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Addison et al.

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(45) **Date of Patent: Sep. 2, 2014**

(54) **METHODS AND SYSTEMS FOR RECALIBRATING A BLOOD PRESSURE MONITOR WITH MEMORY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 435 days.

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(51) **Int. Cl.**
G01L 27/00 (2006.01)

(52) **U.S. Cl.**
USPC **702/98**

(58) **Field of Classification Search**
None
See application file for complete search history.

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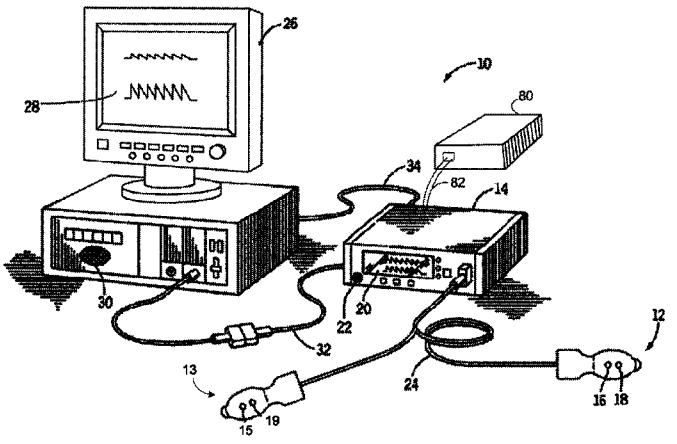
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(57) **ABSTRACT**

Systems and methods are provided for storing and recalling metrics associated with physiological signals. It may be determined that the value of a monitored physiological metric corresponds to a stored value. In such cases, a patient monitor may determine that a calibration is not desired. In some cases, a patient monitor may recall calibration parameters associated with the stored value if it determined that the stored value corresponds to the monitored metric value.

20 Claims, 7 Drawing Sheets



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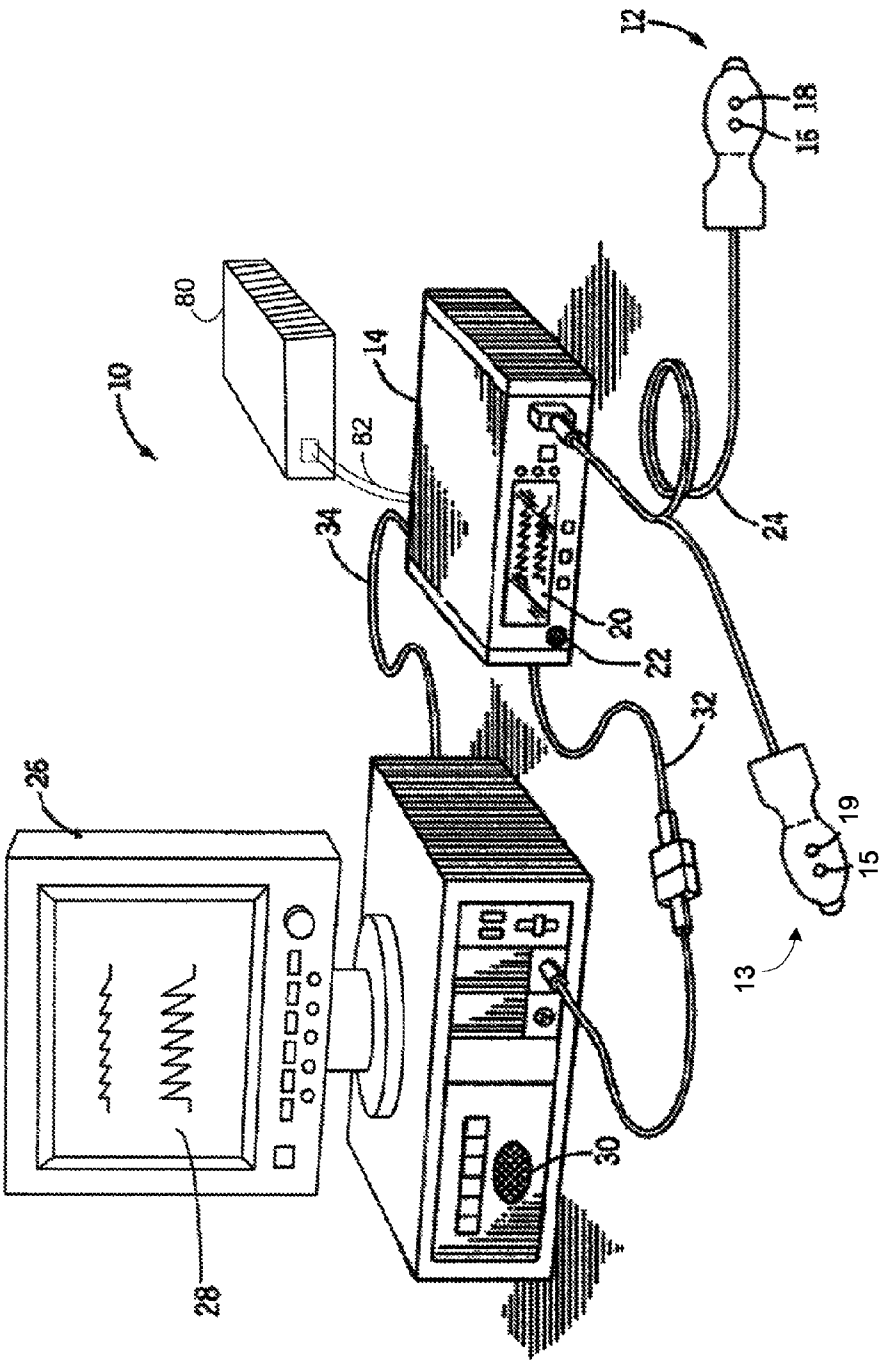


