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(54) **INTELLIGENT PHOTOPLETHYSMOGRAPH SIGNAL-TO-NOISE RATIO CONTROL FOR RECOVERY OF BIOSIGNALS DURING TIMES OF MOTION**

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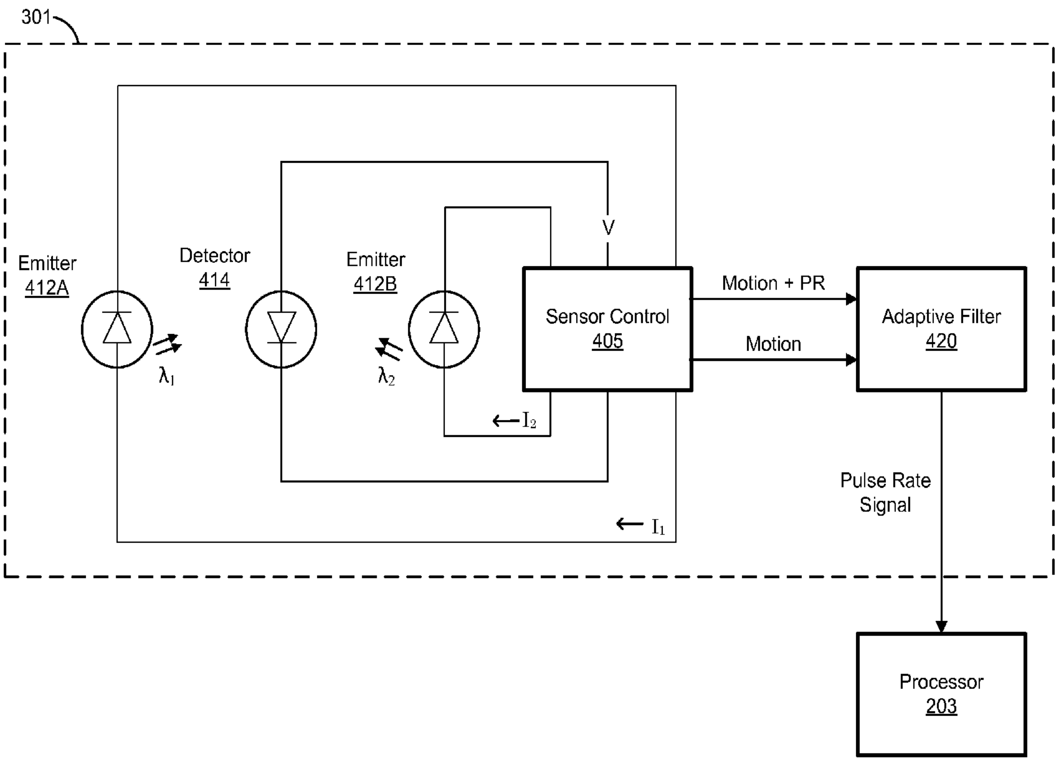
(57) **ABSTRACT**

An optical pulse rate detector includes at least one emitter, a photodetector, and an adaptive filter. The emitter transmits light at a first light output level and a second light output level into body tissue of a user. The photodetector receives reflected light from the body tissue and produces a voltage indicative of an amount of the reflected light. The adaptive filter receives a first output signal from the photodetector indicative of an amount of the light at the first light output level reflected from the body tissue and a second output signal indicative of an amount of the light at the second output level reflected from the body tissue. The adaptive filter removes the second output signal from the first output signal to generate a pulse rate signal indicative of a pulse rate of the user.



