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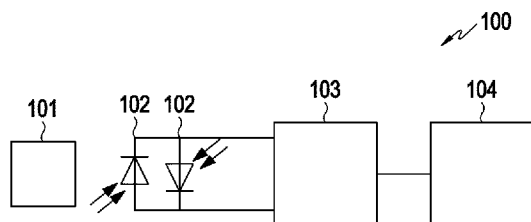
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(54) Title: METHOD AND DEVICE FOR MEASURING HEART RATE



(57) Abstract: A method for measuring heart rate comprises illuminating a body portion with light; detecting light scattered by tissues of the body portion and blood particles by a plurality of photodetectors comprising at least one pair of photodetectors which are connected in anti-parallel in each pair of photodetectors; eliminating a frequency component of motion artifacts in an analog photocurrent differential signal by subtracting a first analog photocurrent signal detected by a first photodetector of a pair of photodetectors of the at least one pair of the photodetectors from a second analog photocurrent signal detected by a second photodetector of the pair of photodetectors; converting the analog photocurrent differential signal into an analog voltage differential signal; converting the analog voltage differential signal into a digital differential signal; calculating an envelope of the digital differential signal; and calculating the heart rate from peaks of the calculated envelope of the digital differential signal.

Description

Title of Invention: METHOD AND DEVICE FOR MEASURING HEART RATE

Technical Field

- [1] The present disclosure generally relates to heart rate measurement using wearable devices, and, in particular, to a method for measuring heart rate with motion artifact resistance and a device for measuring heart rate with motion artifact resistance that can be embedded into various wearable devices such as smart watches, fitness bracelets, etc.

Background Art

- [2] There are devices for measuring heart rate based on photoplethysmography (PPG) or electrocardiography (ECG), which provide an accurate measurement in a stationary state of a person. There are also PPG or ECG based heart rate measurement devices embedded into wearable devices that provide measurement when the person is moving. However, the heart rate measurement with the wearable device, when the person is moving, can be inaccurate due to motion artifacts caused by the movement of the device in relation to a body part of the person wearing the wearable device. The motion artifacts introduce distortions into a measurement signal and a measurement result is inaccurate. To eliminate the influence of motion artifacts in conventional wearable devices, either a strong fixation of the device on the body is used, or the wearable devices additionally comprise sensors that measure motion, and motion artifacts are compensated based on the measurements of these sensors.
- [3] The strong fixation of the heart rate measurement device on the body causes discomfort of wearing this device, and additional sensors and circuits for compensating the motion artifacts increase a size and weight of the device, furthermore, complicate a structure of the device and complicate signal processing.
- [4] In prior art, technical solutions for measuring heart rate are known.
- [5] The US Patent US4476875A issued on 16.10.1984 and titled as "METHOD AND APPARATUS FOR MEASURING FLOW MOTIONS IN A FLUID", proposes a technical solution in which a body portion is illuminated with monochromatic light from a laser, a light scattered from particles in a fluid and from any surrounding stationary structures is transmitted separately to two separate photodetectors. From an output signal of each photodetector a signal is derived, which contains the beat frequency components resulting from interference between light components received by the photodetector, which have different frequencies due to the Doppler frequency shift of the light scattered by moving particles. The two signals so derived from the

output signals of the two photodetectors are subtracted from each other and the signal resulting from this subtraction is used as a measure of flow motions in the fluid. In this technical solution, units of device including amplifiers and analog filters are included in a differential circuit instead of photodetectors. Such solution increases requirements for elements of the electrical circuit, such as the linearity and stability of the amplifiers, the identity of electrical characteristics of all elements included in the differential circuit. In addition, a balanced scheme for arranging photodetectors in relation to the light source, i.e. equality of distances from the light source to each photodetector and equality of photodetector parameters, such as sensitivity, detection area, etc. are not disclosed. This solution uses optical fiber and many signal processing units, therefore, this solution has large size and heavy weight and is intended for stationary measurements and is not suitable for embedding into wearable devices.

- [6] The International Patent Application WO 2007/122375A1 published on 01.11.2007 and titled as "PHOTOPLETHYSMOGRAPHY" proposes a photoplethysmograph device that includes a light source for illuminating a target object. A modulator drives the light source such that the output intensity varies as a function of a modulation signal at a modulation frequency. A detector receives light from the target object and generates an electrical output as a function of the intensity of received light. A demodulator with a local oscillator receives the detector output and produces a demodulated output representing the modulation signal. The demodulator is insensitive to any phase difference between the modulation signal and the oscillator of the demodulator. From the demodulated output, a signal indicative of blood volume as a function of time and/or blood composition is generated. A number of demodulators may be provided to derive signals from multiple light sources of different wavelengths, or from an array of detectors. The plethysmograph may operate in a transmission mode or a reflectance mode. While being in a reflectance mode, the device may use the green part of the optical spectrum and may use polarising filters. This technical solution is intended for measurements in a stationary state, since it does not eliminate the motion artifacts that distort the measurement signal. In addition, the photoplethysmograph device is not suitable for embedding into wearable devices due to the complexity of the device structure and the inability to compensate for the motion artifacts.

- [7] The US Patent US10849513B2 issued on 01.12.2020 and titled as "SENSING AT LEAST ONE BIOLOGICAL PARAMETER, E.G., HEART RATE OR HEART RATE VARIABILITY OF A SUBJECT" proposes a device for sensing at least one biological parameter (e.g., heart rate, heart rate variability) of a subject, the device comprising a contact surface configured for being brought into a contact with a skin surface of the subject. The device has at least one light source for illuminating the skin surface through the contact surface along an illumination source optical axis with illu-

mination including at least one sensing wavelength, and at least one detector for detecting a response of said illumination at least at said wavelength, from the skin surface through the contact surface along a detector optical axis, and providing signals configured for determining said biological parameter based thereon, said illumination optical axis forming with said contact surface an acute included angle. This device does not compensate for the motion artifacts and requires strong fixation on the body portion.

- [8] The US Patent Application US20100298657A1 published on 25.11.2010 and titled as "METHOD FOR CONTINUOUSLY MONITORING A PATIENT USING A BODY-WORN DEVICE AND ASSOCIATED SYSTEM FOR ALARMS/ALERTS" proposes a body-worn monitor that measures a patient's vital signs (e.g. blood pressure, SpO₂, heart rate, respiratory rate, and temperature) while simultaneously characterizing their activity state (e.g. resting, walking, convulsing, falling). The body-worn monitor processes this information to minimize corruption of the vital signs by motion-related artifacts. A software framework generates alarms/alerts based on threshold values that are either preset or determined in real time. The framework additionally includes a series of 'heuristic' rules that take the patient's activity state and motion into account, and process the vital signs accordingly. These rules, for example, indicate that a walking patient is likely breathing and has a regular heart rate, even if their motion-corrupted vital signs suggest otherwise. This technical solution includes several motion-detecting sensors to compensate for the movement of a part of the human body. It also requires additional complex calculations to compensate for the movement of the part of the human body.

- [9] Current devices for measuring heart rate have the following disadvantages. The known devices for measuring heart rate are either designed to measure in a stationary state, or require a strong fixation of the device on the body, or have a complex structure with additional sensors that detect the movement of the part of the human body.

