of optical transmitters **24C1**, **24C2** is positioned in a third direction from the optical receiver **28**—the third direction being offset roughly 90 degrees from the second direction and 180 degrees from the first direction. Thus, the optical receiver **28** can receive the optical signals **40** originating from the optical transmitters **24** from a plurality of angular directions—resulting in optical signal path diversity. The diversity of the optical signal path may result in some diversity of the PPG signal, such as different waveform characteristics resulting from differences in the skin, tissue, motion, or other characteristics along each path.

[0048] The memory element **30** may be embodied by devices or components that store data in general, and digital or binary data in particular, and may include exemplary electronic hardware data storage devices or components such as read-only memory (ROM), programmable ROM, erasable programmable ROM, random-access memory (RAM) such as static RAM (SRAM) or dynamic RAM (DRAM), cache memory, hard disks, floppy disks, optical disks, flash memory, thumb drives, universal serial bus (USB) drives, or the like, or combinations thereof. In some embodiments, the memory element **30** may be embedded in, or packaged in the same package as, the processing element **32**. The memory element **30** may include, or may constitute, a "computer-readable medium". The memory element **30** may store the instructions, code, code statements, code segments, software, firmware, programs, applications, apps, services, daemons, or the like that are executed by the processing element **32**. The memory element **30** may also store settings, data, documents, sound files, photographs, movies, images, databases, and the like.

[0049] The processing element **32** may comprise one or more processors. The processing element **32** may include electronic hardware components such as microprocessors (single-core or multi-core), microcontrollers, digital signal processors (DSPs), field-programmable gate arrays (FPGAs), analog and/or digital application-specific integrated circuits (ASICs), or the like, or combinations thereof. The processing element **32** may generally execute, process, or run instructions, code, code segments, code statements, software, firmware, programs, applications, apps, processes, services, daemons, or the like. The processing element **32** may also include hardware components such as finite-state machines, sequential and combinational logic, and other electronic circuits that can perform the functions necessary for the operation of the current invention. In certain embodiments, the processing element **32** may include multiple computational components and functional blocks that are packaged separately but function as a single unit. The processing element **32** may be in communication with the other electronic components through serial or parallel links that include universal busses, address busses, data busses, control lines, and the like.

[0050] The processing element **32** may include a filter **42** that may implement various signal processing techniques. In some embodiments, the processing element **32** is a single electrical hardware component configured to implement the techniques disclosed herein. In other embodiments, the processing element **32** may comprise a plurality of electrical hardware components configured to communicate with each other to collectively or independently implement the techniques disclosed herein. It is to be understood that the processing element **32** of electronic fitness device **10** may be implemented as any suitable type and/or number of processing elements **32**. For example, the processing element **32** may be a host processing element **32** of electronic fitness device **10** that executes functions and methods relating to the filtering techniques disclosed herein. It should also be appreciated that the discussed functions and methods performed by the processing element **32** may be performed by a filter **42** having analog signal processing components.

[0051] The processing element **32** provides processing functionality for the electronic fitness device **10** and may include any number of processors, micro-controllers, or other processing systems, and resident or external memory for storing data and other information accessed or generated by the electronic fitness device **10**. To provide examples, the processing element **32** may be implemented as an application specific integrated circuit (ASIC), an embedded processing element, a central processing unit associated with electronic fitness device **10**, etc. The processing element **32** may execute one or more software programs that implement the techniques and modules described herein. The processing element **32** is not limited by the materials from which it is formed or the processing mechanisms employed therein and, as such, may be implemented via semiconductor(s) and/or transistors (e.g., electronic integrated circuits (ICs)), and so forth.