FIG. 1

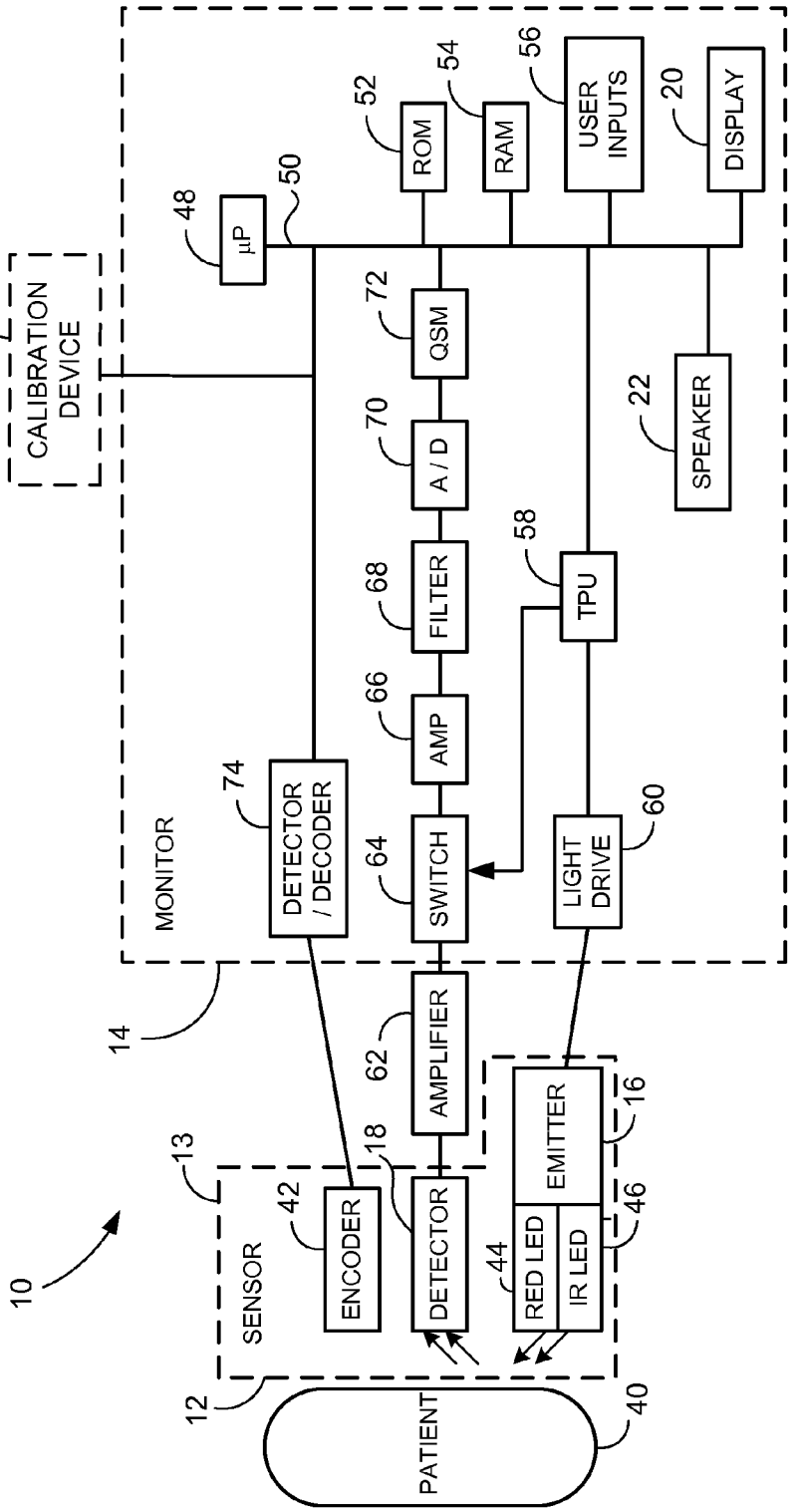

10
12
SENSOR
13
ENCODER
42
DETECTOR
18
RED LED
IR LED
44
EMITTER
16
46
PATIENT
40
14
MONITOR
AMPLIFIER
62
SWITCH
64
AMP
66
FILTER
68
A / D
70
QSM
72
DETECTOR / DECODER
74
LIGHT DRIVE
60
TPU
58
µP
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ROM
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RAM
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USER INPUTS
56
DISPLAY
20
SPEAKER
22
CALIBRATION DEVICE
80

FIG. 2

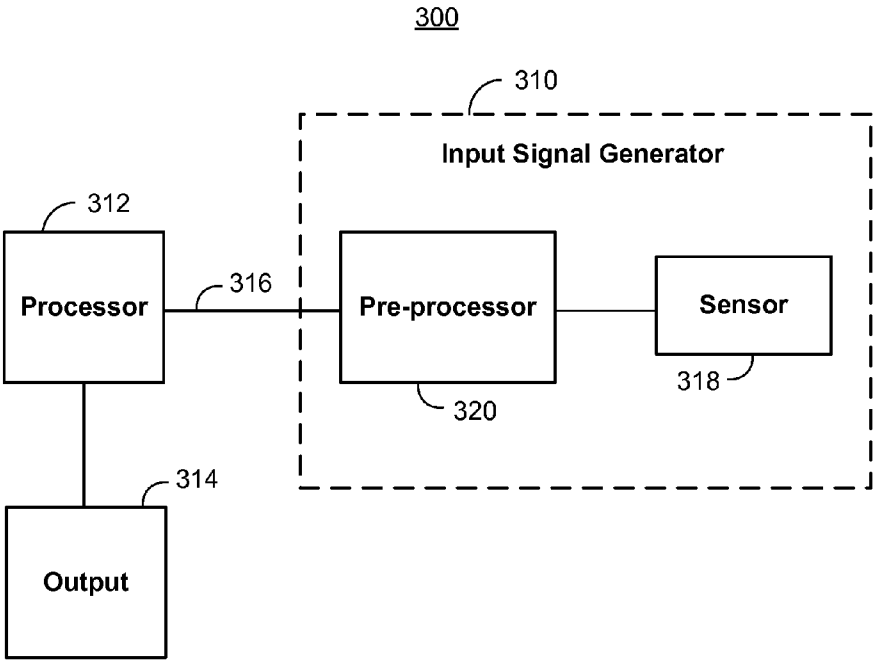

300
310
Input Signal Generator
312
Processor
316
Pre-processor
Sensor
318
320
314
Output

FIG. 3

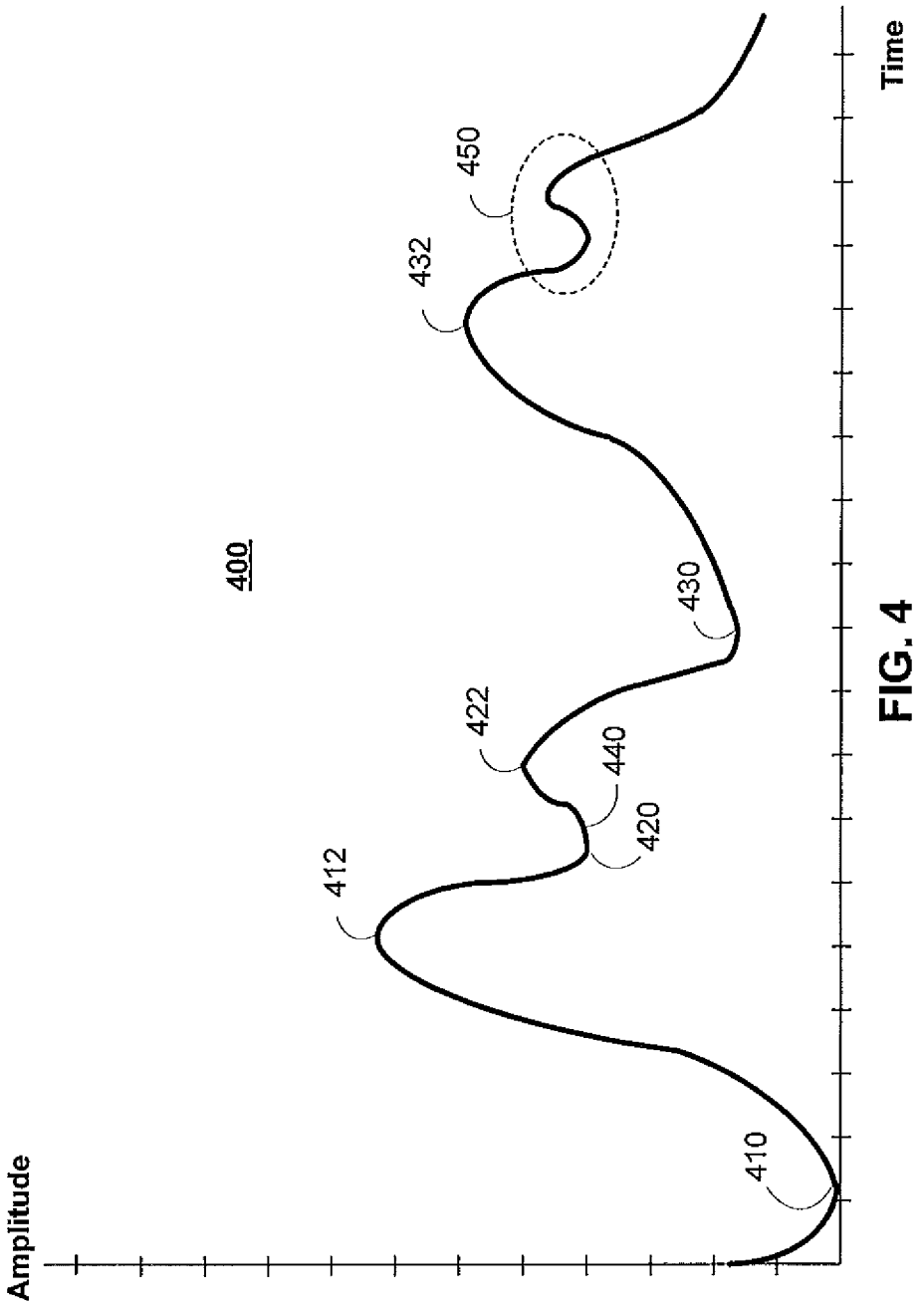


FIG. 4

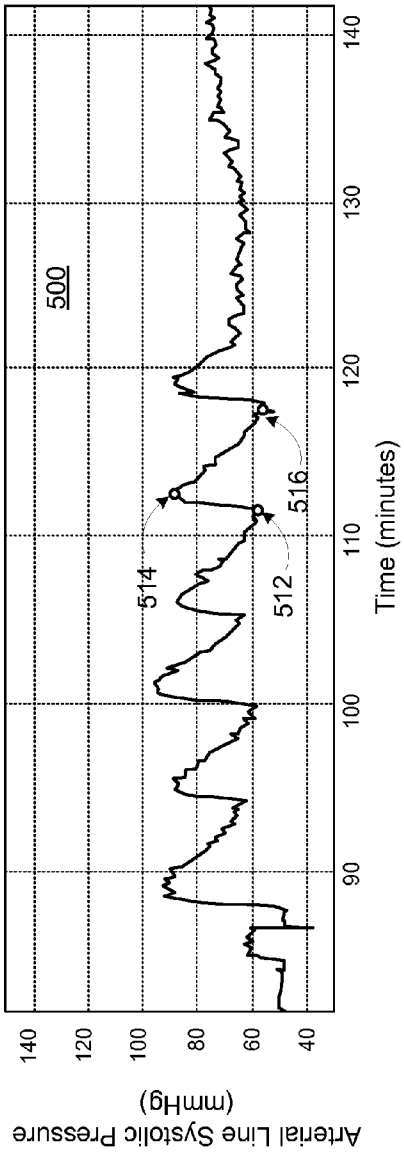


FIG. 5(a)