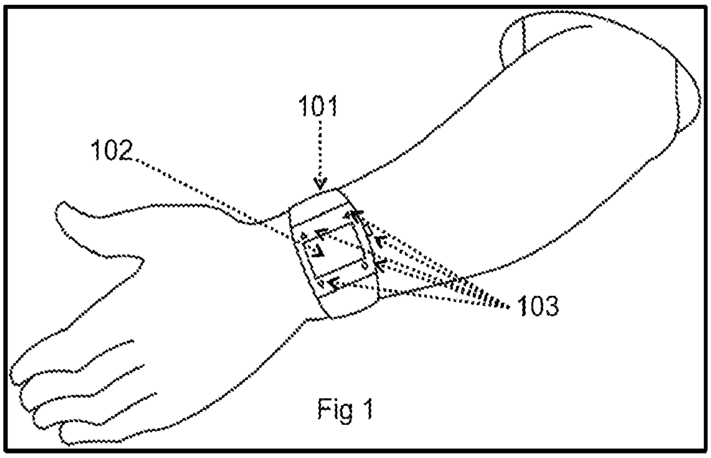


Fig 1

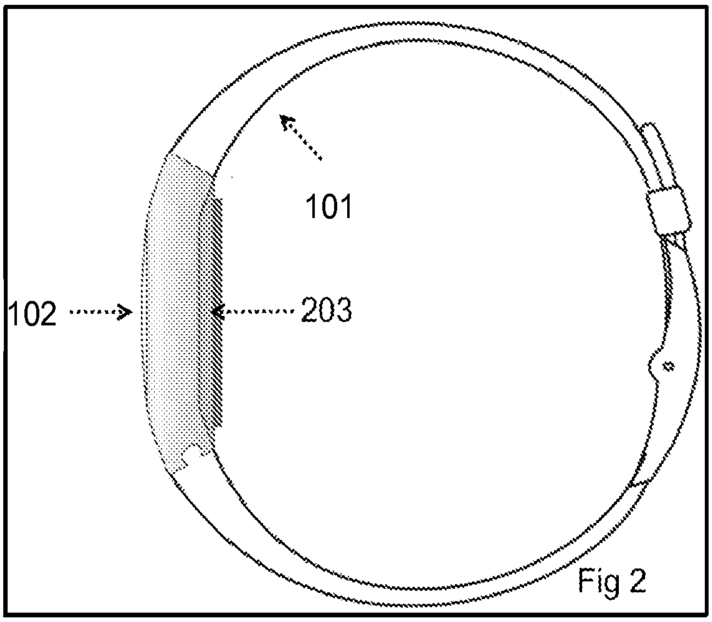


Fig 2

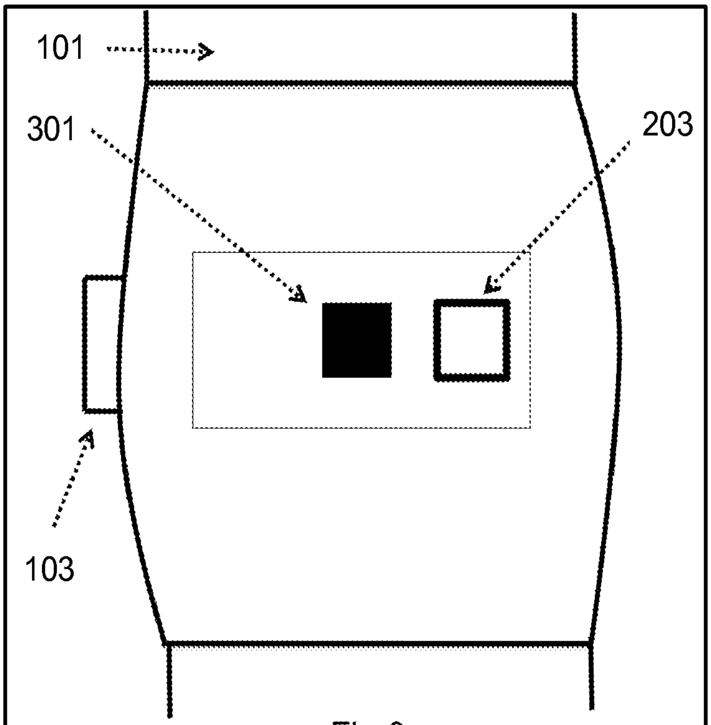


Fig 3

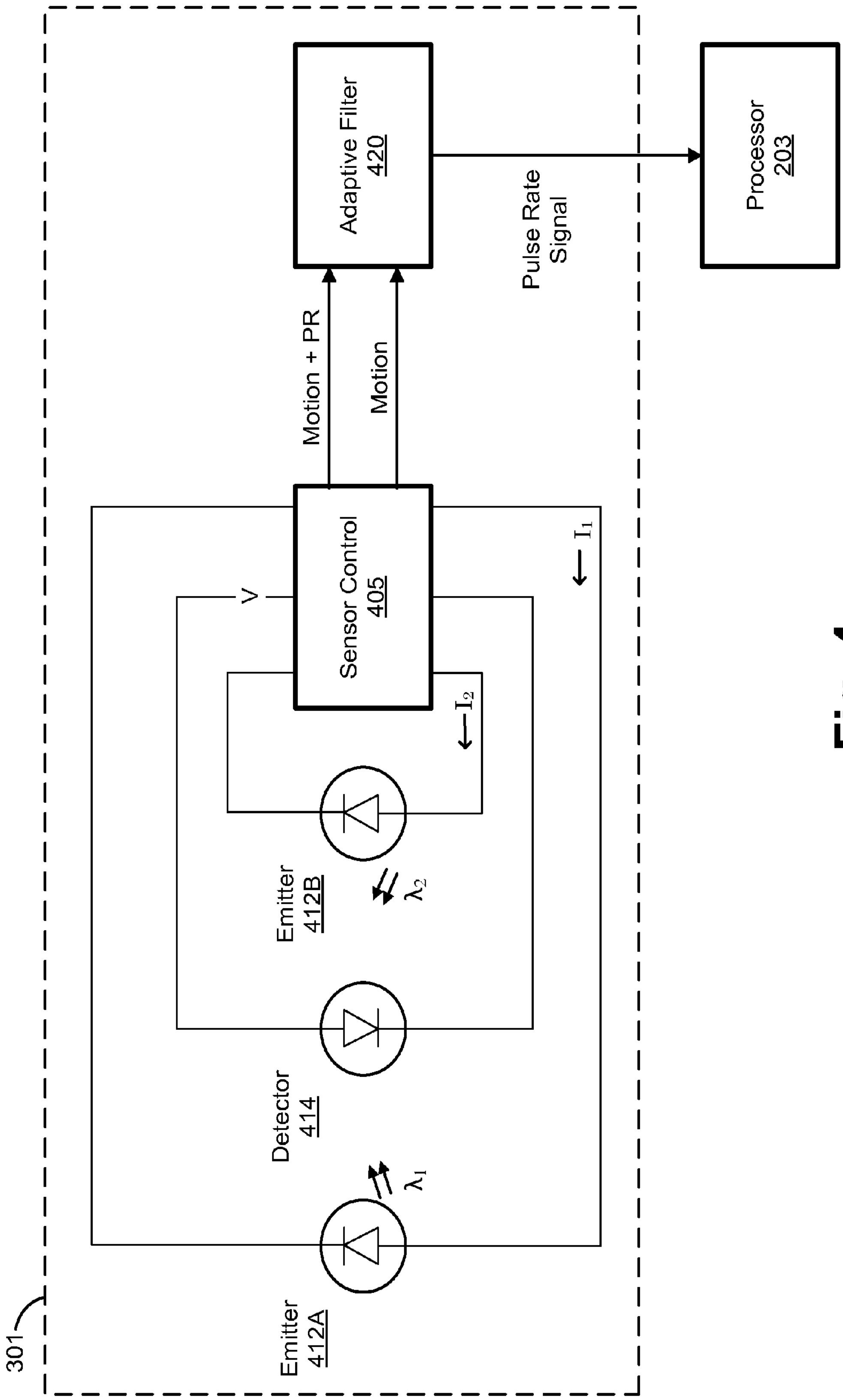

Adaptive Filter 420
Processor 203
Pulse Rate Signal
Motion + PR
Motion
Sensor Control 405
V
I_1
I_2
Emitter 412B
λ_2
Detector 414
λ_1
Emitter 412A
301

Fig. 4

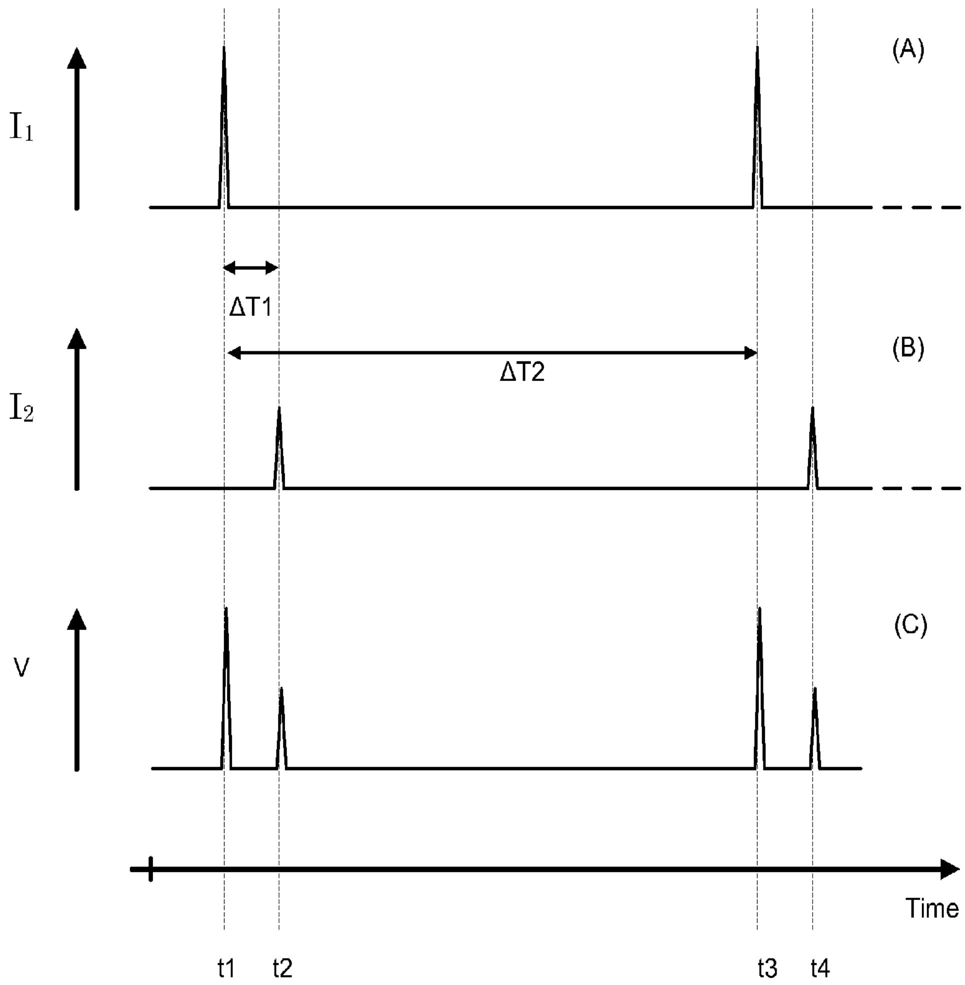


Fig. 5

INTELLIGENT PHOTOPLETHYSMOGRAPH SIGNAL-TO-NOISE RATIO CONTROL FOR RECOVERY OF BIOSIGNALS DURING TIMES OF MOTION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/933,745, filed Jan. 30, 2014, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Optical pulse rate detectors measure pulse rate of users by detecting light reflected from a user's skin. Optical pulse rate detectors are often incorporated into wearable devices for continuously monitoring the user. However, if a user is moving while wearing the wearable device, the amount of light reflected to the optical detector may vary from sample to sample. Thus, during periods of motion, the optical pulse rate detector detects motion artifacts that contaminate the pulse rate signal.