[0052] Referring to FIG. **8**, the processing element **32** may further comprise, or be in communication with, a plurality, or array, of filters **42**. In embodiments, each filter **42** includes an adder **44**, or signal mixer, which receives two PPG signals (labeled "PPG x1" and "PPG x2" in FIG. **8**, wherein "x" denotes which pair of optical transmitters **24** transmitted the optical signals **40** from which the PPG signals are derived). In FIG. **8**, a first filter has reference numeral "**42**A", a second filter has reference numeral "**42**B", a third filter has reference numeral "**42**C", and an Nth filter has reference numeral "**42**N". A first adder has reference numeral "**44**A", a second adder has reference numeral "**44**B", a third adder has reference numeral "**44**C", and an Nth adder has reference numeral "**44**N". In various embodiments, the processing element **32** analyzes the PPG signals in the frequency domain. In such embodiments, the processing element **32** may perform a time domain to frequency domain conversion, such as a fast Fourier transform (FFT), on the PPG signals before they are input to the filter **42** (as indicated by the "(f)" after each PPG signal name in FIG. **8**). In embodiments, only the magnitude of the frequency-domain signals is used (discarding phase information) by the filter **42** of the processing element **32** to perform various filtering techniques. In embodiments, the processing element **32** pre-scales the subtracted PPG signal to substantially match a magnitude of noise components between the two PPG signals.

[0053] The first PPG signal is coupled to a first (positive) input of the adder **44** and the second PPG signal is coupled to a second (negative) input of the adder **44**. Each adder **44** may include a signal inverter to invert, or produce a negative of, the PPG signal received at the second input. An output of each adder **44** is coupled to an output of the filter **42**. The adder **44** subtracts the second PPG signal from the first PPG signal, which results in components having a magnitude that is the same or substantially the same in both PPG signals are removed or substantially reduced as a result of the subtraction. Any components having a magnitude that is different in the two PPG signals will at least partially remain in the result of the subtraction. Thus, by subtracting the second PPG signal from the first PPG signal, the filter **42** removes any components having a magnitude that is substantially the same in both signals. The output signal is a filtered first PPG signal (labeled "PPG x1'" in FIG. **8**, wherein "x" denotes which pair of optical transmitters **24** transmitted the optical signals **40** from which the PPG signals are derived) from which motion noise and other noise is at least partially removed.

[0054] The processing element implements the disclosed filtering techniques on the PPG signals because the first PPG signal and the second PPG signal each include desired and undesired components. As discussed above, each PPG signal includes at least the cardiac component, the motion noise component, and the other noise components. As shown in FIG. **5**, there are differences in absorption of the optical signal **40** by oxygenated and deoxygenated blood in the user's skin or tissue based on a wavelength of the optical signal **40**. These differences in the absorption levels result in a difference in magnitude of the cardiac component of each PPG signal generated by the optical receiver **28**. For example, the cardiac component has a much greater magnitude when an optical signal **40** has a wavelength in the Filter **1** range (considered λ**1**) as compared to a magnitude of the cardiac component of a PPG signal resulting from an optical signal **40** having a wavelength in the Filter **2** range (considered λ**2**). In addition, the cardiac component of the first PPG signal (resulting from the optical signal **40** having λ**1**) typically has a greater signal-to-noise ratio (SNR) than the SNR of the second PPG signal (resulting from the optical signal **40** having λ**2**) partially resulting from the wavelength. However, the magnitudes of certain motion noise and other noise components in PPG signals may remain roughly the same when resulting from optical signals **40** having the two different wavelengths. Therefore, inputting the first PPG signal and the second PPG signal to the filter **42** yields a filtered PPG signal with the motion noise and other noise components having removed or greatly reduced magnitudes because their magnitudes are approximately the same in both PPG signals. The filtered PPG signal retains the cardiac component, albeit with a slightly reduced magnitude, because the cardiac component has a different amplitude in the two PPG signals.

[0055] Aspects of this inventive feature is illustrated in the plots of FIGS. **9-14**. The plots are the result of PPG signals created with the following setup. An optical signal **40** transmitted by the first optical transmitter **24** of any pair of optical transmitters **24** having a first wavelength **λ1** of approximately 550 nm travels through a user's skin and surrounding tissue and is received by the optical receiver **28**, which generates the first PPG signal. The components of the first PPG signal are depicted in FIGS. **9** and **12**. An optical signal **40** transmitted by the second optical transmitter **24** of any pair of optical transmitters **24** having a second wavelength **λ2** of approximately 680 nm travels through a user's skin and surrounding tissue and is received by the optical receiver **28**, which generates the second PPG signal. The components of the second PPG signal are depicted in FIGS. **10** and **13**. Processing element **32** receives the first and second PPG signals and performs a time domain to frequency domain conversion to obtain a first PPG signal in the frequency domain, such as PPG A1 (*f*) shown in FIG. **8**, and a second PPG signal in the frequency domain, such as PPG A2 (*f*) shown in FIG. **8**.