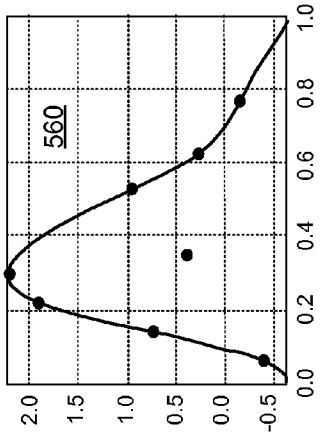


FIG. 5(d)

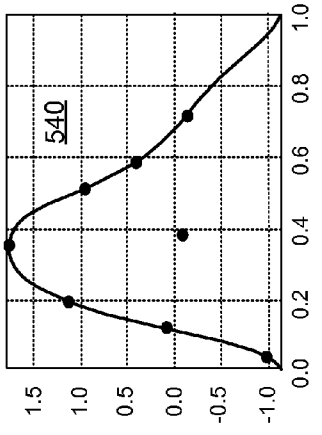


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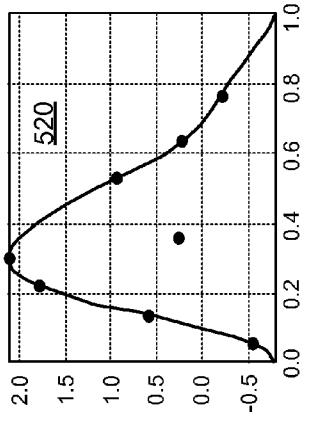


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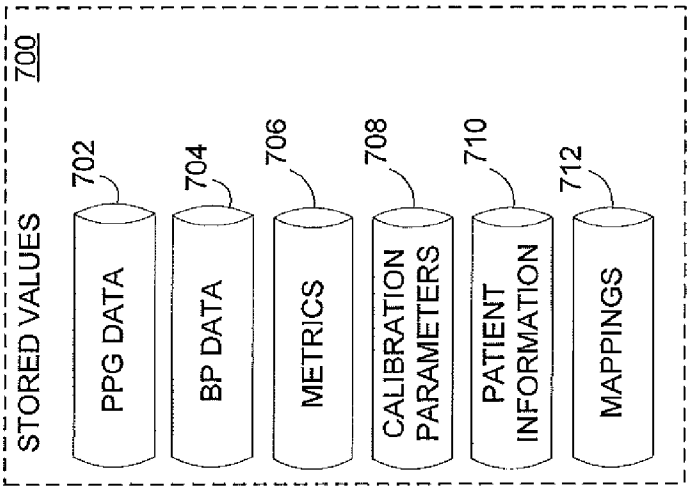

STORED VALUES
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BP DATA
704
METRICS
706
CALIBRATION PARAMETERS
708
PATIENT INFORMATION
710
MAPPINGS
712

FIG. 7

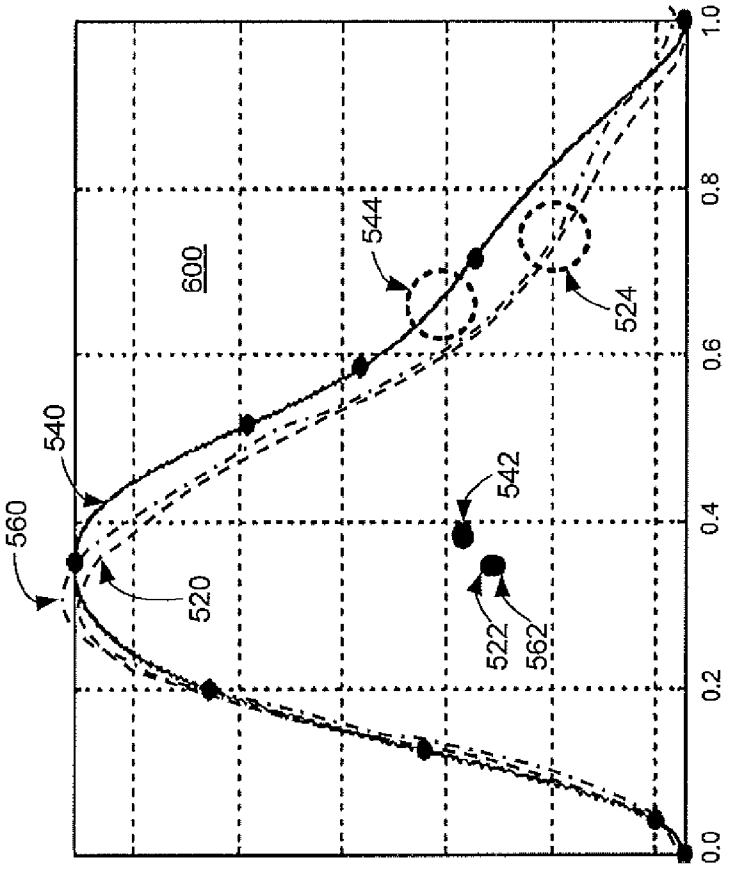

600
540
560
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542
522
562
524
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0.4
0.6
0.8
1.0