[0003] Some wearable devices use a second sensor, such as an accelerometer, to measure the motion of a wearer of the device. However, as the orientation of the wearable device (and thus the orientation of the accelerometer), stride patterns, and so forth vary from person to person, the signal generated by an accelerometer is not directly correlated to the motion artifacts measured by an optical pulse rate detector. Thus, it is difficult to remove the motion artifacts using a second sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The disclosed embodiments have other advantages and features which will be more readily apparent from the detailed description, the appended claims, and the accompanying figures (or drawings). A brief introduction of the figures is below.

[0005] FIG. **1** illustrates a wearable device, according to one embodiment.

[0006] FIG. **2** illustrates an alternative view of a wearable device, according to one embodiment.

[0007] FIG. **3** illustrates another view of a wearable device, according to one embodiment.

[0008] FIG. **4** is a schematic illustrating components of an optical pulse rate detector, according to one embodiment.

[0009] FIG. **5** illustrates operational waveforms of the optical pulse rate detector, according to one embodiment.

DETAILED DESCRIPTION

[0010] The Figures (FIGS.) and the following description relate to preferred embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles of what is claimed.

[0011] Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict embodiments of the disclosed system (or method) for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

Configuration Overview

[0012] An optical pulse rate detector is configured to measure pulse rate of a user while the pulse rate detector is moving. The optical pulse rate detector takes two successive samples per sampling period: one to sample the pulse of the user, and one to sample motion of the user. Using an adaptive filter, the optical pulse rate sensor removes motion artifacts from the measured pulse rate to increase the signal-to-noise ratio of the pulse rate signal. Because the optical pulse rate detector measures both the user's pulse rate and the user's motion, the measured motion more closely approximates the motion artifacts in the detected pulse rate signal than motion measured by an external sensor. In one embodiment, the pulse rate detector is a component of a wearable device monitoring physiological and kinematic parameters of a wearer of the device.

Example Wearable Device

[0013] FIG. (FIG. **1** illustrates an example of a wearable device **100** configured to be in close proximity to or in contact with a user. For example, the device **100** may be worn on a user's appendage or portion thereof, such as an arm or a wrist. A fastening system **101** fastens the device **100** to a user's appendage. The fastening elements **101** may be removable, exchangeable, or customizable. Furthermore, although embodiments are described herein with respect to a wrist-worn device, other form factors or designed wear locations of the wearable device **100** may alternatively be used. For example, embodiments of the method described herein may be implemented in arm-worn devices, head-worn devices, clip-on devices, and so forth. Furthermore, the various components of the device **100** described herein may alternatively be components of two or more devices communicatively coupled by wired or wireless communication, rather than enclosed within a single device. In one embodiment, the wearable device **100** is a physiological monitoring device for monitoring activities of its wearer and calculating various physiological and kinematic parameters, such as activity levels, caloric expenditure, step counts, heart-rate, and sleep patterns.

[0014] The wearable device **100** includes a display (or screen) **102** and several user interaction points **103**. The display **102** and user interaction points **103** may be separate components of the device **100**, or may be a single component. For example, the display **102** may be a touch-sensitive display configured to receive user touch inputs and display information to the user. The wearable device may also have a display element such as **102** without interaction points, or interaction points **103** without a display element such as **102**. The interaction points **103** used by the user to interface with the device and may be, for example, physical buttons, solid state touch sensitive sensors, a separate touch sensitive display or dedicated regions of the display **102**.

[0015] It should be noted that the device **100** may include additional components not shown in FIG. **1**. In particular, the device **100** includes one or more sensors for monitoring various physiological or kinematic parameters of the wearer of the device **100**, for example, pulse rate, blood flow, body temperature, and motion.

[0016] FIG. **2** is a side view of an embodiment of the device **100**, showing a fastening system **101**, a display (or screen) **102**, and one or more processors (generally, processor **203**). Another view of an embodiment of the wearable device **100** is shown in FIG. **3**. FIG. **3** shows a view from beneath the device **100**, illustrating the fastening mechanism **101**, the processor **203**, an optical pulse rate detector **301**, and one or more user interaction points **103** visible from beneath.

[0017] The amount of light reflected to the optical pulse rate detector **301** depends in part on the orientation of the device **100**. Thus, as a wearer of the device **100** is moving, the amount of light reflected to the optical pulse rate detector **301** is a function of not only the volume of blood beneath the wearer's skin, but also the wearer's movements. The optical pulse rate detector **301** is configured to measure a baseline reflectance of the wearer's skin in addition to measuring the blood volume. The baseline reflectance represents an amount of light reflected by the skin independent of the volume of blood beneath the skin. Using the baseline reflectance, the optical sensor **301** removes motion artifacts from the detected blood volume to generate data indicative of the pulse rate of the wearer. The optical sensor **301** is described further with respect to FIG. **4**.