[0056] The frequency spectral content of the first PPG signal is shown in FIG. **9**, which shows the three components of the PPG signal and their center frequencies. The cardiac component of the first PPG signal has a center frequency of approximately 75 bpm. The motion noise component has a center frequency of approximately 125 bpm. The other noise component has a center frequency of approximately 225 bpm. For this example, each component has a normalized magnitude that is roughly equal to the others and has a value of approximately 1. A ratio of the cardiac component to a DC component of the first PPG signal is approximately equal to a ratio of the motion and other noise components to the DC component of the first PPG signal.

[0057] The frequency spectral content of the second PPG signal is shown in FIG. **10**, which shows the three components of the PPG signal and their center frequencies. The center frequencies of the three components are roughly the same as for the first PPG signal shown in FIG. **9**. The motion noise and other noise components have a normalized magnitude that is also roughly the same as for the first PPG signal, with a value of approximately 1. The cardiac component of the second PPG signal, however, has a greatly reduced magnitude in comparison to the cardiac component of the first PPG signal, of, for example, 0.4. This reduced magnitude of the cardiac component of the second PPG signal is partly due to the reduced absorption of the optical signal **40** by the user's skin and surrounding tissue at a wavelength of approximately 680 nm as compared with a wavelength of 550 nm, as shown in FIG. **5**. A ratio of the cardiac component to a DC component of the second PPG signal is lower than a ratio of the motion and other noise components to the DC component of the second PPG signal. Additionally, as seen in FIGS. **9** and **10**, the ratio of the cardiac component to a DC component of the second PPG signal is lower than the ratio of the cardiac component to the DC component of the first PPG signal.

[0058] The first and second PPG signals PPG A**1** (*f*) and PPG A**2** (*f*) are input to one of the filters **42** as shown in FIG. **8**. The frequency spectral content of the output filtered first PPG signal is shown in FIG. **11**. Each filter **42** may subtract the components shown in FIG. **10** from the components in FIG. **9**. The result is that, since the motion noise and other noise components in this example have roughly the same magnitude in both PPG signals, the motion noise and other noise components each has a very small magnitude (near zero) after a subtraction function is performed by the filter **42**. The smaller magnitude cardiac component of the second PPG signal depicted in FIG. **10** is subtracted from the larger magnitude cardiac component of the first PPG signal depicted in FIG. **9**, yielding a slightly reduced magnitude cardiac component depicted in FIG. **11**. After the filter **42** of the processing element **32** performs filtration technique, the cardiac component has a much greater SNR than it did before the filtration techniques.

[0059] The filtration performed by the filter **42** over time is shown in FIGS. **12-14**. The configuration discussed for FIGS. **9-11** is performed continuously, such that the first and second PPG signals are repeatedly received and filtered by the filter **42** of the processing element **32**.

[0060] FIG. **12** shows, for a time period of approximately 2 minutes, the components of the first PPG signal resulting from the optical signal **40** having the first wavelength **λ1** of approximately 550 nm. The thickness of the lines corresponding to components on the plot indicates the relative magnitude of each component, wherein a thicker line corresponds to a greater magnitude for that component. The cardiac component, motion noise and the other noise components are present throughout the 2 minute period depicted in FIGS. **12-14**. During the first minute, the user was at rest. During the second minute, the user started moving and was active. Thus, during the first minute, there is no motion noise component, while there is a motion noise component during the second minute. The center frequencies of each component is roughly the same as in the plots of FIGS. **9-11**. The relative magnitude of each component is roughly equal to the other components.