FIG. 6

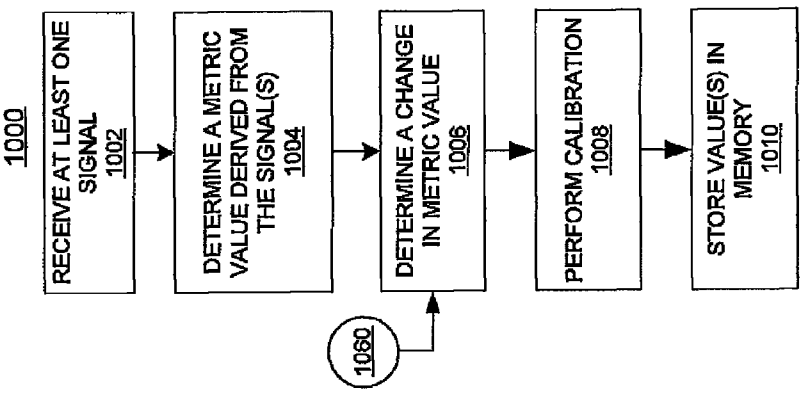


FIG. 10

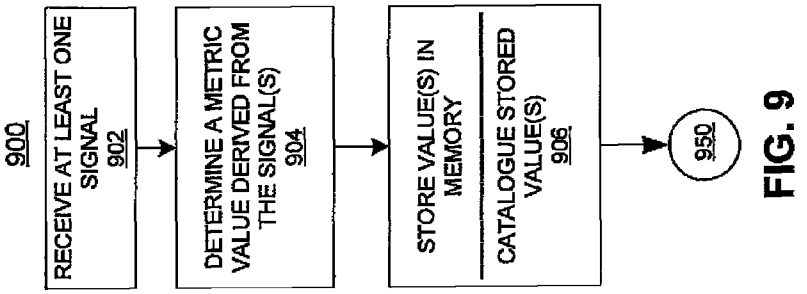


FIG. 9

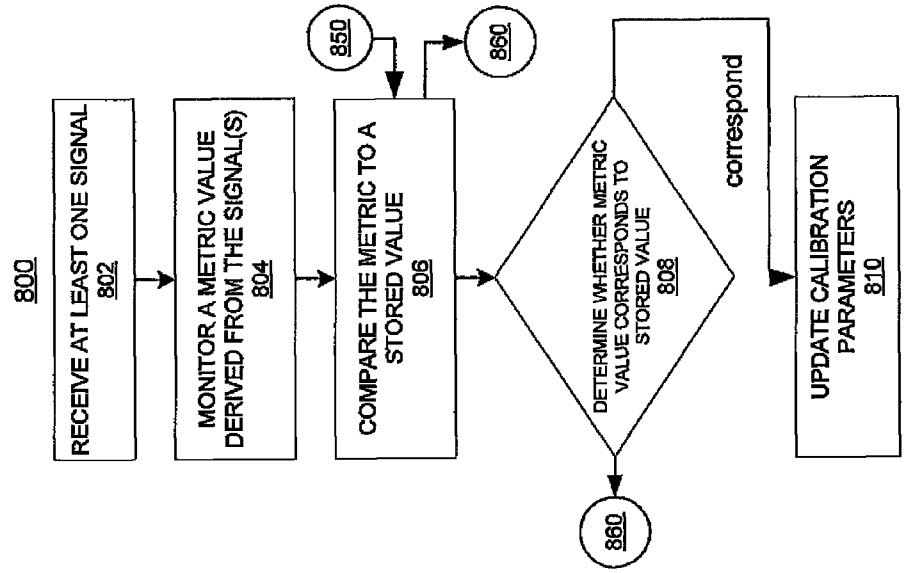


FIG. 8

METHODS AND SYSTEMS FOR RECALIBRATING A BLOOD PRESSURE MONITOR WITH MEMORY

SUMMARY

Continuous non-invasive blood pressure (CNIBP) monitoring systems allow a patient's blood pressure to be tracked continuously, unlike standard occlusion cuff techniques, and without the hazards of invasive arterial lines. In some embodiments, multiple pulse oximetry type sensors may be placed at multiple body sites on a patient to measure photoplethysmograph (PPG) signals. The resulting multiple PPG signals may be compared against each other to estimate the patient's blood pressure. When the locations of two sensors are at different distances from the heart or along different paths from the heart (e.g., at the finger and forehead), a differential pulse transit time (DPTT) may be determined. A DPTT may represent the difference in the arrival times of a portion of a cardiac wave between the two locations, and may be determined by comparing corresponding fiducial points in the two PPG signals (e.g., a maximum, minimum, or a notch). In some techniques, two DPTTs are determined in order to calculate multiple physiological parameters, such as systolic and diastolic blood pressure. These DPTTs may be determined during different phases of the PPG signal representing different physiological occurrences. For example, one DPTT may be determined when the cardiovascular system is in a systolic state and a second DPTT may be determined when the cardiovascular system is in a diastolic state.

During physiological monitoring of a patient with a patient monitoring system, recalibration of the patient monitoring system may be desired. For example, a CNIBP system may be periodically calibrated with a NIBP system. It may be desirous in some instances to reduce the number of calibrations that are performed. For example, an inflatable cuff type NIBP system may be used to calibrate a PPG-based CNIBP system, and a reduction in the number of cuff inflations may be desirous. In some circumstances, performing a calibration is likely to result in calibration parameters similar to those of a previous calibration.

Systems and methods are provided herein for calibrating a patient monitoring system with stored calibration parameters. Calibration parameters may be stored in a suitable memory device, and recalled during suitable calibration conditions. Values of one or more metrics associated with one or more physiological signals (e.g., PPG signals) may be monitored by a patient monitoring system and compared with stored metric values. If it is determined by the patient monitoring system that the value of the monitored metric corresponds to a stored metric value, the patient monitoring system may recall calibration parameters associated with the stored value.

In some embodiments, for example, metrics may be stored in any suitable database. Calibration parameters associated with the stored metrics may also be stored in any suitable database (e.g., the same database where the metrics are stored). Metrics may include signal morphology parameters such as, for example, pulse wave area, pulse wave skew, derivatives of a signal, heart rate, length of a pulse upstroke, any other suitable metric or any combination thereof. Metrics derived from a physiological signal may change due to, for example, effects of vasoactive drugs, patient movement, or other factors which may change arterial compliance.

In some embodiments, a patient monitoring system may monitor one or more metrics derived from a physiological signal. One or more metrics of the physiological signal may change over time due to any suitable cause or combination of causes. In some circumstances, following the temporal change in the one or more metrics, the values of the one or more metrics may return to or about their past values as computed prior to the change. The patient monitoring system may then recall stored calibration parameters associated with the past values rather than performing an actual recalibration. For example, a CNIBP device calibrated with initial calibration parameters may be used to monitor a physiological metric associated with a patient. At a particular time, a vasoactive drug may be administered, and the value of the metric may change. At a particular time after the drug was administered, the value of the metric may return to the metric's value prior to the drug administration. The patient monitoring system may, in response to the return of the metric's value, revert to the stored initial calibration parameters rather than initiating a new NIBP (e.g., cuff device) calibration to determine new calibration parameters.

The methods and systems of the present disclosure will be illustrated with reference to the monitoring of a physiological signal (which may be a PPG signal). However, it will be understood that the disclosure is not limited to monitoring physiological signals and is usefully applied within a number of signal monitoring settings.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features of the present disclosure, its nature and various advantages will be more apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings in which:

FIG. **1** shows an illustrative patient monitoring system in accordance with an embodiment;

FIG. **2** shows a block diagram of the illustrative patient monitoring system of FIG. **1** coupled to a patient in accordance with an embodiment;

FIG. **3** shows a block diagram of an illustrative signal processing system in accordance with an embodiment;

FIG. **4** shows an illustrative signal which may be analyzed in accordance with an embodiment;

FIG. **5**(*a*) shows an illustrative time series of a blood pressure measurement in accordance with an embodiment;

FIG. **5**(*b*) shows an illustrative portion of a PPG signal corresponding to some data of FIG. **5**(*a*) in accordance with an embodiment;

FIG. **5**(*c*) shows an illustrative portion of a PPG signal corresponding to some data of FIG. **5**(*a*) in accordance with an embodiment;

FIG. **5**(*d*) shows an illustrative portion of a PPG signal corresponding to some data of FIG. **5**(*a*) in accordance with an embodiment;

FIG. **6** shows a superposition of illustrative PPG signals of FIGS. **5**(*b*)-**5**(*d*) in accordance with an embodiment;

FIG. **7** is a block diagram of an illustrative database in accordance with an embodiment;

FIG. **8** is a flow diagram of illustrative steps for updating monitoring system calibration parameters in accordance with an embodiment;

FIG. **9** is a flow diagram of illustrative steps for storing physiological signals and metrics in accordance with an embodiment; and

FIG. **10** is a flow diagram of illustrative steps for storing physiological signals and metrics associated with a calibration in accordance with an embodiment.

DETAILED DESCRIPTION

An oximeter is a medical device that may determine the oxygen saturation of the blood. One common type of oxime-

ter is a pulse oximeter, which may indirectly measure the oxygen saturation of a patient's blood (as opposed to measuring oxygen saturation directly by analyzing a blood sample taken from the patient). Pulse oximeters may be included in patient monitoring systems that measure and display various blood flow characteristics including, but not limited to, the oxygen saturation of hemoglobin in arterial blood. Such patient monitoring systems may also measure and display additional physiological parameters, such as a patient's pulse rate and blood pressure.