- [10] A measurement device capable of providing accurate heart rate measurement even under intensive motion conditions without strong fixation of the measurement device on the body, having small size, simple structure, and without complex signal processing is required. The present disclosure has been made to overcome above disadvantages and to provide advantages described below.

Disclosure of Invention

Solution to Problem

- [11] The aim of the present disclosure is to simplify a structure, to reduce a size and to simplify a signal processing of a device for measuring heart rate with motion artifact

resistance that does not require strong fixation on a human body and can be embedded into wearable devices such as smart watches, fitness bracelets, etc.

- [12] An aspect of present disclosure provides a method for measuring heart rate. The method may comprise illuminating a body portion with light emitted from a light source. The method may comprise detecting light scattered by tissues of the body portion and blood particles by a plurality of photodetectors comprising at least one pair of photodetectors which are connected in anti-parallel in each pair of photodetectors. The method may comprise eliminating a frequency component of motion artifacts in an analog photocurrent differential signal by subtracting a first analog photocurrent signal detected by a first photodetector of a pair of photodetectors of the at least one pair of the photodetectors from a second analog photocurrent signal detected by a second photodetector of the pair of photodetectors. The method may comprise converting the analog photocurrent differential signal into an analog voltage differential signal. The method may comprise converting the analog voltage differential signal into a digital differential signal. The method may comprise calculating an envelope of the digital differential signal. The method may comprise calculating the heart rate from peaks of the calculated envelope of the digital differential signal.
- [13] An aspect of the present disclosure provides a device for measuring heart rate. The device may comprise a light source configured to illuminate a body portion with light. The device may comprise a plurality of photodetectors comprising at least one pair of photodetectors which are connected in anti-parallel in each pair of photodetectors and configured to detect light scattered by tissues of the body portion and blood particles, and eliminate a frequency component of motion artifacts in an analog photocurrent differential signal by subtracting a first analog photocurrent signal detected by a first photodetector of a pair of photodetectors of the at least one pair of the photodetectors from a second analog photocurrent signal detected by a second photodetector of the pair of photodetectors. The device may comprise a converter configured to convert the analog photocurrent differential signal into an analog voltage differential signal, and convert the analog voltage differential signal into a digital differential signal. The device may comprise a calculator configured to calculate an envelope of the digital differential signal, and calculate the heart rate from peaks of the calculated envelope of the digital differential signal.
- [14] An aspect of the present disclosure provides a method for measuring heart rate. The method may comprise illuminating a body portion with coherent light emitted from a light source. The method may comprise detecting light scattered by tissues of the body portion and blood particles by a plurality of photodetectors, comprising a first subset of photodetectors connected in one direction, and a second subset of photodetectors connected in a second direction opposite to the first direction. The method may

comprise converting, by at least two converters, at least one first analog photocurrent signal detected by the first subset of photodetectors into at least one first analog voltage signal, and at least one second analog photocurrent signal detected by the second subset of photodetectors into at least one second analog voltage signal. The method may comprise converting, by the at least two converters, the at least one first analog voltage signal into at least one first digital signal, and the at least one second analog voltage signal into at least one second digital signal. The method may comprise eliminating a frequency component of motion artifacts in a digital differential signal by subtracting the at least one first digital signal from the at least one second digital signal. The method may comprise calculating (S306) an envelope of the digital differential signal. The method may comprise calculating the heart rate from peaks of the calculated envelope of the digital differential signal.

- [15] An aspect of the present disclosure provides a device for measuring heart rate. The device may comprise a light source configured to illuminate a body portion with coherent light. The device may comprise a plurality of photodetectors (102) comprising a first subset of photodetectors connected in one direction, and a second subset of photodetectors connected in a second direction opposite to the first direction, wherein the plurality of photodetectors is configured to detect light scattered by tissues of the body portion and blood particles. The device may comprise at least two converters comprising at least one first converter connected to the first subset of photodetectors, configured to convert at least one first analog photocurrent signal detected by the first subset of photodetectors into at least one first analog voltage signal, and convert the at least one first analog voltage signal into at least one first digital signal, and at least one second converter connected to the second subset of photodetectors, configured to convert at least one second analog photocurrent signal detected by the second subset of photodetectors into at least one second analog voltage signal, and convert the at least one second analog voltage signal into at least one second digital signal. The device may comprise a calculator configured to eliminate a frequency component of motion artifacts in a digital differential signal by subtracting the at least one first digital signal from the at least one second digital signal, calculate an envelope of the digital differential signal, and calculate the heart rate from peaks of the calculated envelope of the digital differential signal.

Brief Description of Drawings

- [16] The above mentioned and other aspects, features and advantages of the present disclosure will be better understood from the following detailed description accompanied by drawings, in which:
- [17] Fig. 1 schematically illustrates a heart rate detection process.

- [18] Fig. 2 schematically illustrates a balanced optical scheme.
- [19] Fig. 3 illustrates analog signals detected by photodetectors.
- [20] Fig. 4 illustrates an analog differential signal.
- [21] Fig. 5 illustrates a digital differential signal and its envelope.
- [22] Fig. 6 is a block diagram of a device for measuring heart rate according to an embodiment of the present disclosure.
- [23] Fig. 7 is a block diagram of a device for measuring heart rate according to an embodiment of the present disclosure.
- [24] Fig. 8 is a block diagram of a device for measuring heart rate according to an embodiment of the present disclosure.
- [25] Fig. 9 is a block diagram of a device for measuring heart rate according to an embodiment of the present disclosure.
- [26] Fig. 10 is a block diagram of a device for measuring heart rate according to an embodiment of the present disclosure.
- [27] Fig. 11 is a block diagram of a device for measuring heart rate according to an embodiment of the present disclosure.
- [28] Fig. 12 is a flowchart of a method for measuring heart rate according to an embodiment of the present disclosure.
- [29] Fig. 13 is a flowchart of a method for measuring heart rate according to an embodiment of the present disclosure.
- [30] In the following description, unless otherwise specified, the same reference numbers are used for the same elements when they are shown in different drawings, and their associated description is not given.

Mode for the Invention

- [31] The following description with reference to the accompanying drawings is provided in order to facilitate a complete understanding of various embodiments of the present disclosure, defined by the claims, and its equivalents. The description includes various specific details to facilitate such understanding, but these details should be considered only as exemplary. Accordingly, those skilled in the art will appreciate that various changes and modifications of the various embodiments described in this application can be developed without departing from the scope of the present disclosure. In addition, descriptions of well-known functions and structures may be omitted for clarity and brevity.
- [32] The terms and formulations used in the following description and claims are not limited to bibliographic meanings, but are merely used by the inventors of the present disclosure in order to provide a clear and consistent understanding of the present disclosure. Accordingly, it should be clear to those skilled in the art that the following

description of various embodiments of the present disclosure is provided for illustration only.