[0061] FIG. **13** shows, for a time period of approximately 2 minutes, the components of the second PPG signal resulting from the optical signal **40** having the second wavelength **λ2** of approximately 680 nm. The plot is substantially similar to that of FIG. **12**, except that the relative magnitude of the cardiac component of the second PPG signal in FIG. **13** is lower than the cardiac component of the first PPG signal depicted in FIG. **12**. As discussed above for FIG. **10**, the reduced magnitude of the cardiac component of the second PPG signal is partly the result of reduced absorption of the optical signal **40** by the user's skin and surrounding tissue at a wavelength of approximately 680 nm as compared with a wavelength of 550 nm, as shown in FIG. **5**.

[0062] FIG. **14** shows, for a time period of approximately 2 minutes, the components of the filtered first PPG signal (i.e., the output of the filter **42**). As can be seen, the relative magnitudes of the motion noise and other noise components are removed or greatly reduced for the reasons discussed above. Likewise, the relative magnitude of the cardiac component is slightly reduced for the reasons discussed above. Application of the filtering techniques by the processing element **32** results in a SNR of the filtered first PPG signal being significantly increased compared with the SNR of the first PPG signal before the filtration techniques.

[0063] In exemplary embodiments, the processing element **32** includes at least three filters **42**, one for each of the pairs of optical transmitters **24** utilized with the electronic fitness device **10**. Thus, there is a first filter **42**A that receives the PPG signals derived from the optical signals **40** transmitted by the first pair of optical transmitters **24**A**1**, **24**A**2**, a second filter **42**B that receives the PPG signals derived from the optical signals **40** transmitted by the second pair of optical transmitters **24**B**1**, **24**B**2**, and a third filter **42**C that receives the PPG signals derived from the optical signals **40** transmitted by the third pair of optical transmitters **24**C**1**, **24**C**2**. However, in other embodiments, two filters **42** of processing element **32** are used.

[0064] The processing element **32** may be operable, configured, or programmed to perform the following functions by utilizing hardware, software, firmware, or combinations thereof. The processing element **32** generates the electrical input signal or control signal, which may include an electric voltage or electric current that is constant or variable, analog or digital, or data, as a single number or a stream of numbers, and communicates the signal to one of the optical transmitters **24**. Typically, the processing element **32** generates and communicates the electrical input or control signal to each of the optical transmitters **24** of one pair of optical transmitters **24** in a time division multiplexing (TDM) fashion. That is, the processing element **32** generates and communicates the electrical input or control signal to the first of the pair of optical transmitters **24**, waits for a period of time, and then generates and communicates the electrical input or control signal to the second of the pair of optical transmitters **24**—although the order in which the electrical input or control signals are communicated may be reversed. In embodiments, the processing element **32** controls the first optical transmitter **24**A**1**, **24**B**1**, **24**C**1** of each pair to emit or transmit an optical signal **40** before the second optical transmitter of that pair **24**A**2**, **24**B**2**, **24**C**2**. One or more optical receivers **28** may generate a PPG signal resulting from reflections of each optical signal **40** received from the user's skin or tissue.

[0065] The processing element **32** may also generate and communicate the electrical input or control signal to any combination of the three pairs of optical transmitters **24**. When the processing element **32** generates and communicates the electrical input or control signal to more than one pair of optical transmitters **24**, it may do so in a TDM fashion as well. That is, the processing element **32** may generate and communicate the electrical input or control signal to a first pair of optical transmitters **24** using the TDM process, waits for a period of time, and then generate and communicate the electrical input or control signal to a second pair of optical transmitters **24** using the TDM process. If necessary, or desired, the processing element **32** may wait for a period of time before generating and communicating the electrical input or control signal to a third pair of optical transmitters **24** using the TDM process.

[0066] The processing element **32** receives PPG signals from the optical receiver **28**. In some embodiments, the processing element **32** may sample the analog PPG signal from the optical receiver **28** to produce a digital form of the PPG signal. In other embodiments, the processing element **32** may receive the digital form of the PPG signal from the optical receiver **28**.