An oximeter may include a light sensor that is placed at a site on a patient, typically a fingertip, toe, forehead or earlobe, or in the case of a neonate, across a foot. The oximeter may use a light source to pass light through blood perfused tissue and photoelectrically sense the absorption of the light in the tissue. In addition, locations which are not typically understood to be optimal for pulse oximetry serve as suitable sensor locations for the blood pressure monitoring processes described herein, including any location on the body that has a strong pulsatile arterial flow. For example, additional suitable sensor locations include, without limitation, the neck to monitor carotid artery pulsatile flow, the wrist to monitor radial artery pulsatile flow, the inside of a patient's thigh to monitor femoral artery pulsatile flow, the ankle to monitor tibial artery pulsatile flow, and around or in front of the ear. Suitable sensors for these locations may include sensors for sensing absorbed light based on detecting reflected light. In all suitable locations, for example, the oximeter may measure the intensity of light that is received at the light sensor as a function of time. The oximeter may also include sensors at multiple locations. A signal representing light intensity versus time or a mathematical manipulation of this signal (e.g., a scaled version thereof, a log taken thereof, a scaled version of a log taken thereof, etc.) may be referred to as the photoplethysmograph (PPG) signal. In addition, the term "PPG signal," as used herein, may also refer to an absorption signal (i.e., representing the amount of light absorbed by the tissue) or any suitable mathematical manipulation thereof. The light intensity or the amount of light absorbed may then be used to calculate any of a number of physiological parameters, including an amount of a blood constituent (e.g., oxyhemoglobin) being measured as well as a pulse rate and when each individual pulse occurs.

In some applications, the light passed through the tissue is selected to be of one or more wavelengths that are absorbed by the blood in an amount representative of the amount of the blood constituent present in the blood. The amount of light passed through the tissue varies in accordance with the changing amount of blood constituent in the tissue and the related light absorption. Red and infrared (IR) wavelengths may be used because it has been observed that highly oxygenated blood will absorb relatively less Red light and more IR light than blood with a lower oxygen saturation. By comparing the intensities of two wavelengths at different points in the pulse cycle, it is possible to estimate the blood oxygen saturation of hemoglobin in arterial blood.

When the measured blood parameter is the oxygen saturation of hemoglobin, a convenient starting point assumes a saturation calculation based at least in part on Lambert-Beer's law. The following notation will be used herein:

$$I(\lambda,t)=I_O(\lambda)\exp(-(s\beta_O(\lambda)+(1-s)\beta_r(\lambda))l(t)) \quad (1)$$

where:

λ=wavelength;

t=time;

I=intensity of light detected;

I_0=intensity of light transmitted;

s=oxygen saturation;

β_0, β_r=empirically derived absorption coefficients; and

l(t)=a combination of concentration and path length from emitter to detector as a function of time.

The traditional approach measures light absorption at two wavelengths (e.g., Red and IR), and then calculates saturation by solving for the "ratio of ratios" as follows.

1. The natural logarithm of Eq. 1 is taken ("log" will be used to represent the natural logarithm) for IR and Red to yield

$$\log I=\log I_O-(s\beta_O+(1-s)\beta_r)l. \quad (2)$$

2. Eq. 2 is then differentiated with respect to time to yield

$$\frac{d\log I}{dt}=-(s\beta_o+(1-s)\beta_r)\frac{dl}{dt}. \quad (3)$$

3. Eq. 3, evaluated at the Red wavelength λ_R, is divided by Eq. 3 evaluated at the IR wavelength λ_{IR} in accordance with

$$\frac{d\log I(\lambda_R)/dt}{d\log I(\lambda_{IR})/dt}=\frac{s\beta_o(\lambda_R)+(1-s)\beta_r(\lambda_R)}{s\beta_o(\lambda_{IR})+(1-s)\beta_r(\lambda_{IR})}. \quad (4)$$

4. Solving for s yields

$$s=\frac{\frac{d\log I(\lambda_{IR})}{dt}\beta_r(\lambda_R)-\frac{d\log I(\lambda_R)}{dt}\beta_r(\lambda_{IR})}{\frac{d\log I(\lambda_R)}{dt}(\beta_o(\lambda_{IR})-\beta_r(\lambda_{IR}))-\frac{d\log I(\lambda_{IR})}{dt}(\beta_o(\lambda_R)-\beta_r(\lambda_R))}. \quad (5)$$

5. Note that, in discrete time, the following approximation can be made:

$$\frac{d\log I(\lambda,t)}{dt}\simeq\log I(\lambda,t_2)-\log I(\lambda,t_1). \quad (6)$$

6. Rewriting Eq. 6 by observing that log A−log B=log(A/B) yields

$$\frac{d\log I(\lambda,t)}{dt}\simeq\log\left(\frac{I(t_2,\lambda)}{I(t_1,\lambda)}\right). \quad (7)$$

7. Thus, Eq. 4 can be expressed as

$$\frac{\frac{d\log I(\lambda_R)}{dt}}{\frac{d\log I(\lambda_{IR})}{dt}}\simeq\frac{\log\left(\frac{I(t_1,\lambda_R)}{I(t_2,\lambda_R)}\right)}{\log\left(\frac{I(t_1,\lambda_{IR})}{I(t_2,\lambda_{IR})}\right)}=R, \quad (8)$$

where R represents the "ratio of ratios."

8. Solving Eq. 4 for s using the relationship of Eq. 5 yields

$$s=\frac{\beta_r(\lambda_R)-R\beta_r(\lambda_{IR})}{R(\beta_o(\lambda_{IR})-\beta_r(\lambda_{IR}))-\beta_o(\lambda_R)+\beta_r(\lambda_R)}. \quad (9)$$

9. From Eq. 8, R can be calculated using two points (e.g., PPG maximum and minimum), or a family of points. One method applies a family of points to a modified version of Eq. 8. Using the relationship

$$\frac{d\log I}{dt} = \frac{\frac{dI}{dt}}{I}, \tag{10}$$

Eq. 8 becomes

$$\frac{\frac{d\log I(\lambda_R)}{dt}}{\frac{d\log I(\lambda_{IR})}{dt}} \simeq \frac{\frac{I(t_2,\lambda_R)-I(t_1,\lambda_R)}{I(t_1,\lambda_R)}}{\frac{I(t_2,\lambda_{IR})-I(t_1,\lambda_{IR})}{I(t_1,\lambda_{IR})}} = \frac{[I(t_2,\lambda_R)-I(t_1,\lambda_R)]I(t_1,\lambda_{IR})}{[I(t_2,\lambda_{IR})-I(t_1,\lambda_{IR})]I(t_1,\lambda_R)} = R, \tag{11}$$

which defines a cluster of points whose slope of y versus x will give R when

$$x=[I(t_2,\lambda_{IR})-I(t_1,\lambda_{IR})]I(t_1,\lambda_R) \tag{12}$$

and

$$y=[I(t_2,\lambda_R)-I(t_1,\lambda_R)]I(t_1,\lambda_{IR}). \tag{13}$$

Once R is determined or estimated, for example, using the techniques described above, the blood oxygen saturation can be determined or estimated using any suitable technique for relating a blood oxygen saturation value to R. For example, blood oxygen saturation can be determined from empirical data that may be indexed by values of R, and/or it may be determined from curve fitting and/or other interpolative techniques.

FIG. **1** is a perspective view of an embodiment of a patient monitoring system **10**. System **10** may include sensor unit **12** and monitor **14**. In an embodiment, sensor unit **12** may be part of a continuous, non-invasive blood pressure (CNIBP) monitoring system and/or an oximeter. Sensor unit **12** may include an emitter **16** for emitting light at one or more wavelengths into a patient's tissue. A detector **18** may also be provided in sensor **12** for detecting the light originally from emitter **16** that emanates from the patient's tissue after passing through the tissue. Any suitable physical configuration of emitter **16** and detector **18** may be used. In an embodiment, sensor unit **12** may include multiple emitters and/or detectors, which may be spaced apart. System **10** may also include one or more additional sensor units, such as sensor unit **13**, which may take the form of any of the embodiments described herein with reference to sensor unit **12**. For example, sensor unit **13** may include emitter **15** and detector **19**. Sensor unit **13** may be the same type of sensor unit as sensor unit **12**, or sensor unit **13** may be of a different sensor unit type than sensor unit **12**. Sensor units **12** and **13** may be capable of being positioned at two different locations on a subject's body; for example, sensor unit **12** may be positioned on a patient's forehead, while sensor unit **13** may be positioned at a patient's fingertip.