- [33] It should be understood that the singular form includes the plurality, unless otherwise is clearly specified by the context.
- [34] Additionally, it should be understood that the terms "comprises", "comprising", "includes" and/or "including", when used in this application, mean the presence of the stated features, values, operations, elements and/or components, but do not exclude the presence or addition of one or more other features, values, operations, elements, components, and/or their groups.
- [35] Fig. 1 illustrates the photoplethysmography process used to measure heart rate in the present disclosure. The light source 101 illuminates the body portion with coherent light, and at least two photodetectors 102 detect light scattered by the tissues of the body portion and the blood particles. The intensity of the detected light and, consequently, the magnitude of the photodetector signal are proportional to the change in blood volume in the examined body portion during contraction and relaxation of the heart muscle. The more blood is in a vessel, i.e., the more erythrocytes scattering the light in it, the stronger the light is reflected from them and the magnitude of the photodetector signal is higher. In Fig. 1, only two photodetectors 102 are shown, however, the present disclosure is not limited to two photodetectors 102, and the device for measuring heart rate according to the present disclosure may include more than two photodetectors 102.
- [36] In the present disclosure, it is preferable to use a coherent light source having small size, for example, a laser LED, as the light source 101. However, the present disclosure is not limited to the laser LED, the light source 101 can be any coherent light source that has size allowing to embed it into a wearable device, for example, a smart watch, fitness bracelet, etc.
- [37] The photodetectors 102 can be any photodetectors operating in the photodiode mode, the output of which is a current signal. Two or more photodetectors 102 are connected in anti-parallel to provide a differential connection of photodetectors 102. The light source and photodetectors form a balanced optical scheme.
- [38] Fig. 2 schematically illustrates a balanced optical scheme. The balanced optical scheme is the arrangement of the photodetectors 102 at the same distances from the light source 101 as shown by a broken line circle in Fig. 2 and the photodetectors 102 have the same parameters such as sensitivity, detection area, and so on. For example, the photodetectors 102 can be symmetrically arranged with respect to the light source 101. The symmetrical arrangement of the photodetectors 102 can better eliminate motion artifacts that occur in different directions of movement of the device 100 in relation to the body portion in which the measurement is made. However, the

disclosure is not limited to the symmetrical arrangement of the photodetectors 102 in relation to the light source 101, the main condition is the arrangement of the photodetectors 102 at the same distance from the light source 101. A balanced optical scheme provides signals having the same frequency component of the motion artifacts from all photodetectors 102 due to the arrangement of the photodetectors 102 at the same distance from the light source 101 and the same parameters of all photodetectors 102 such as sensitivity, detection area, etc.

[39] Figs. 3-5 schematically illustrate the signals from the photodetectors 102 before and after conversion.

[40] Fig. 3 illustrates analog signals detected by the photodetectors 102. For ease of explanation, in Fig. 3, only two analog signals from two photodetectors 102 connected in anti-parallel are shown. One analog signal is shown as a solid curved line, and the other analog signal is shown as a dotted curved line. However, the number of signals in the present disclosure may be equal to the number of the photodetectors 102. The frequency component of the motion artifacts in the signals of the photodetectors 102 is depicted by a dashed curved line. The frequency component of the motion artifacts is introduced into the signals of the photodetectors 102 due to the movement of the device for measuring heart rate in relation to the body portion where the heart rate is measured. An oscillation frequency of the frequency component of the motion artifacts of the signals of the photodetectors 102 is defined by the frequency of the movement of the device 100 for measuring heart rate in relation to the body portion in which the heart rate measurement is performed. To simplify the illustration of the analog signals detected by the photodetectors 102, the frequency component of the motion artifacts is shown as a smooth curved line. However, in real practice, the frequency component of the motion artifacts has a variable oscillation frequency depending on the frequency of the movement of the device 100 for measuring heart rate in relation to the body portion in which the heart rate measurement is performed, since the movements of the device 100 can occur in different directions and at different frequencies. In different parts of the detected signal, the frequency component of the motion artifacts may have the same oscillation frequency as the heart rate, higher or lower than the heart rate. Therefore, the frequency component of the motion artifacts cannot be eliminated by filtering the detected signal. The detection level is depicted by a dash-dotted straight line. The detection level is set in advance so as to take into account all heartbeats, for example, when performing the measurement without moving the device for measuring heart rate in relation to the body portion, i.e. when the frequency component of the motion artifacts is not introduced into the photodetector signals. As shown in the middle part of the waveform of the photodetectors 102, not all heartbeats are detected due to the influence of the frequency component of the motion artifacts.

- [41] Fig. 4 illustrates the analog differential signal obtained by subtracting the signals of the photodetectors 102 due to the connection of the photodetectors 102 in a differential circuit. The differential signal is shown as a solid curved line. Since the photodetectors 102 and the light source 101 form a balanced optical scheme, the frequency component of the motion artifacts in all signals of the photodetectors 102 will be the same and will be reduced when the signals are subtracted, as shown by the dotted straight line passing through the value 0 on the vertical axis of the graph. Therefore, the influence of the motion artifacts is eliminated, and all heartbeats can be detected at the detection level depicted by the dash-dotted straight line.
- [42] Fig. 5 illustrates a digital differential signal and its envelope. To improve the accuracy of heartbeat detection, an analog photocurrent differential signal of the photodetectors 102 is converted into an analog voltage differential signal to increase the signal-to-noise ratio, and the analog voltage differential signal is converted into a digital differential signal. The envelope of the digital differential signal is then calculated by, for example, using a Hilbert transform, a digital low-pass filter, etc. The envelope is shown as a dashed curved line. Any known method for calculating the envelope of the digital signal can be used in the present disclosure. Methods for calculating the envelope of a digital signal are known in the art and therefore their description is omitted. The detection level is depicted by the dash-dotted straight line. The heart rate is calculated from peaks in the envelope of the digital differential signal, that reach or exceed the detection level. The horizontal axis in the graph represents time in seconds and, therefore, it is possible to count the number of peaks that reach or exceed the detection level over time, i.e. to calculate heart rate. For example, Fig. 5 illustrates 3 peaks per 3 seconds, hence, the heart rate shown in Fig. 5 is 60 heartbeats per minute.
- [43] Figs. 3-5 illustrate only one of the signal processing orders in the present disclosure. In the present disclosure, it is also possible, in first, to convert the analog photocurrent signals detected by the photodetectors 102 into the analog voltage signals, to convert the analog voltage signals into digital signals, and then to obtain the digital differential signal by subtracting the digital signals and to calculate its envelope.
- [44] Hereinafter, various embodiments of the present disclosure are described in more detail with reference to the accompanying drawings.
- [45] Fig. 12 is a flowchart of a method 200 for measuring heart rate according to an embodiment of the present disclosure. The method 200 may be performed by a device 100 in one of Figs. 6-8.
- [46] In step S201, the body portion is illuminated with light emitted from the light source 101. The light emitted from the light source 101 may be coherent.
- [47] In step S202, the light from the light source 101 scattered by the tissues of the body

portion and blood particles is detected by a plurality of photodetectors comprising at least one pair of photodetectors 102. The photodetectors 102 in each pair of photodetectors are connected in anti-parallel. The light source 101 and the photodetectors 102 may form the balanced optical scheme.

[48] In some aspects of the present disclosure, the light scattered by the tissues of the body portion and the blood particles may be detected through a converging lens disposed in front of the light source 101 and each photodetector 102.

[49] In step S203, the frequency component of the motion artifacts in the analog photocurrent differential signal is eliminated by subtracting the first analog photocurrent signal detected by a first photodetector 102 of the pair of photodetectors 102 of the at least one pair of the photodetectors from a second analog photocurrent signal detected by second photodetector 102 of the pair of photodetectors 102.

[50] In step S204, the analog photocurrent differential signal obtained in step S203 is converted into an analog voltage differential signal. Step 203 may be performed by a transimpedance amplifier (TIA) in the conversion unit 103.