[0018] The processor **203** is communicatively coupled (e.g., via a data bus) to the optical pulse rate detector **301** for processing the pulse rate data captured by the optical pulse rate detector **301**. Using the pulse rate data received from the optical pulse rate detector **301**, the processor **203** generates biometric data about the wearer of the device **100**, such as pulse rate, beat-to-beat variance, respiration, beat-to-beat magnitude, and beat-to-beat coherence. The processor **203** is also communicatively coupled to the display **102** for controlling the display **102**. Under the control of the processor **203**, the display **102** displays various pieces of information to a user, such as the biometric data generated by the processor **203**. Although the processor **203** is shown in FIG. **3** as being integrated into the device **100**, in other embodiments the processor **203** is external to the device **100**.

Example Optical Pulse Rate Detector

[0019] Referring now to FIG. **4**, illustrated is a schematic of the optical pulse rate detector **301** configured to measure a pulse rate signal in the presence of body motion. In one embodiment, the optical pulse rate detector **301** includes a sensor control **405**, one or more emitters (generally, **412**), a photodetector **414**, and an adaptive filter **420**.

[0020] The emitters **412**A, B and photodetector **414** are configured to be placed in proximity to the skin of a wearer (or user) of the device **100**, such that the emitters **412** emit light onto the skin of the wearer and the photodetector **414** measures light reflected from the skin of the wearer. In the embodiment illustrated in FIG. **4**, the optical pulse rate detector **301** includes two emitters **412**A, **412**B. Each emitter **412**A, **412**B may be configured to emit monochromatic light, or may be configured to emit light of more than one wavelength. For example, the emitters **412**A, **412**B may be light emitting diodes (LEDs). In one embodiment, the emitter **412**A is configured to emit light of a wavelength λ_1 that is responsive to blood flow (e.g., green light), while the emitter **412**B is configured to emit light of a wavelength λ_2 that is responsive to motion (e.g., amber light). In another embodiment, the optical pulse rate detector **301** has a single emitter **412**. The photodetector **414** measures intensity of the light reflected from the skin of the wearer and converts the measured intensity into a voltage, V, which is input to the sensor control **405**.

[0021] The sensor control **405** is a controller configured to receive, process, and transmit signals. For example, the sensor control **405** is configured to send a periodic current signal to one or both emitters **412** of the optical pulse rate detector **301** and receive a voltage signal from the photodetector **414** indicating an amount of light reflected from the skin of the wearer. When an emitter **412** emits light of a wavelength that is responsive to blood flow, the voltage signal received from the photodetector **414** is indicative of a volume of blood beneath the skin of the wearer. Accordingly, the sensor control **405** samples the pulse rate of the wearer by sending a current pulse to an emitter **412**. If light from an emitter **412** is not as readily absorbed by blood, the amount of light detected by the photodetector **414** (and the voltage signal generated thereby) is a baseline reflectance. The change in the baseline reflectance from one sample to the next is indicative of an amount of motion of the optical pulse rate detector **301**.

[0022] The sensor control **405** drives the optical pulse rate detector **301** to produce two samples at different light outputs. A first light output from the optical pulse rate detector **301** is responsive to blood flow, while a second light output is responsive to motion of the user of the device **100**. For example, the first light output is light having a wavelength readily absorbed by blood and/or light having a higher intensity than the second light output. The second light output is, for example, light having a wavelength that is not as readily absorbed by blood as the first light output. The sensor control **405** samples the volume of blood beneath the wearer's skin using the first light output and samples the baseline reflectance of the skin of the wearer using the second light output.

[0023] In embodiments of the device **100** including two emitters **412**A, **412**B, the sensor control **405** generates a current signal I_1 to drive emitter **412**A to sample the blood volume. The current signal I_1 includes a series of pulses that cause the emitter **412**A to emit a first light signal at wavelength λ_1 and an intensity proportional to the magnitude of the pulses. At each pulse, the photodetector **414** detects an amount of the first light signal reflected by the wearer's skin and generates a voltage V, which is received by the sensor control **405**.

[0024] Similarly, to sample the baseline reflectance, the sensor control **405** generates a current signal I_2 to drive emitter **412**B. The current signal I_2 includes a series of pulses that cause the emitter **412**B to emit a second light signal at wavelength λ_2, where the intensity of the second light signal is also proportional to the magnitude of the pulses. At each pulse of the current signal I_2, the photodetector **414** detects an amount of the second light signal reflected by the wearer's skin and generates a voltage V input to the sensor control **405**.

[0025] In some cases, the magnitudes of the pulses of the current signals I_1 and I_2 may be the same, or the wavelengths λ_1 and λ_2 may be the same. For example, the sensor control **405** may drive both emitters with current signals having pulses with equal magnitude while sampling the blood volume using light at wavelength λ_1 and the baseline reflectance using light at wavelength λ_2 (in which $\lambda_1 \neq \lambda_2$). As another example, both emitters may emit light at wavelength λ_1 and the sensor control **405** drives the emitters with current signals I_1 and I_2 to sample the blood volume and baseline reflectance, respectively, in which the magnitude of the pulses of I_1 is greater than the pulse magnitude of I_2. In other cases, the blood volume and baseline reflectance are sampled using light having both different intensities and different wavelengths λ_1 and λ_2. In embodiments of the device **100** having a single emitter **412**, the sensor control **405** drives emitter **412** to produce a first light output using a current signal I_1 having a first magnitude, and drives emitter **412** to produce a second light output using a current signal I_2 having a second magnitude that is lower than the first magnitude.