Sensor units **12** and **13** may each detect any signal that carries information about a patient's physiological state, such as an electrocardiograph signal, arterial line measurements, or the pulsatile force exerted on the walls of an artery using, for example, oscillometric methods with a piezoelectric transducer. According to another embodiment, system **10** may include a plurality of sensors forming a sensor array in lieu of either or both of sensor units **12** and **13**. Each of the sensors of a sensor array may be a complementary metal oxide semiconductor (CMOS) sensor. Alternatively, each sensor of an array may be charged coupled device (CCD) sensor. In an embodiment, a sensor array may be made up of a combination of CMOS and CCD sensors. The CCD sensor may comprise a photoactive region and a transmission region for receiving and transmitting data whereas the CMOS sensor may be made up of an integrated circuit having an array of pixel sensors. Each pixel may have a photodetector and an active amplifier. It will be understood that any type of sensor, including any type of physiological sensor, may be used in one or more of sensor units **12** and **13** in accordance with the systems and techniques disclosed herein. It is understood that any number of sensors measuring any number of physiological signals may be used to determine physiological information in accordance with the techniques described herein.

According to an embodiment, emitter **16** and detector **18** may be on opposite sides of a digit such as a finger or toe, in which case the light that is emanating from the tissue has passed completely through the digit. In an embodiment, emitter **16** and detector **18** may be arranged so that light from emitter **16** penetrates the tissue and is reflected by the tissue into detector **18**, such as in a sensor designed to obtain pulse oximetry data from a patient's forehead.

In an embodiment, sensor unit **12** may be connected to and draw its power from monitor **14** as shown. In another embodiment, the sensor may be wirelessly connected to monitor **14** and include its own battery or similar power supply (not shown). Monitor **14** may be configured to calculate physiological parameters (e.g., heart rate, blood pressure, blood oxygen saturation) based at least in part on data relating to light emission and detection received from one or more sensor units such as sensor units **12** and **13**. In an alternative embodiment, the calculations may be performed on the sensor units or an intermediate device and the result of the calculations may be passed to monitor **14**. Further, monitor **14** may include a display **20** configured to display the physiological parameters or other information about the system. In the embodiment shown, monitor **14** may also include a speaker **22** to provide an audible sound that may be used in various other embodiments, such as for example, sounding an audible alarm in the event that a patient's physiological parameters are not within a predefined normal range. In an embodiment, the monitor **14** includes a blood pressure monitor. In alternative embodiments, the system **10** includes a stand-alone blood pressure monitor in communication with the monitor **14** via a cable or a wireless network link.

In an embodiment, sensor unit **12** may be communicatively coupled to monitor **14** via a cable **24**. However, in other embodiments, a wireless transmission device (not shown) or the like may be used instead of or in addition to cable **24**.

In the illustrated embodiment, system **10** includes a multi-parameter patient monitor **26**. The monitor **26** may include a cathode ray tube display, a flat panel display (as shown) such as a liquid crystal display (LCD) or a plasma display, or may include any other type of monitor now known or later developed. Multi-parameter patient monitor **26** may be configured to calculate physiological parameters and to provide a display **28** for information from monitor **14** and from other medical monitoring devices or systems (not shown). For example, multi-parameter patient monitor **26** may be configured to display an estimate of a patient's blood oxygen saturation generated by monitor **14** (referred to as an "SpO_2" measurement), pulse rate information from monitor **14** and blood pressure from monitor **14** on display **28**. Multi-parameter patient monitor **26** may include a speaker **30**.

Monitor **14** may be communicatively coupled to multi-parameter patient monitor **26** via a cable **32** or **34** that is coupled to a sensor input port or a digital communications port, respectively and/or may communicate wirelessly (not shown). In addition, monitor **14** and/or multi-parameter patient monitor **26** may be coupled to a network to enable the sharing of information with servers or other workstations (not shown). Monitor **14** may be powered by a battery (not shown) or by a conventional power source such as a wall outlet.

Calibration device **80**, which may be powered by monitor **14** via a cable **82**, a battery, or by a conventional power source such as a wall outlet, may include any suitable signal calibration device. Calibration device **80** may be communicatively coupled to monitor **14** via cable **82**, and/or may communicate wirelessly (not shown). In other embodiments, calibration device **80** is completely integrated within monitor **14**. For example, calibration device **80** may take the form of any invasive or non-invasive blood pressure monitoring or measuring system used to generate reference blood pressure measurements for use in calibrating a CNIBP monitoring technique as described herein. Such calibration devices may include, for example, an aneroid or mercury sphygmomanometer and occluding cuff, a pressure sensor inserted directly into a suitable artery of a patient, an oscillometric device or any other device or mechanism used to sense, measure, determine, or derive a reference blood pressure measurement. In some embodiments, calibration device **80** may include a manual input device (not shown) used by an operator to manually input reference signal measurements obtained from some other source (e.g., an external invasive or non-invasive physiological measurement system).

Calibration device **80** may also access reference signal measurements stored in memory (e.g., RAM, ROM, or a storage device). For example, in some embodiments, calibration device **80** may access reference blood pressure measurements from a relational database stored within calibration device **80**, monitor **14**, or multi-parameter patient monitor **26**. The reference blood pressure measurements generated or accessed by calibration device **80** may be updated in real-time, resulting in a continuous source of reference blood pressure measurements for use in continuous or periodic calibration. Alternatively, reference blood pressure measurements generated or accessed by calibration device **80** may be updated periodically, and calibration may be performed on the same periodic cycle or a different periodic cycle. Reference blood pressure measurements may be generated when recalibration is triggered.

FIG. **2** is a block diagram of a patient monitoring system, such as patient monitoring system **10** of FIG. **1**, which may be coupled to a patient **40** in accordance with an embodiment. Certain illustrative components of sensor unit **12** and monitor **14** are illustrated in FIG. **2**. Because sensor units **12** and **13** may include similar components and functionality, only sensor unit **12** will be discussed in detail for ease of illustration. It will be understood that any of the concepts, components, and operation discussed in connection with sensor unit **12** may be applied to sensor unit **13** as well (e.g., emitter **16** and detector **18** of sensor unit **12** may be similar to emitter **15** and detector **19** of sensor unit **13**). It will be noted that patient monitoring system **10** may include one or more additional sensor units or probes, which may take the form of any of the embodiments described herein with reference to sensor units **12** and **13** (FIG. **1**). These additional sensor units included in system **10** may take the same form as sensor unit **12**, or may take a different form. In an embodiment, multiple sensors (distributed in one or more sensor units) may be located at multiple different body sites on a patient.

Sensor unit **12** may include emitter **16**, detector **18**, and encoder **42**. In the embodiment shown, emitter **16** may be configured to emit at least two wavelengths of light (e.g., Red and IR) into a patient's tissue **40**. Hence, emitter **16** may include a Red light emitting light source such as Red light emitting diode (LED) **44** and an IR light emitting light source such as IR LED **46** for emitting light into the patient's tissue **40** at the wavelengths used to calculate the patient's physiological parameters. In one embodiment, the Red wavelength may be between about 600 nm and about 700 nm, and the IR wavelength may be between about 800 nm and about 1000 nm. In embodiments where a sensor array is used in place of a single sensor, each sensor may be configured to emit a single wavelength. For example, a first sensor emits only a Red light while a second emits only an IR light. In another example, the wavelengths of light used are selected based on the specific location of the sensor.

It will be understood that, as used herein, the term "light" may refer to energy produced by radiation sources and may include one or more of ultrasound, radio, microwave, millimeter wave, infrared, visible, ultraviolet, gamma ray or X-ray electromagnetic radiation. As used herein, light may also include electromagnetic radiation having any wavelength within the radio, microwave, infrared, visible, ultraviolet, or X-ray spectra, and that any suitable wavelength of electromagnetic radiation may be appropriate for use with the present techniques. Detector **18** may be chosen to be specifically sensitive to the chosen targeted energy spectrum of the emitter **16**.

In an embodiment, detector **18** may be configured to detect the intensity of light at the Red and IR wavelengths. Alternatively, each sensor in the array may be configured to detect an intensity of a single wavelength. In operation, light may enter detector **18** after passing through the patient's tissue **40**. Detector **18** may convert the intensity of the received light into an electrical signal. The light intensity is directly related to the absorbance and/or reflectance of light in the tissue **40**. That is, when more light at a certain wavelength is absorbed or reflected, less light of that wavelength is received from the tissue by the detector **18**. After converting the received light to an electrical signal, detector **18** may send the signal to monitor **14**, where physiological parameters may be calculated based on the absorption of the Red and IR wavelengths in the patient's tissue **40**.