[51] The at least one pair of photodetectors may comprise at least two pairs of photodetectors connected in parallel to obtain a summed analog photocurrent differential signal as shown in Figs. 7 and 8. Then, The method 200 may comprise converting the summed analog photocurrent differential signal into a summed analog voltage differential signal, and converting the summed analog voltage differential signal into the digital differential signal.

[52] In step S205, the analog voltage differential signal obtained in step S204 is converted into the digital differential signal. Step 204 may be performed by an analog-to-digital converter (ADC) in the conversion unit 103.

[53] In step S206, the envelope of the digital differential signal obtained in step S205 is calculated.

[54] In step S207, the heart rate is calculated from the peaks of the envelope of the digital differential signal calculated in step S206.

[55] Figs. 6-8 show block diagrams of embodiments of a device 100 for measuring heart rate that performs the method 200 for measuring heart rate. The device 100 comprises a light source 101, at least one pair of photodetectors 102, a conversion unit 103, and a calculation unit 104. The conversion unit 103 may be referred to as a converter. The calculation unit 104 may be referred to as a calculator.

[56] The light source 101 illuminates the body portion with light where heart rate measurement is performed. The light emitted from the light source 101 may be coherent.

[57] In one embodiment that shown in FIG. 6, the device 100 may comprise one pair of photodetectors 102. In another embodiment that shown in Fig. 7, device 100 may comprise two pairs of photodetectors 102. In yet another embodiment that shown in

Fig. 8, device 100 may comprise more than two pairs of photodetectors 102.

- [58] The at least one pair of photodetectors 102 detects the light from the light source 101 scattered by the tissues of the body portion and blood particles. The photodetectors 102 in each pair of photodetectors are connected in anti-parallel. The light source 101 and the photodetectors 102 form the balanced optical scheme. The balanced optical scheme provides signals having the same frequency component of the motion artifacts from all photodetectors 102 due to the arrangement of the photodetectors 102 at the same distance from the light source 101 and the same parameters of all photodetectors 102 such as sensitivity, detection area, etc. By connecting the photodetectors 102 in anti-parallel, i.e. in a differential circuit, the pair of photodetectors 102 outputs the analog photocurrent differential signal by subtracting the analog photocurrent signal detected by one photodetector 102 of the pair of photodetectors 102 from the analog photocurrent signal detected by another photodetector 102 of the pair of photodetectors 102. Since the signals from all photodetectors 102 have the same frequency component of the motion artifacts, the subtraction of the signals eliminates the frequency component of the motion artifacts in the analog photocurrent differential signal.
- [59] The conversion unit 103 comprises the transimpedance amplifier (TIA) and the analog-to-digital converter (ADC). The TIA converts the analog photocurrent differential signal into the analog voltage differential signal. The ADC converts the analog voltage differential signal into the digital differential signal.
- [60] The calculation unit 104 calculates the envelope of the digital differential signal, and calculates the heart rate from the peaks of the calculated envelope of the digital differential signal.
- [61] If the device 100 comprises two or more pairs of photodetectors 102 as shown in the embodiments on Figs. 7 and 8, the pairs of photodetectors 102 are connected in parallel to produce a summed analog photocurrent differential signal. The converting unit 103 converts the summed analog photocurrent differential signal into a summed analog voltage differential signal by the TIA, and converts the summed analog voltage differential signal into the digital differential signal by the ADC.
- [62] Fig. 11 partially shows yet another embodiment of the device 100, in which the device 100 according to all of the above embodiments may further comprise a converging lens 105 in front of the light source 101 and each photodetector 102. The converging lenses 105 allow to get a stronger signal and increase the signal-to-noise ratio of the processed signals.
- [63] The device 100 according to all of the above embodiments may be embedded into a wearable device for measuring heart rate such as a smart watch, a fitness bracelet, etc.
- [64] Fig. 13 is a flowchart of a method 300 for measuring heart rate according to an embodiment of the present disclosure. The method 300 may be performed by a device 100

in one of Figs. 9-10.

[65] In step S301, the body portion is illuminated with light emitted from the light source 101. The light emitted from the light source 101 may be coherent.

[66] In step S302, the light from the light source 101 scattered by the tissues of the body portion and blood particles is detected by a plurality of photodetectors 102. The plurality of photodetectors 102 comprises a first subset of photodetectors 102 connected in one direction and a second subset of photodetectors 102 connected in a second direction opposite to the first direction, i.e. the first subset of photodetectors 102 and the second subset of photodetectors 102 form a differential circuit. At least one photodetector 102 is connected to a separate conversion unit 103 comprising the TIA and the ADC. The light source 101 and the photodetectors 102 may form the balanced optical scheme.

[67] In some aspects of the present disclosure, the light scattered by the tissues of the body portion and the blood particles may be detected through a converging lens disposed in front of the light source 101 and each photodetector 102.

[68] In step S303, by at least two conversion units 103, the at least one first analog photocurrent signal detected by the first subset of photodetectors is converted into at least one first analog voltage signal, and at least one second analog photocurrent signal detected by the second subset of photodetectors is converted into at least one second analog voltage signal. Step 303 may be performed by the TIA in each of the at least two conversion units 103.

[69] The first subset of photodetectors may be connected in parallel, and the second subset of photodetectors may be connected in parallel as shown in Fig. 10. Then, the at least one first analog photocurrent signal detected by the first subset of photodetectors may be converted into the at least one first analog voltage signal using only a first conversion unit of the at least two conversion units, and the at least one second analog photocurrent signal detected by the second subset of photodetectors may be converted into the at least one second analog voltage signal using only a second conversion unit of the at least two conversion units.

[70] The least two converters may comprise a plurality of conversion units having the number same as a number of the plurality of photodetectors as shown in Fig. 9. Then, the analog photocurrent signal detected by each of the plurality of photodetectors may be converted into the analog voltage signal using respective conversion unit of the plurality of conversion units.

[71] In step S304, by at least two conversion units 103, the at least one first analog voltage signal is converted into at least one first digital signal, and the at least one second analog voltage signal is converted into at least one second digital signal. Step 304 may be performed by the ADC in each of the at least two conversion units 103.

- [72] In step S305, the frequency component of the motion artifacts is eliminated in the digital differential signal by subtracting the at least one first digital signal obtained from the at least one first analog photocurrent signal detected by the first subset of photodetectors from the at least one second digital signal obtained from the at least one second analog photocurrent signal detected by the second subset of photodetectors.
- [73] In step S306, the envelope of the digital differential signal obtained in step S305 is calculated.
- [74] In step S307, the heart rate is calculated from the peaks of the envelope of the digital differential signal calculated in step S306.
- [75] Figs. 9-10 show block diagrams of embodiments of a device 100 for measuring heart rate that performs the method 300 for measuring heart rate. The device 100 comprises the light source 101, the plurality of photodetectors 102, the conversion unit 103, and the calculation unit 104. The conversion unit 103 may be referred to as a converter. The calculation unit 104 may be referred to as a calculator.
- [76] The light source 101 illuminates the body portion with light where heart rate measurement is performed. The light emitted from the light source 101 may be coherent.
- [77] The plurality of photodetectors 102 detect the light from the light source 101 scattered by the tissues of the body portion and blood particles. The plurality of photodetectors 102 consists of the first subset of photodetectors 102 connected in one direction and the second subset of photodetectors 102 connected in the second direction opposite to the first direction. The light source 101 and the photodetectors 102 form the balanced optical scheme. The balanced optical scheme provides signals having the same frequency component of the motion artifacts from all photodetectors 102 due to the arrangement of the photodetectors 102 at the same distance from the light source 101 and the same parameters of all photodetectors 102 such as sensitivity, detection area, etc.
- [78] Each of the at least two conversion units 103 comprises the TIA and the ADC. Each conversion unit 103 is connected to at least one photodetector 102. Each conversion unit 103 converts the analog photocurrent signal detected by at least one photodetector 102 into the analog voltage signal by the TIA, and converts the analog voltage signal into the digital signal by the ADC.
- [79] The calculation unit 104 calculates the digital differential signal by subtracting the digital signals obtained by the at least one conversion unit 103 from the analog photocurrent signals detected by the first subset of the photodetectors 102 from the digital signals obtained by the at least one conversion unit 103 from the analog photocurrent signals detected by the second subset of photodetectors. The subtraction of the digital signals eliminates the frequency component of the motion artifacts in the digital differential signal, since all signals have the same frequency component of the motion