[0026] Referring to FIG. **5**, it illustrates graphically example drive signals I_1 and I_2 generated by the sensor control **405** to drive the emitters **412**, as well as the voltage output by the photodetector **414**. In the three graphs shown, (A) and (B) show current in along the y-axis and time along the x-axis. The graph at (C) shows voltage along the y-axis and time along the x-axis.

[0027] As shown in FIG. **5**, the sensor control samples the blood volume at time **t1**, t**3**, etc., and samples the baseline reflectance at time t**2**, t**4**, etc. The interval between a sample of the blood volume and a sample of the baseline reflectance is given by $\Delta T1 = t2 - t1$, and the interval between two successive samples of the blood volume is given by $\Delta T2 = t3 - t1$. The interval ΔT**2** defines the sampling period of the wearer's pulse rate, and can be adjusted to achieve a desired sampling frequency.

[0028] In one embodiment, the sensor control **405** samples the baseline reflectance shortly after sampling the blood volume, such that $\Delta T1 < \Delta T2$. When ΔT**1** is small, the baseline reflectance closely approximates the actual baseline reflectance at the time the pulse rate was sampled. The interval ΔT**1** may be selected based on properties of the emitters **412**, the photodetector **414**, or other hardware of the optical sensor **301**. For example, ΔT**1** is selected based on the response time of the photodetector **414** to ensure the response of the photodetector **414** to the baseline reflectance sample is distinct from the response to the blood volume sample. It is noted that rather than sampling the baseline reflectance after sampling the blood volume, the sensor control **405** may alternatively sample the baseline reflectance first. As also shown in FIG. **5**, V (graph (C)) represents the voltage output by the photodetector **414** in response to both the first light output sample and the second light output sample.

[0029] The optical pulse rate detector **301** measures pulse rate of a user by measuring volume of blood in a given area over time. An emitter of the optical pulse rate detector **301** sends a light signal to skin and tissue of the wearer of the device **100** and measures the amount of light reflected to a photodetector. A portion of the light signal emitted by the emitter is absorbed by the wearer's tissue and a portion is reflected to the photodetector. In particular, if the light is of a wavelength absorbed by blood, a portion of the light is absorbed by the blood of the wearer of the device. Thus, the amount of light reflected to the photodetector depends in part on the volume of blood under the skin. As blood volume in the measured area cyclically changes due to cardiac cycles, the amount of light detected by the photodetector cyclically varies. The photodetector converts the measured light intensity into a voltage, which is analyzed for regular variations that indicate the heart's pulsation of blood throughout the body of the wearer.

[0030] Returning to FIG. **4**, the sensor control **405** converts the voltage V received from the photodetector **414** to digital samples of the baseline reflectance and blood volume, and generates two output signals: Motion and Motion +Pulse Rate (PR). The Motion +PR signal is a function of pulse and a function of motion, comprising the digital samples of the voltage V generated by the photodetector **414** in response to the first output light signal. Thus, the Motion +PR signal is a sequence of samples of the blood volume beneath the wearer's skin, but includes motion artifacts. The Motion signal is a function of the wearer's motion and comprises a sequence of samples of the voltage, V, generated by the photodetector **414** in response to the second light output signal, corresponding to samples of the baseline reflectance of the skin of the wearer.

[0031] In one embodiment, the sensor control **405** is also configured to determine the second light output based on the voltage received from the photodetector **414**. The sensor control **405** compares the Motion +PR signal to the Motion signal, and adjusts the magnitude of the pulses of the current signal I_2 driving the emitter **412**B based on the comparison. For example, if a correlation between the Motion +PR signal and the Motion signal is greater than a threshold, the sensor controller **405** decreases the pulse magnitude of the drive signal I_2. Accordingly, the sensor control **405** adjusts the magnitude of the pulses of I_2 to reduce the dependency of the Motion signal on the volume of blood beneath the skin of the wearer.

[0032] The adaptive filter **420** receives the signals Motion and Motion+PR from the sensor control **405**. Using the Motion signal as an indicator of the wearer's motion, the adaptive filter **420** removes the motion artifacts from the Motion+PR signal to generate a pulse rate signal. In various embodiments, the adaptive filter **420** may implement a least mean squares algorithm, a recursive least squares algorithm, or another type of adaptive filter algorithm. The adaptive filter **420** sends the derived pulse rate signal to the processor **203**, which analyzes the signal to determine pulse rate of the wearer of the device **100**.

[0033] By removing the motion of the wearer from the detected pulse rate signal, the adaptive filter **420** increases the signal to noise ratio of the pulse rate signal. In addition, motion measured by the same sensor as used to measure pulse rate more closely approximates the motion artifacts in the detected pulse rate signal than motion measured by an external sensor. As a result, the adaptive filter **420** improves the accuracy of the pulse rate determined by the processor **203** through analysis of the pulse rate signal. Furthermore, using a single sensor to measure both pulse rate and motion reduces the complexity of the wearable device.

Additional Configuration Considerations

[0034] Throughout this specification, plural instances may implement components, operations, or structures described as a single instance. Although individual operations of one or more methods are illustrated and described as separate operations, one or more of the individual operations may be performed concurrently, and nothing requires that the operations be performed in the order illustrated. Structures and functionality presented as separate components in example configurations may be implemented as a combined structure or component. Similarly, structures and functionality presented as a single component may be implemented as separate components. These and other variations, modifications, additions, and improvements fall within the scope of the subject matter herein.