In an embodiment, encoder **42** may contain information about sensor **12**, such as what type of sensor it is (e.g., whether the sensor is intended for placement on a forehead or digit) and the wavelengths of light emitted by emitter **16**. This information may be used by monitor **14** to select appropriate algorithms, lookup tables and/or calibration coefficients stored in monitor **14** for calculating the patient's physiological parameters.

Encoder **42** may contain information specific to patient **40**, such as, for example, the patient's age, weight, and diagnosis. This information about a patient's characteristics may allow monitor **14** to determine, for example, patient-specific threshold ranges in which the patient's physiological parameter measurements should fall and to enable or disable additional physiological parameter algorithms. This information may also be used to select and provide coefficients for equations from which, for example, blood pressure and other measurements may be determined based at least in part on the signal or signals received at sensor unit **12**. For example, some pulse oximetry sensors rely on equations to relate an area under a portion of a photoplethysmograph (PPG) signal corresponding to a physiological pulse to determine blood pressure. These equations may contain coefficients that depend upon a

patient's physiological characteristics as stored in encoder **42**. Encoder **42** may, for instance, be a coded resistor which stores values corresponding to the type of sensor unit **12** or the type of each sensor in the sensor array, the wavelengths of light emitted by emitter **16** on each sensor of the sensor array, and/or the patient's characteristics. In another embodiment, encoder **42** may include a memory on which one or more of the following information may be stored for communication to monitor **14**: the type of the sensor unit **12**; the wavelengths of light emitted by emitter **16**; the particular wavelength each sensor in the sensor array is monitoring; a signal threshold for each sensor in the sensor array; any other suitable information; or any combination thereof.

In an embodiment, signals from detector **18** and encoder **42** may be transmitted to monitor **14**. In the embodiment shown, monitor **14** may include a general-purpose microprocessor **48** connected to an internal bus **50**. Microprocessor **48** may be adapted to execute software, which may include an operating system and one or more applications, as part of performing the functions described herein. Also connected to bus **50** may be a read-only memory (ROM) **52**, remote memory **90**, a random access memory (RAM) **54**, user inputs **56**, display **20**, and speaker **22**.

RAM **54** and ROM **52** are illustrated by way of example, and not limitation. Any suitable computer-readable media may be used in the system for data storage. Computer-readable media are capable of storing information that can be interpreted by microprocessor **48**. This information may be data or may take the form of computer-executable instructions, such as software applications, that cause the microprocessor to perform certain functions and/or computer-implemented methods. Depending on the embodiment, such computer-readable media may include computer storage media and communication media. Computer storage media may include volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information such as computer-readable instructions, data structures, program modules or other data. Computer storage media may include, but is not limited to, RAM, ROM, EPROM, EEPROM, flash memory or other solid state memory technology, CD-ROM, DVD, or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by components of the system.

Remote memory **90** may include any suitable volatile memory, non-volatile memory, or any combination thereof. Remote memory **90** may include, but is not limited to, RAM, ROM, EPROM, EEPROM, flash memory or other solid state memory technology, CD-ROM, DVD, or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by components of the system. In some embodiments, remote memory **90** may be separate and remote from other components included in the patient monitoring system. For example, in some embodiments, remote memory **90** may be included in a database server, application server, remote processing facility or device, cloud-based information storage system, any other suitable accessible information storage system or device, or any suitable combination thereof.

Communications path **92** may, in some embodiments, couple remote memory **90** to bus **50** via a suitable interface, or any other suitable component of patient monitoring system **10**. Communication path **92** may include any suitable type of wired network (e.g., local area network, ethernet, universal serial bus), wireless network (e.g., WiFi, Global System for Mobile Communication, BLUETOOTH), optical communications path (e.g., a fiber optic network), any other suitable communications path, or any suitable combination thereof.

In the embodiment shown, a time processing unit (TPU) **58** may provide timing control signals to light drive circuitry **60**, which may control when emitter **16** is illuminated and multiplexed timing for Red LED **44** and IR LED **46**. TPU **58** may also control the gating-in of signals from detector **18** through amplifier **62** and switching circuit **64**. These signals are sampled at the proper time, depending upon which light source is illuminated. The received signal from detector **18** may be passed through amplifier **66**, low pass filter **68**, and analog-to-digital converter **70**. The digital data may then be stored in a queued serial module (QSM) **72** (or buffer) for later downloading to RAM **54** as QSM **72** fills up. In one embodiment, there may be multiple separate parallel paths having components equivalent to amplifier **66**, filter **68**, and/or A/D converter **70** for multiple light wavelengths or spectra received.

In an embodiment, microprocessor **48** may determine the patient's physiological parameters, such as SpO_2, pulse rate, and/or blood pressure, using various algorithms and/or look-up tables based on the value of the received signals and/or data corresponding to the light received by detector **18**. Signals corresponding to information about patient **40**, and particularly about the intensity of light emanating from a patient's tissue over time, may be transmitted from encoder **42** to decoder **74**. These signals may include, for example, encoded information relating to patient characteristics. Decoder **74** may translate these signals to enable the microprocessor to determine the thresholds based at least in part on algorithms or look-up tables stored in ROM **52**. User inputs **56** may be used to enter information about the patient, such as age, weight, height, diagnosis, medications, treatments, and so forth. In an embodiment, display **20** may exhibit a list of values which may generally apply to the patient, such as, for example, age ranges or medication families, which the user may select using user inputs **56**.

The optical signal through the tissue can be degraded by noise, among other sources. One source of noise is ambient light that reaches the light detector. Another source of noise is electromagnetic coupling from other electronic instruments. Movement of the patient also introduces noise and affects the signal. For example, the contact between the detector and the skin, or the emitter and the skin, can be temporarily disrupted when movement causes either to move away from the skin. In addition, because blood is a fluid, it responds differently than the surrounding tissue to inertial effects, thus resulting in momentary changes in volume at the point to which the oximeter probe is attached.

Noise (e.g., from patient movement) can degrade a sensor signal relied upon by a care provider, without the care provider's awareness. This is especially true if the monitoring of the patient is remote, the motion is too small to be observed, or the care provider is watching the instrument or other parts of the patient, and not the sensor site. Processing sensor signals (e.g., PPG signals) may involve operations that reduce the amount of noise present in the signals or otherwise identify noise components in order to prevent them from affecting measurements of physiological parameters derived from the sensor signals.

Pulse oximeters, in addition to providing other information, can be utilized for continuous non-invasive blood pressure monitoring. As described in Chen et al., U.S. Pat. No. 6,599,251, the entirety of which is incorporated herein by reference, PPG and other pulse signals obtained from mul-

tiple probes can be processed to calculate the blood pressure of a patient. In particular, blood pressure measurements may be derived based on a comparison of time differences between certain components of the pulse signals detected at each of the respective probes. As described in U.S. patent application Ser. No. 12/242,238, filed on Sep. 30, 2008 and entitled "Systems and Methods For Non-Invasive Blood Pressure Monitoring," the entirety of which is incorporated herein by reference, blood pressure can also be derived by processing time delays detected within a single PPG or pulse signal obtained from a single pulse oximeter probe. In addition, as described in U.S. patent application Ser. No. 12/242,867, filed on Sep. 30, 2008 and entitled "Systems and Methods For Non-Invasive Continuous Blood Pressure Determination," the entirety of which is incorporated herein by reference, blood pressure may also be obtained by calculating the area under certain portions of a pulse signal. Finally, as described in U.S. patent application Ser. No. 12/242,862, filed on Sep. 30, 2008 and entitled "Systems and Methods For Maintaining Blood Pressure Monitor Calibration," the entirety of which is incorporated herein by reference, a blood pressure monitoring device may be recalibrated in response to arterial compliance changes.

As described above, some CNIBP monitoring techniques utilize two probes or sensors positioned at two different locations on a subject's body. The elapsed time, T, between the arrivals of corresponding points of a pulse signal at the two locations may then be determined using signals obtained by the two probes or sensors. The estimated blood pressure, p, may then be related to the elapsed time, T, by

$$p=a+b\cdot\ln(T) \tag{14}$$

where a and b are constants that may be dependent upon the nature of the subject and the nature of the signal detecting devices. Other suitable equations using an elapsed time between corresponding points of a pulse signal may also be used to derive an estimated blood pressure measurement.