artifacts. The calculation unit 104 calculates the envelope of the digital differential signal, and calculates the heart rate from the peaks of the calculated envelope of the digital differential signal.

[80] In one embodiment shown in Fig. 9, in the device 100, the number of conversion units 103 is equal to the number of photodetectors 102. One conversion unit 103 is connected to one photodetector 102.

[81] In another embodiment shown in Fig. 10, device 100 comprises a first parallel connection scheme of the first subset of photodetectors 102, a second parallel connection scheme of the second subset of photodetectors 102, and two conversion units 103. One conversion unit 103 is connected to the first parallel connection scheme of the first subset of photodetectors 102, and the other conversion unit 103 is connected to the second parallel connection scheme of the second subset of photodetectors 102.

[82] Fig. 11 partially shows yet another embodiment of the device 100, in which the device 100 according to all of the above embodiments may further comprise the converging lens 105 in front of the light source 101 and each photodetector 102. The converging lenses 105 allow to get a stronger signal and increase the signal-to-noise ratio of the processed signals.

[83] The device 100 according to all of the above embodiments may be embedded into a wearable device for measuring heart rate such as a smart watch, a fitness bracelet, etc.

[84] The above descriptions of the embodiments are illustrative, and configuration modifications and implementations are within the scope of the present description. For example, although the embodiments of the disclosure have been described in general in connection with Figs. 6-13 the descriptions given are exemplary. Although the subject matter is described in a language characteristic of structural features or methodological operations, it is clear that the subject matter defined by the proposed claims is not necessarily limited by the specific features or operations described above. Moreover, the specific features and operations described above are disclosed as exemplary embodiments of the claims.

[85] Accordingly, it is assumed that the scope of the embodiments of the disclosure is limited only by the following claims.

Claims

- [Claim 1] A method for measuring heart rate by a device (100), comprising:
illuminating (S201) a body portion with light emitted from a light source;
detecting (S202) light scattered by tissues of the body portion and blood particles by a plurality of photodetectors comprising at least one pair of photodetectors which are connected in anti-parallel in each pair of photodetectors;
eliminating (S203) a frequency component of motion artifacts in an analog photocurrent differential signal by subtracting a first analog photocurrent signal detected by a first photodetector of a pair of photodetectors of the at least one pair of the photodetectors from a second analog photocurrent signal detected by a second photodetector of the pair of photodetectors;
converting (S204) the analog photocurrent differential signal into an analog voltage differential signal;
converting (S205) the analog voltage differential signal into a digital differential signal;
calculating (S206) an envelope of the digital differential signal; and
calculating (S207) the heart rate from peaks of the calculated envelope of the digital differential signal.
- [Claim 2] The method of claim 1,
wherein the at least one pair of photodetectors comprises at least two pairs of photodetectors connected in parallel to obtain a summed analog photocurrent differential signal,
wherein the method further comprises converting the summed analog photocurrent differential signal into a summed analog voltage differential signal, and converting the summed analog voltage differential signal into the digital differential signal.
- [Claim 3] The method of claim 1, wherein the light scattered by the tissues of the body portion and the blood particles is detected through a converging lens disposed in front of the light source and each photodetector.
- [Claim 4] A device (100) for measuring heart rate, comprising:
a light source (101) configured to illuminate a body portion with light;
a plurality of photodetectors (102) comprising at least one pair of photodetectors which are connected in anti-parallel in each pair of photodetectors and configured to:

detect light scattered by tissues of the body portion and blood particles ,
and

eliminate a frequency component of motion artifacts in an analog photocurrent differential signal by subtracting a first analog photocurrent signal detected by a first photodetector of a pair of photodetectors of the at least one pair of the photodetectors from a second analog photocurrent signal detected by a second photodetector of the pair of photodetectors;

a converter (103) configured to:

convert the analog photocurrent differential signal into an analog voltage differential signal, and

convert the analog voltage differential signal into a digital differential signal; and

a calculator (104) configured to:

calculate an envelope of the digital differential signal, and

calculate the heart rate from peaks of the calculated envelope of the digital differential signal.

[Claim 5]

The device of claim 4,

wherein the at least one pair of photodetectors comprises at least two pairs of photodetectors connected in parallel to obtain a summed analog photocurrent differential signal,

wherein the converter is configured to convert the summed analog photocurrent differential signal into a summed analog voltage differential signal, and to convert the summed analog voltage differential signal into the digital differential signal.

[Claim 6]

The device of claim 4, further comprising a converging lens in front of the light source and each photodetector.

[Claim 7]

A method for measuring heart rate by a device (100), comprising:

illuminating (S301) a body portion with coherent light emitted from a light source;

detecting (S302) light scattered by tissues of the body portion and blood particles by a plurality of photodetectors, comprising a first subset of photodetectors connected in one direction, and a second subset of photodetectors connected in a second direction opposite to the first direction;

converting (S303), by at least two converters, at least one first analog photocurrent signal detected by the first subset of photodetectors into at least one first analog voltage signal, and at least one second analog

photocurrent signal detected by the second subset of photodetectors into at least one second analog voltage signal;
converting (S304), by the at least two converters, the at least one first analog voltage signal into at least one first digital signal, and the at least one second analog voltage signal into at least one second digital signal;
eliminating (S305) a frequency component of motion artifacts in a digital differential signal by subtracting the at least one first digital signal from the at least one second digital signal;
calculating (S306) an envelope of the digital differential signal; and
calculating (S307) the heart rate from peaks of the calculated envelope of the digital differential signal.

[Claim 8] The method of claim 7,
wherein the first subset of photodetectors are connected in parallel, and the second subset of photodetectors are connected in parallel, and wherein the at least one first analog photocurrent signal detected by the first subset of photodetectors are converted into the at least one first analog voltage signal using only a first converter of the at least two converters, and the at least one second analog photocurrent signal detected by the second subset of photodetectors are converted into the at least one second analog voltage signal using only a second converter of the at least two converters.

[Claim 9] The method of claim 7,
wherein the at least two converters comprises a plurality of converters having a number same as a number of the plurality of photodetectors; wherein an analog photocurrent signal detected by each of the plurality of photodetectors is converted into an analog voltage signal using respective converter of converters.