[0035] Certain embodiments are described herein as including logic or a number of components, modules, or mechanisms. Modules may constitute either software modules (e.g., code embodied on a machine-readable medium or in a transmission signal) or hardware modules. A hardware module is tangible unit capable of performing certain operations and may be configured or arranged in a certain manner. In example embodiments, one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware modules of a computer system (e.g., a processor or a group of processors) may be configured by software (e.g., an application or application portion) as a hardware module that operates to perform certain operations as described herein.

[0036] In various embodiments, a hardware module may be implemented mechanically or electronically. For example, a hardware module may comprise dedicated circuitry or logic that is permanently configured (e.g., as a special-purpose processor, such as a field programmable gate array (FPGA) or an application-specific integrated circuit (ASIC)) to perform certain operations. A hardware module may also comprise programmable logic or circuitry (e.g., as encompassed within a general-purpose processor or other programmable processor) that is temporarily configured by software to perform certain operations. It will be appreciated that the decision to implement a hardware module mechanically, in dedicated and permanently configured circuitry, or in temporarily configured circuitry (e.g., configured by software) may be driven by cost and time considerations.

[0037] The various operations of example methods described herein may be performed, at least partially, by one or more processors that are temporarily configured (e.g., by software) or permanently configured to perform the relevant operations. Whether temporarily or permanently configured, such processors may constitute processor-implemented modules that operate to perform one or more operations or functions. The modules referred to herein may, in some example embodiments, comprise processor-implemented modules.

[0038] The one or more processors may also operate to support performance of the relevant operations in a "cloud computing" environment or as a "software as a service" (SaaS). For example, at least some of the operations may be performed by a group of computers (as examples of machines including processors), these operations being accessible via a network (e.g., the Internet) and via one or more appropriate interfaces (e.g., application program interfaces (APIs).)

[0039] The performance of certain of the operations may be distributed among the one or more processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the one or more processors or processor-implemented modules may be located in a single geographic location (e.g., within a home environment, an office environment, or a server farm). In other example embodiments, the one or more processors or processor-implemented modules may be distributed across a number of geographic locations.

[0040] Some portions of this specification are presented in terms of algorithms or symbolic representations of operations on data stored as bits or binary digital signals within a machine memory (e.g., a computer memory). These algorithms or symbolic representations are examples of techniques used by those of ordinary skill in the data processing arts to convey the substance of their work to others skilled in the art. As used herein, an "algorithm" is a self-consistent sequence of operations or similar processing leading to a desired result. In this context, algorithms and operations involve physical manipulation of physical quantities. Typically, but not necessarily, such quantities may take the form of electrical, magnetic, or optical signals capable of being stored, accessed, transferred, combined, compared, or otherwise manipulated by a machine. It is convenient at times, principally for reasons of common usage, to refer to such signals using words such as "data," "content," "bits," "values," "elements," "symbols," "characters," "terms," "numbers," "numerals," or the like. These words, however, are merely convenient labels and are to be associated with appropriate physical quantities.

[0041] Unless specifically stated otherwise, discussions herein using words such as "processing," "computing," "calculating," "determining," "presenting," "displaying," or the like may refer to actions or processes of a machine (e.g., a computer) that manipulates or transforms data represented as physical (e.g., electronic, magnetic, or optical) quantities within one or more memories (e.g., volatile memory, non-volatile memory, or a combination thereof), registers, or other machine components that receive, store, transmit, or display information.

[0042] As used herein any reference to "one embodiment" or "an embodiment" means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

[0043] Some embodiments may be described using the expression "coupled" and "connected" along with their derivatives. For example, some embodiments may be described using the term "coupled" to indicate that two or more elements are in direct physical or electrical contact. The term "coupled," however, may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other. The embodiments are not limited in this context.

[0044] As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0045] In addition, use of the "a" or "an" are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

[0046] Upon reading this disclosure, those of skill in the art will appreciate still additional alternative structural and functional designs for a system and a process for measuring pulse rate of a user during periods of motion through the disclosed principles herein. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the disclosed embodiments are not limited to the precise construction and components disclosed herein. Various modifications, changes and variations, which will be apparent to those skilled in the art, may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope defined in the appended claims.

1. A device configured to be worn by a user during an activity, the device comprising:

an optical pulse rate detector including:

a first emitter to transmit light at a first light output level into body tissue of the user,

a second emitter to transmit light at a second light output level into the body tissue of the user,

a photodetector to receive reflected light from the body tissue and producing a voltage indicative of an amount of the reflected light,

a sensor controller operable to:

drive the first emitter to output the light at the first light output level and the second emitter to output the light at the second light output level, and

sample the voltage produced by the photodetector to generate a first output signal indicative of an amount of the light at the first light output level reflected from the body tissue and a second output signal indicative of an amount of the light at the second light output level reflected from the body tissue, and

an adaptive filter to generate a pulse rate signal by removing the second output signal from the first output signal; and

a processor to determine a pulse rate of the user using the generated pulse rate signal.