[0067] Typically, the processing element **32** receives a first PPG signal from the optical receiver **28** resulting from the optical signal **40** having the first wavelength **λ1** and then, after a period of time, receives a second PPG signal resulting from the optical signal **40** having a second wavelength **λ2**. The processing element **32** may receive similar first and second PPG signals for additional pairs after receiving the first and second PPG signals for the first pair. The processing element **32** may perform a time domain to frequency domain conversion, such as an FFT, on each of the PPG signals. The PPG signals may be input to one of the filters **42** which may subtract the second PPG signal from the first PPG signal to generate the filtered first PPG signal. The filtered first PPG signal may contain a cardiac component having a higher signal to noise ratio (SNR) and may be analyzed by the processing element **32** to determine the user's heart rate, stress level, pulse oximetry, and other cardiac information. In embodiments, the filtered first PPG signal may be converted from the frequency domain back to the time domain to generate the filtered first PPG signal, which may be used to determine cardiac information for the user, may be stored in the memory element **30**, or may be further processed to determine and provide additional information.

[0068] As discussed above, if multiple pairs of PPG signals are received by the optical receiver **28**, then the processing element **32** performs the time domain to frequency domain conversion on each PPG signal. Each pair of PPG signals are received by the processing element **32** and input to one of the filters **42**, as shown in FIG. **8**. The filtration process, as described above, is performed on each pair of frequency domain PPG signals, which produces the filtered first PPG signal for each pair of PPG signals. Each filtered PPG signal may be stored in the memory element **30** or may be converted back to the time domain for storage or further processing. For instance, filter **42** of the processing element **32** may implement or perform mathematical functions on the multiple filtered PPG signals, such as averaging, correlating, or so forth, which may have the effect of enhancing or maximizing the cardiac component (desired portion) while reducing or minimizing any residual noise components (undesired portions). In some embodiments, the processing element may compute a moving average (e.g., simple, weighted, etc.) of the multiple filtered PPG signals. In other embodiments, the processing element may correlate the PPG signals by identifying a component of one PPG signal that is substantially correlated with one or more components of the other PPG signal and producing (generating) a PPG signal based on the correlation of the two or more PPG signals.

[0069] The electronic fitness device **10** may operate as follows. The user may desire to determine his blood-related and cardiac information. The user may engage the user interface **18** to direct the processing element **32** to begin the process of generating optical signals **40** and PPG signals. Alternatively, or additionally, the processing element **32** may have an operating mode in which it automatically initiates the process of generating optical signals **40** and PPG signals when a particular event is determined to have occurred or on a periodic basis (e.g., every second, every minute, hourly, daily, etc.).

[0070] The processing element 32 generates and communicates the electrical input or control signal to one or more of the three pairs of optical transmitters 24 to emit an optical signal 40. The first optical transmitter 24 of each pair of optical transmitters 24 transmits an optical signal 40 having the first wavelength λ1 into the user's skin and surrounding tissue. The optical signal 40 is reflected and travels to the optical receiver 28 which generates a first PPG signal resulting from the optical signal 40 having the first wavelength λ1. The second optical transmitter 24 of each pair of optical transmitters 24 transmits an optical signal 40 having the second wavelength λ2 into the user's skin and surrounding tissue. The optical signal 40 is reflected and travels to the optical receiver 28 which generates a second PPG signal resulting from the optical signal 40 having the second wavelength λ2. The first and second PPG signals are received by the processing element 32, which may perform a time domain to frequency domain conversion on each PPG signal. The first and second frequency domain PPG signals are input to the filter 42 of the processing element 32 to generate a filtered first PPG signal. The filtered first PPG signal may be used, alone or in combination, to determine the user's heart rate, stress level, pulse oximetry, and other cardiac information.

[0071] Although the technology has been described with reference to the embodiments illustrated in the attached drawing figures, it is noted that equivalents may be employed and substitutions made herein without departing from the scope of the technology as recited in the claims.

[0072] Having thus described various embodiments of the technology, what is claimed as new and desired to be protected by Letters Patent includes the following:

What is claimed is:

1. An electronic fitness device comprising:
- a housing including a bottom wall;
- a first optical transmitter positioned along the bottom wall and configured to transmit a first optical signal having a first wavelength, the first optical signal to be directed into skin of a user;
- a second optical transmitter positioned along the bottom wall and configured to transmit a second optical signal having a second wavelength, the second optical signal to be directed into the skin of the user;
- an optical receiver positioned along the bottom wall, the optical receiver configured to receive the first and second optical signals modulated by the skin of the user and generate a first photoplethysmogram (PPG) signal resulting from the received first optical signal and a second PPG signal resulting from the second optical signal; and
- a processing element in electronic communication with the first optical transmitter, the second optical transmitter, and the optical receiver, the processing element configured to:
  - control the first optical transmitter to transmit the first optical signal during a first period of time,
  - control the second optical transmitter to transmit the second optical signal during a second period of time,
  - receive the first and second PPG signals from the optical receiver, and
  - utilize the second PPG signal to reduce a noise component of the first PPG signal.