[Claim 10] The method of claim 7, wherein the light scattered by the tissues of the body portion and the blood particles is detected through a converging lens in front of the light source and each photodetector.

[Claim 11] A device (100) for measuring heart rate, comprising:
a light source (101) configured to illuminate a body portion with coherent light;
a plurality of photodetectors (102) comprising a first subset of photodetectors connected in one direction, and a second subset of photodetectors connected in a second direction opposite to the first direction, wherein the plurality of photodetectors is configured to detect

light scattered by tissues of the body portion and blood particles;
at least two converters (103) comprising
at least one first converter connected to the first subset of photodetectors, configured to convert at least one first analog photocurrent signal detected by the first subset of photodetectors into at least one first analog voltage signal, and convert the at least one first analog voltage signal into at least one first digital signal, and
at least one second converter connected to the second subset of photodetectors, configured to convert at least one second analog photocurrent signal detected by the second subset of photodetectors into at least one second analog voltage signal, and convert the at least one second analog voltage signal into at least one second digital signal;
a calculator (104) configured to:
eliminate a frequency component of motion artifacts in a digital differential signal by subtracting the at least one first digital signal from the at least one second digital signal,
calculate an envelope of the digital differential signal, and
calculate the heart rate from peaks of the calculated envelope of the digital differential signal.

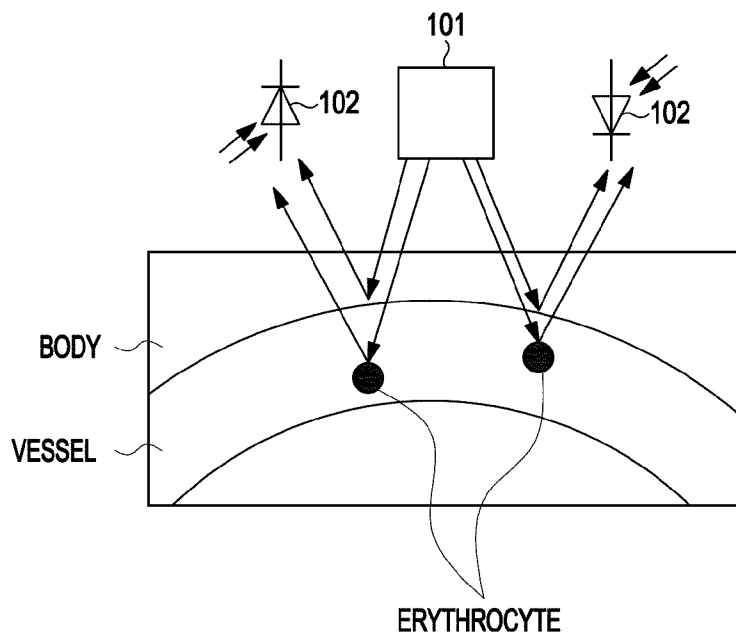
[Claim 12] The device of claim 11,
wherein the first subset of photodetectors are connected in parallel, and
the second subset of photodetectors are connected in parallel, and
wherein the at least one first converter comprises only one first converter connected to the first subset of photodetectors, and the at least one second converter comprises only one second converter connected to the second subset of photodetectors.

[Claim 13] The device of claim 11,
wherein the at least two converters comprises a plurality of converters each connected to a photodetector of the plurality of photodetectors.

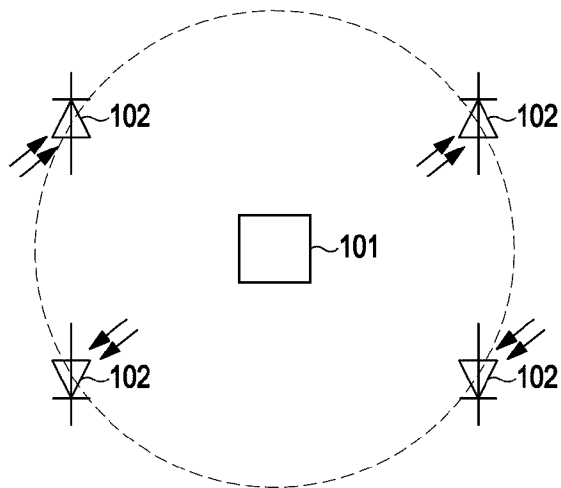
[Claim 14] The device of claims 11, further comprising a converging lens in front of the light source and each photodetector.

[Claim 15] The method of claim 1, the device of claim 4, the method of claim 7, or the device of claim 11, wherein distance between the light source and each of the plurality of photodetectors is the same, and at least one parameter of each of the plurality of photodetectors is the same.

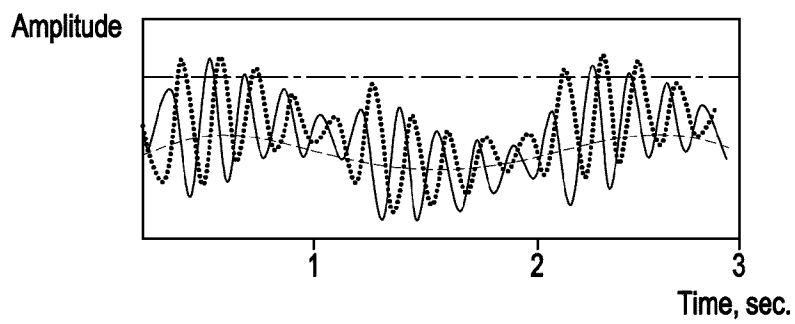
[Fig. 1]



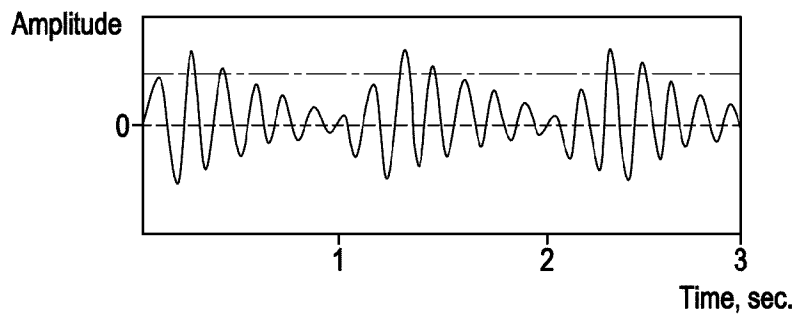
[Fig. 2]



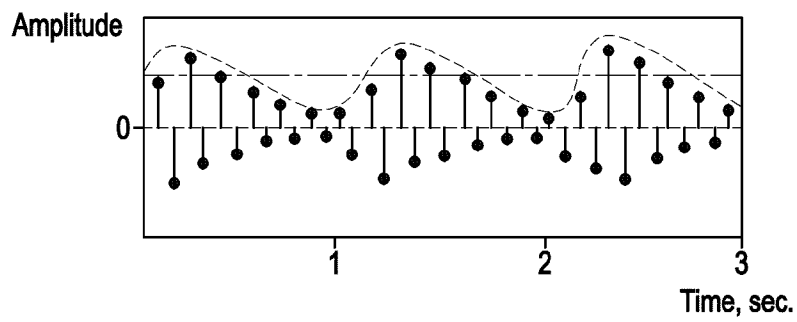
[Fig. 3]