2. The device of claim **1**, wherein the sensor controller is operable to drive the first emitter to output the light at the first light output level and the second emitter to output the light at the second light output level by further being operable to:

generate a first drive signal to drive the first emitter, the first drive signal comprising a plurality of current pulses; and

generate a second drive signal to drive the second emitter, the second drive signal comprising a plurality of current pulses each generated between consecutive current pulses of the first drive signal.

3. The device of claim **2**, wherein the current pulses of the first drive signal have a higher magnitude than the current pulses of the second drive signal.

4. The device of claim **2**, wherein the sensor controller adjusts a magnitude of the current pulses of the second drive signal based on a comparison of the second output signal to the first output signal.

5. The device of claim **1**, wherein the first emitter transmits light having a wavelength responsive to blood volume.

6. The device of claim **1**, wherein the second emitter transmits light having a wavelength responsive to motion of the user.

7. The device of claim **1**, wherein the processor further determines at least one of a beat-to-beat variance of the pulse rate, a beat-to-beat magnitude of the pulse rate, a beat-to-beat coherence of the pulse rate, and a respiration rate of the user using the pulse rate signal.

8. An optical pulse rate detector, comprising:

at least one emitter to transmit light at a first light output level into body tissue of a user and transmit light at a second light output level into the body tissue of the user;

a photodetector to receive reflected light from the body tissue and producing a voltage indicative of an amount of the reflected light; and

an adaptive filter to receive from the photodetector, a first output signal indicative of an amount of the light at the first light output level reflected from the body tissue and a second output signal indicative of an amount of the light at the second output level reflected from the body tissue, the adaptive filter configured to generate a pulse rate signal indicative of pulse rate of the user by removing the second output signal from the first output signal.

9. The optical pulse rate detector of claim **8**, further comprising a sensor controller to drive the at least one emitter, the sensor controller operable to:

generate a first drive signal to drive the at least one emitter, the first drive signal comprising a plurality of current pulses; and

generate a second drive signal to drive the at least one emitter, the second drive signal comprising a plurality of current pulses each generated between consecutive current pulses of the first drive signal.

10. The optical pulse rate detector of claim **9**, wherein the current pulses of the first drive signal have a higher magnitude than the current pulses of the second drive signal.

11. The optical pulse rate detector of claim **9**, wherein the sensor controller adjusts a magnitude of the current pulses of the second drive signal based on a comparison of the second output signal to the first output signal.

12. The optical pulse rate detector of claim **8**, wherein the at least one emitter transmits light having a wavelength responsive to blood volume.

13. The optical pulse rate detector of claim **12**, wherein the at least one emitter comprises a second emitter to transmit light having a wavelength responsive to motion of the user.

14. The optical pulse rate detector of claim **8**, wherein the processor further determines at least one of a beat-to-beat variance of the pulse rate, a beat-to-beat magnitude of the pulse rate, a beat-to-beat coherence of the pulse rate, and a respiration rate of the user using the pulse rate signal.

15. A non-transitory computer-readable storage medium storing executable instructions for determining a pulse rate of a user of a wearable device, the wearable device comprising an optical pulse rate detector including at least one emitter, an adaptive filter, and a processor, the instructions when executed by a processor causing the processor to:

transmit by the emitter, light at a first light output level into body tissue of the user; transmit by the emitter, light at a second light output level into the body tissue of the user;

receive at the adaptive filter, a first signal indicative of an amount of the light at the first light output level reflected from the body tissue and a second output signal indicative of an amount of the light at the second light output level;

generate a pulse rate signal indicative of a pulse rate of the user by removing the second output signal from the first output signal; and

determine a pulse rate of the user using the pulse rate signal.

16. The non-transitory computer-readable storage medium of claim **15**, further comprising instructions that when executed by the processor cause the processor to:

generate a first drive signal to drive the emitter to output the light at the first light output level, the first drive signal comprising a plurality of current pulses; and

generate a second drive signal to drive the emitter to output the light at the second light output level, the second drive signal comprising a plurality of current pulses each generated between consecutive current pulses of the first drive signal.

17. The non-transitory computer-readable storage medium of claim **16**, wherein the current pulses of the first drive signal have a higher magnitude than the current pulses of the second drive signal.

18. The non-transitory computer-readable storage medium of claim **16**, further comprising instructions that when executed by the processor cause the processor to adjust a magnitude of the current pulses of the second drive signal based on a comparison of the second output signal to the first output signal.

19. The non-transitory computer-readable storage medium of claim **15**, wherein the light at the first light output level has a wavelength responsive to blood volume.

20. The non-transitory computer-readable storage medium of claim **19**, wherein the optical pulse rate detector includes a second emitter emitting the light at the second light output level, and wherein the light at the second output level has a wavelength responsive to motion of the user.

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摘要(译)

光脉冲速率检测器包括至少一个发射器，一光检测器，和一个自适应滤波器。发射器在第一光输出电平和第二光输出电平到用户的身体组织透射光。光检测器从身体组织接收反射的光，并产生表示反射光的量的电压。自适应滤波器接收从表示在所述第一光输出电平从身体组织，并在第二输出电平表示的光的量的第二输出信号的反射的光的量的光检测器从主体反射的第一输出信号组织。自适应滤波器从第一输出信号中去除所述第二输出信号以产生指示所述用户的脉搏率的脉率信号。