2. The electronic fitness device of claim 1, wherein a signal to noise ratio of a cardiac component of the first PPG signal is greater than a signal to noise ratio of a cardiac component of the second PPG signal.

3. The electronic fitness device of claim 2, wherein a ratio of the cardiac component to a DC component of the second PPG signal is lower than a ratio of the cardiac component to the DC component of the first PPG signal.

4. The electronic fitness device of claim 1, wherein the utilizing the second PPG signal to reduce the noise component of the first PPG signal comprises subtracting the second PPG signal from the first PPG signal.

5. The electronic fitness device of claim 1, wherein the processing element is further configured to convert the first PPG signal and the second PPG signal from the time domain to the frequency domain before utilizing the second PPG signal to reduce the noise component from the first PPG signal.

6. The electronic fitness device of claim 2, wherein the first optical transmitter is positioned proximate to the second optical transmitter.

7. The electronic fitness device of claim 1, wherein the first wavelength is a wavelength between approximately 520 nanometers (nm) and approximately 580 nm.

8. The electronic fitness device of claim 1, wherein the second wavelength is a wavelength between approximately 650 nm and approximately 700 nm.

9. An electronic fitness device comprising:
- a housing including a bottom wall;
- a first optical transmitter positioned along the bottom wall and configured to transmit a first optical signal having a first wavelength, the first optical signal to be directed into skin of a user;
- a second optical transmitter positioned along the bottom wall and configured to transmit a second optical signal having a second wavelength, the second optical signal to be directed into the skin of the user;
- an optical receiver positioned along the bottom wall, the optical receiver configured to receive the first and second optical signals modulated by the skin of the user and generate a first photoplethysmogram (PPG) signal resulting from the received first optical signal and a second PPG signal resulting from the second optical signal;
- a processing element in electronic communication with the first optical transmitter, the second optical transmitter, and the optical receiver, the processing element configured to:
  - control the first optical transmitter to transmit the first optical signal during a first period of time,
  - control the second optical transmitter to transmit the second optical signal during a second period of time,
  - receive the first and second PPG signals from the optical receiver, and
  - convert the first PPG signal and the second PPG signal from the time domain to the frequency domain; and
  - remove noise components from the first PPG signal by subtracting the second PPG signal from the first PPG signal in the frequency domain in the frequency domain to generate a filtered first PPG signal.

10. The electronic fitness device of claim 9, wherein the first optical transmitter is positioned proximate to the second optical transmitter.

11. The electronic fitness device of claim 9, wherein the first PPG signal has a cardiac component with a first magnitude, the second PPG signal has a cardiac component

with a second magnitude, and the filtered first PPG signal has a cardiac component with a third magnitude equal to a difference between the first magnitude and the second magnitude.

12. The electronic fitness device of claim **9**, wherein a magnitude of the noise components of the first PPG signal is roughly equal to a magnitude of the noise components of the second PPG signal.

13. The electronic fitness device of claim **12**, wherein the processing element removes the noise components by subtracting the noise components of the second PPG signal from the noise components of the first PPG signal.

14. The electronic fitness device of claim **9**, wherein the first wavelength is a wavelength between approximately 520 nanometers (nm) and approximately 580 nm.

15. The electronic fitness device of claim **9**, wherein the second wavelength is a wavelength between approximately 650 nm and approximately 700 nm.