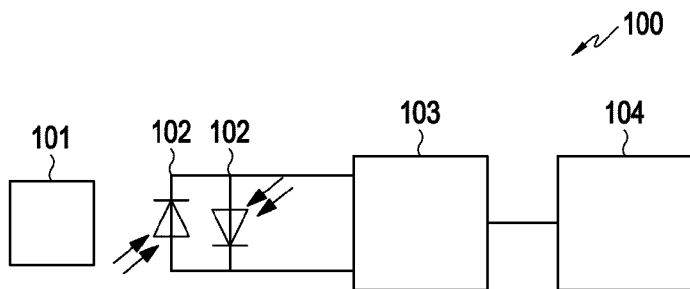
[Fig. 4]



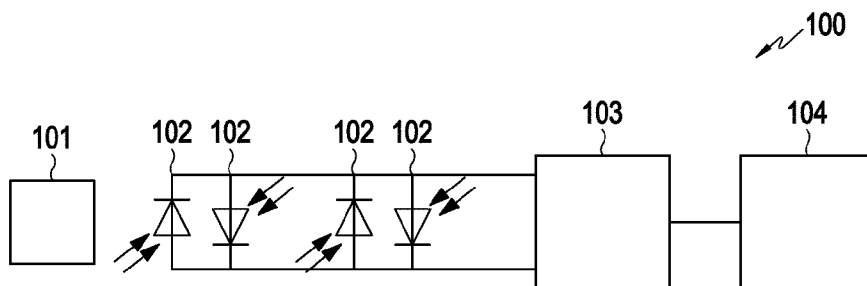
[Fig. 5]



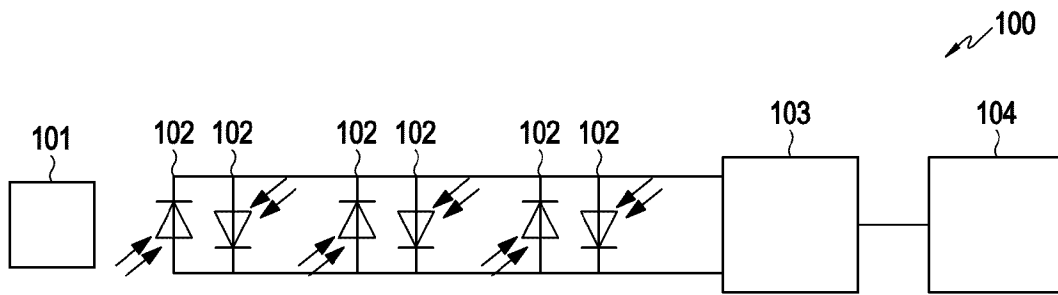
[Fig. 6]



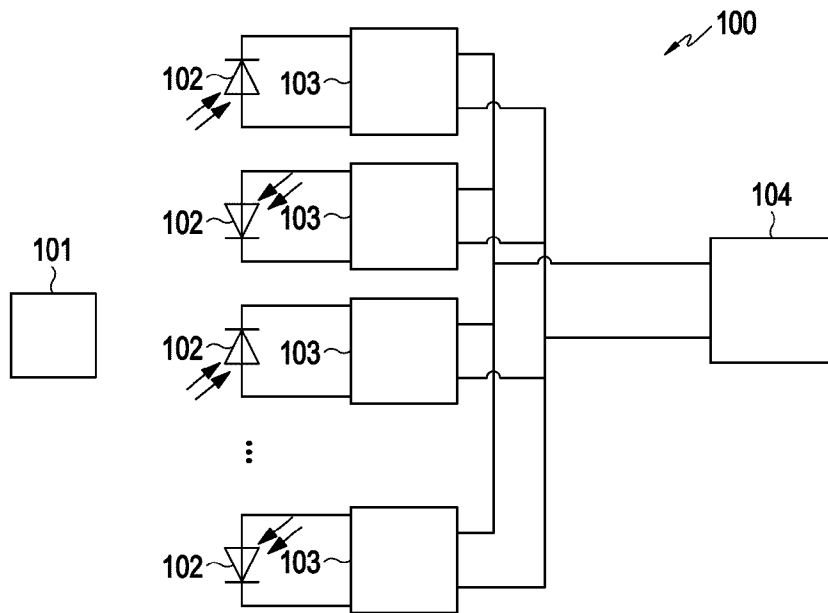
[Fig. 7]



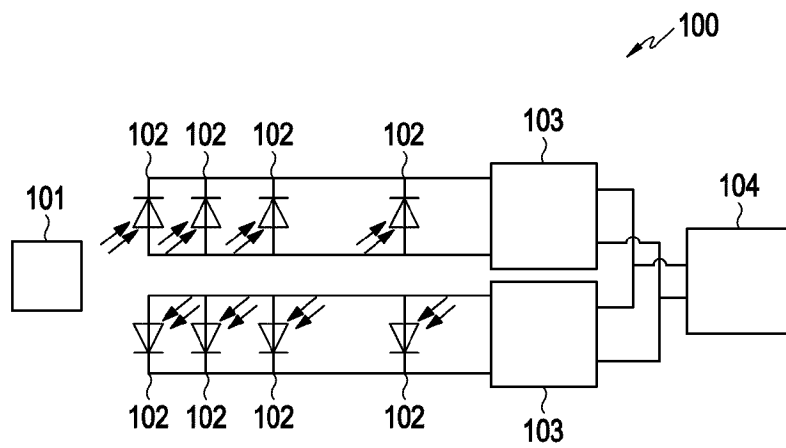
[Fig. 8]



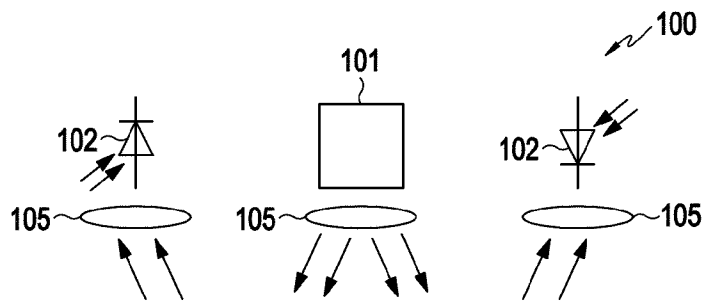
[Fig. 9]



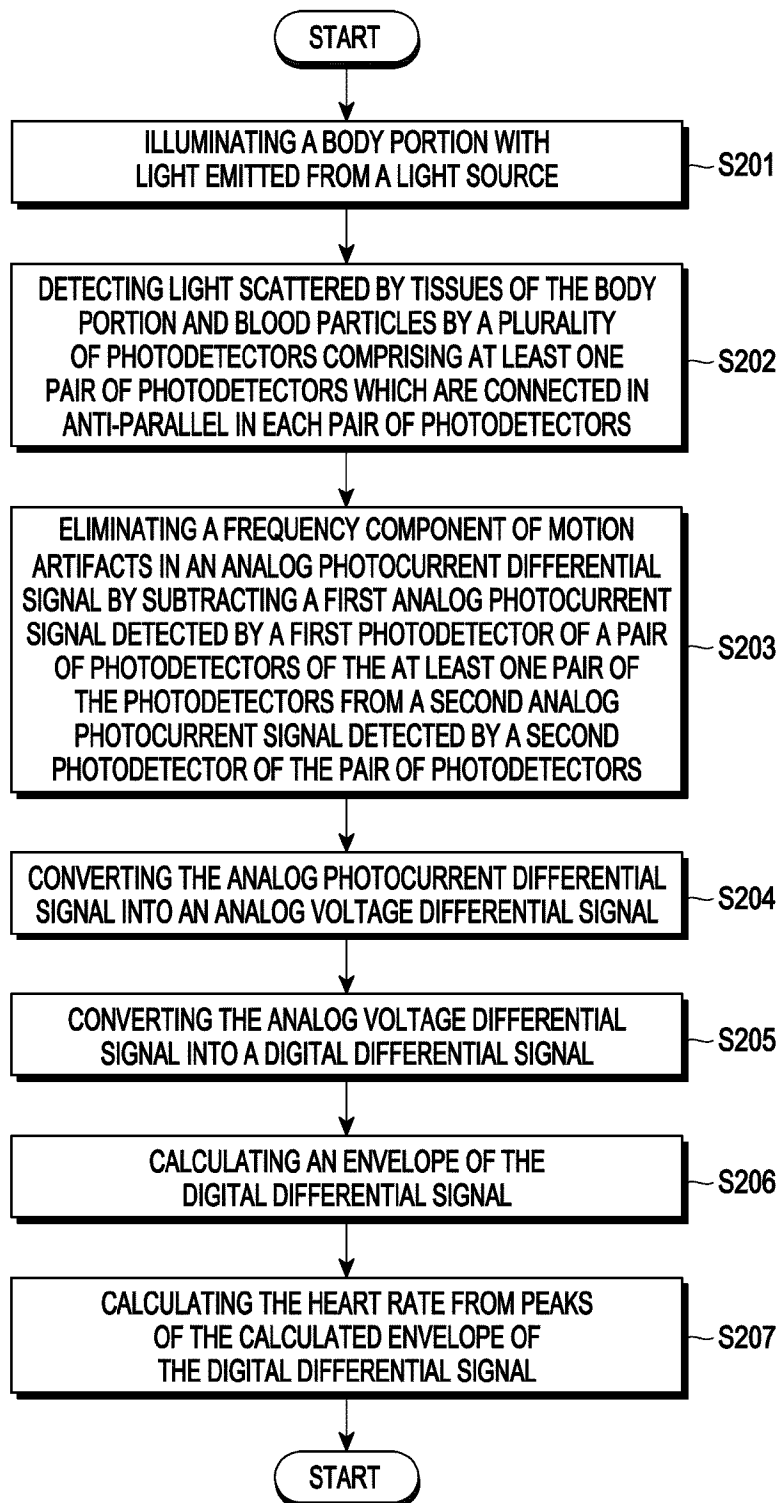
[Fig. 10]



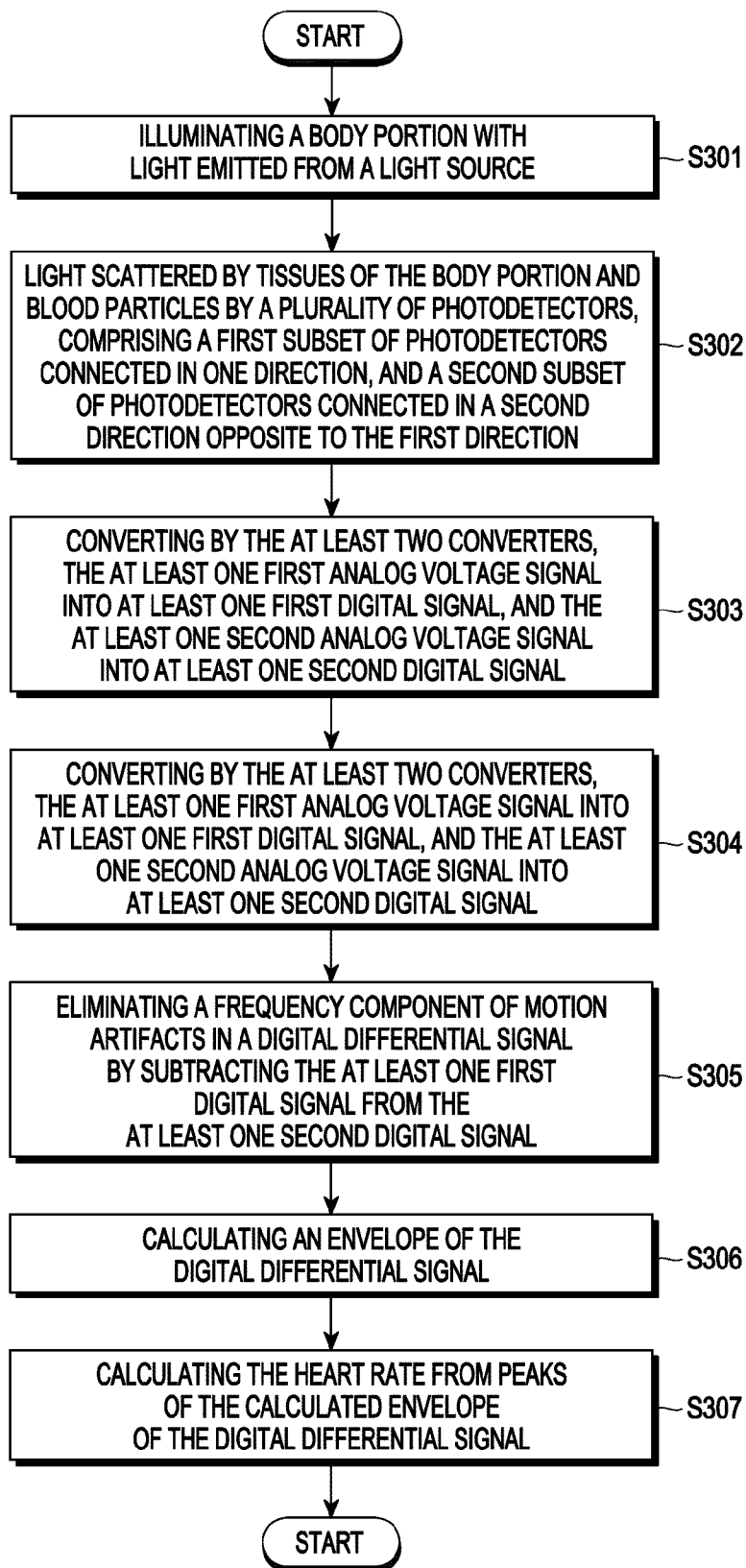
[Fig. 11]



[Fig. 12]



[Fig. 13]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2022/013902

A. CLASSIFICATION OF SUBJECT MATTER A61B 5/024(2006.01)i; A61B 5/00(2006.01)i According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) A61B 5/024(2006.01); A61B 5/00(2006.01); A61B 5/02(2006.01); A61B 5/0472(2006.01); G06K 9/00(2006.01); H01L 31/02(2006.01); H01L 31/107(2006.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models Japanese utility models and applications for utility models Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: heart, rate, light, photodetector, array, motion, artifact, envelop, peak		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 2018-0098708 A1 (LG INNOTEK CO., LTD.) 12 April 2018 (2018-04-12) whole document	1-15
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 30 December 2022		Date of mailing of the international search report 02 January 2023
Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon 35208, Republic of Korea Facsimile No. +82-42-481-8578		Authorized officer KIM, Yeon Kyung Telephone No. +82-42-481-3325

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Information on patent family members

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