16. An electronic fitness device comprising:

a housing including a bottom wall;

a first optical transmitter positioned along the bottom wall and configured to transmit a first optical signal having a first wavelength, the first optical signal to be directed into skin of a user;

a second optical transmitter positioned proximate to the first optical transmitter along the bottom wall and configured to transmit a second optical signal having a second wavelength, the second optical signal to be directed into the skin of the user;

a third optical transmitter positioned along the bottom wall and configured to transmit a third optical signal having a first wavelength, the first optical signal to be directed into skin of a user;

a fourth optical transmitter positioned proximate to the third optical transmitter along the bottom wall and configured to transmit a fourth optical signal having a second wavelength, the first optical signal to be directed into skin of a user;

an optical receiver positioned along the bottom wall, the optical receiver configured to receive the first and second optical signals modulated by the skin of the user and generate a first photoplethysmogram (PPG) signal resulting from the received first optical signal and a second PPG signal resulting from the second optical signal;

a processing element in electronic communication with the first optical transmitter, the second optical transmitter, the third optical transmitter, the fourth optical transmitter, and the optical receiver, the processing element configured to:

receive the first and second PPG signals from the optical receiver,

remove noise components from the first PPG signal by subtracting the first PPG signal from the second PPG signal to generate a filtered first PPG signal,

receive the third and fourth PPG signals from the optical receiver, and

remove noise components from the third PPG signal by subtracting the fourth PPG signal from the third PPG signal to generate a filtered third PPG signal.

17. The electronic fitness device of claim **16**, wherein the first PPG signal has a cardiac component with a first magnitude, the second PPG signal has a cardiac component with a second magnitude, and the filtered first PPG signal has a cardiac component with a third magnitude equal to a difference between the first magnitude and the second magnitude, and wherein third PPG signal has a cardiac component with a fourth magnitude, the fourth PPG signal has a cardiac component with a fifth magnitude, and the filtered third PPG signal has a cardiac component with a sixth magnitude equal to a difference between the fourth magnitude and the fifth magnitude.

18. The electronic fitness device of claim **16**, wherein a first path traveled by the optical signals output by the first and second optical transmitters is substantially different from a second path traveled by the optical signals output by the third and fourth optical transmitters.

19. The electronic fitness device of claim **18**, wherein the optical receiver is equidistant to the first and third optical transmitters.

20. The electronic fitness device of claim **16**, wherein the first wavelength is a wavelength between approximately 520 nanometers (nm) and approximately 580 nm, and wherein the second wavelength is a wavelength between approximately 650 nm and approximately 700 nm.

* * * * *

专利名称(译)	光学运动抑制		
公开(公告)号	US20180317852A1	公开(公告)日	2018-11-08
申请号	US15/969574	申请日	2018-05-02
申请(专利权)人(译)	GARMIN瑞士GMBH		
当前申请(专利权)人(译)	GARMIN瑞士GMBH		
[标]发明人	MACDONALD PAUL R KULACH CHRISTOPHER J		
发明人	MACDONALD, PAUL R. KULACH, CHRISTOPHER J.		
IPC分类号	A61B5/00 A61B5/024		
CPC分类号	A61B5/7214 A61B5/02427 A61B5/02438 A61B5/681 A61B2562/0238 A61B2562/043 A61B2562/046 A61B5/02416 A61B5/14535 A61B5/14542 A61B5/14552 A61B5/4875 A61B5/6824 A61B5/7207 A61B5/7246 A61B5/725 A61B5/7253 A61B2503/10 A61B2505/09 A61B2560/0462 A61B2562/0242 A61B2562/04 A61B5/0004 A61B5/7257 A61B5/7278 A61B5/7282		
优先权	62/501522 2017-05-04 US 62/571606 2017-10-12 US 62/580308 2017-11-01 US 62/580024 2017-11-01 US		
外部链接	Espacenet USPTO		

摘要(译)

一种电子健身装置，包括第一和第二光发射器，光接收器和处理元件。第一光发射器被配置为发射具有第一波长的第一光信号。第二光发射器被配置为发送具有第二波长的第一光信号。光接收器被配置为接收第一和第二光信号并产生分别由接收的光信号产生的第一和第二光电容积描记图（PPG）信号。处理元件被配置为控制第一和第二光发射器以发送第一和第二光信号，接收第一和第二PPG信号，以及利用第二PPG信号来减少来自第一PPG信号的噪声分量。