In an embodiment, Eq. 14 may include a non-linear function which is monotonically decreasing and concave upward in T in a manner specified by the constant parameters (in addition to or instead of the expression of Eq. 14). Eq. 14 may be used to calculate an estimated blood pressure from the time difference T between corresponding points of a pulse signal received by two sensors or probes attached to two different locations of a subject.

In an embodiment, constants a and b in Eq. 14 above may be determined by performing a calibration. The calibration may involve taking a reference blood pressure reading to obtain a reference blood pressure P_0, measuring the elapsed time T_0 corresponding to the reference blood pressure, and then determining values for both of the constants a and b from the reference blood pressure and elapsed time measurement. Calibration may be performed at any suitable time (e.g., once initially after monitoring begins) or on any suitable schedule (e.g., a periodic or event-driven schedule).

In an embodiment, the calibration may include performing calculations mathematically equivalent to

$$a = c_1 + \frac{c_2(P_0 - c_1)}{\ln(T_0) + c_2} \tag{15}$$

and

$$b = \frac{P_0 - c_1}{\ln(T_0) + c_2} \tag{16}$$

to obtain values for the constants a and b, where c_1 and c_2 are parameters that may be determined, for example, based on empirical data.

In an embodiment, the calibration may include performing calculations mathematically equivalent to

$$a=P_0-(c_3T_0+c_4)\ln(T_0) \tag{17}$$

and

$$b=c_3T_0+c_4 \tag{18}$$

where a and b are first and second parameters and c_3 and c_4 are parameters that may be determined, for example, based on empirical data.

Parameters c_1, c_2, c_3, and c_4 may be predetermined constants empirically derived using experimental data from a number of different patients. A single reference blood pressure reading from a patient, including reference blood pressure P_0 and elapsed time T_0 from one or more signals corresponding to that reference blood pressure, may be combined with such inter-patient data to calculate the blood pressure of a patient. The values of P_0 and T_0 may be referred to herein as a calibration point. According to this example, a single calibration point may be used with the predetermined constant parameters to determine values of constants a and b for the patient (e.g., using Eqs. 15 and 16 or 17 and 18). The patient's blood pressure may then be calculated using Eq. 14. Recalibration may be performed by collecting a new calibration point and recalculating the constants a and b used in Eq. 14. Calibration and recalibration may be performed using calibration device **80** (FIG. **1**).

In an embodiment, multiple calibration points from a patient may be used to determine the relationship between the patient's blood pressure and one or more PPG signals. This relationship may be linear or non-linear and may be extrapolated and/or interpolated to define the relationship over the range of the collected recalibration data. For example, the multiple calibration points may be used to determine values for parameters c_1 and c_2 or c_3 and c_4 (described above). These determined values will be based on information about the patient (intra-patient data) instead of information that came from multiple patients (inter-patient data). As another example, the multiple calibration points may be used to determine values for parameters a and b (described above). Instead of calculating values of parameters a and b using a single calibration point and predetermined constants, values for parameters a and b may be empirically derived from the values of the multiple calibration points. As yet another example, the multiple calibration points may be used directly to determine the relationship between blood pressure and PPG signals. Instead of using a predefined relationship (e.g., the relationship defined by Eq. 14), a relationship may be directly determined from the calibration points.

Additional examples of continuous and non-invasive blood pressure monitoring techniques are described in Chen et al., U.S. Pat. No. 6,566,251, which is hereby incorporated by reference herein in its entirety. The technique described by Chen et al. may use two sensors (e.g., ultrasound or photoelectric pulse wave sensors) positioned at any two locations on a subject's body where pulse signals are readily detected. For example, sensors may be positioned on an earlobe and a finger, an earlobe and a toe, or a finger and a toe of a patient's body.

FIG. **3** is an illustrative signal processing system **300** in accordance with an embodiment that may implement the non-invasive blood pressure techniques described herein. In this embodiment, input signal generator **310** generates an

input signal **316**. As illustrated, input signal generator **310** may include pre-processor **320** coupled to sensor **318**, which may provide input signal **316**. In an embodiment, pre-processor **320** may be an oximeter and input signal **316** may be a PPG signal. In an embodiment, pre-processor **320** may be any suitable signal processing device and input signal **316** may include one or more PPG signals and one or more other physiological signals, such as an electrocardiogram (ECG) signal. It will be understood that input signal generator **310** may include any suitable signal source, signal generating data, signal generating equipment, or any combination thereof to produce signal **316**. Signal **316** may be a single signal, or may be multiple signals transmitted over a single pathway or multiple pathways.

Pre-processor **320** may apply one or more signal processing operations to the signal generated by sensor **318**. For example, pre-processor **320** may apply a pre-determined set of processing operations to the signal provided by sensor **318** to produce input signal **316** that can be appropriately interpreted by processor **312**, such as performing A/D conversion. Pre-processor **320** may also perform any of the following operations on the signal provided by sensor **318**: reshaping the signal for transmission, multiplexing the signal, modulating the signal onto carrier signals, compressing the signal, encoding the signal, and filtering the signal.

In an embodiment, signal **316** may include PPG signals at one or more frequencies, such as a Red PPG signal and an IR PPG signal. In an embodiment, signal **316** may include signals measured at one or more sites on a patient's body, for example, a patient's finger, toe, ear, arm, or any other body site. In an embodiment, signal **316** may include multiple types of signals (e.g., one or more of an ECG signal, an EEG signal, an acoustic signal, an optical signal, a signal representing a blood pressure, and a signal representing a heart rate). Signal **316** may be any suitable biosignal or signals, such as, for example, electrocardiogram, electroencephalogram, electrogastrogram, electromyogram, heart rate signals, pathological sounds, ultrasound, or any other suitable biosignal. The systems and techniques described herein are also applicable to any dynamic signals, non-destructive testing signals, condition monitoring signals, fluid signals, geophysical signals, astronomical signals, electrical signals, financial signals including financial indices, sound and speech signals, chemical signals, meteorological signals including climate signals, any other suitable signal, and/or any combination thereof.

In an embodiment, signal **316** may be coupled to processor **312**. Processor **312** may be any suitable software, firmware, hardware, or combination thereof for processing signal **316**. For example, processor **312** may include one or more hardware processors (e.g., integrated circuits), one or more software modules, computer-readable media such as memory, firmware, or any combination thereof. Processor **312** may, for example, be a computer or may be one or more chips (i.e., integrated circuits). Processor **312** may, for example, be configured of analog electronic components. Processor **312** may perform the calculations associated with the information determination techniques of the present disclosure as well as the calculations associated with any calibration of processing system **300** or other auxiliary functions. For example, processor **312** may locate one or more fiducial points in one or more signals, determine one or more DPTTs, and compute one or more of a systolic blood pressure, a diastolic blood pressure and a mean arterial pressure. Processor **312** may perform any suitable signal processing of signal **316** to filter signal **316**, such as any suitable band-pass filtering, adaptive filtering, closed-loop filtering, any other suitable filtering, and/or any combination thereof. Processor **312** may also receive input signals from additional sources (not shown). For example, processor **312** may receive an input signal containing information about treatments provided to the patient. Additional input signals may be used by processor **312** in any of the calculations or operations it performs in accordance with processing system **300**.

Processor **312** may be coupled to one or more memory devices (not shown) or incorporate one or more memory devices such as any suitable volatile memory device (e.g., RAM, registers, etc.), non-volatile memory device (e.g., ROM, EPROM, magnetic storage device, optical storage device, flash memory, etc.), or both. The memory may be used by processor **312** to, for example, store data corresponding to blood pressure monitoring, including current blood pressure calibration values, blood pressure monitoring calibration thresholds, and patient blood pressure history. In an embodiment, processor **312** may store physiological measurements or previously received data from signal **316** in a memory device for later retrieval. In an embodiment, processor **312** may store calculated values, such as a systolic blood pressure, a diastolic blood pressure, a blood oxygen saturation, a differential pulse transit time, a fiducial point location or characteristic, or any other calculated values, in a memory device for later retrieval.

Processor **312** may be coupled to a calibration device. This coupling may take any of the forms described above with reference to calibration device **80** within system **10**. For example, the calibration device may be a stand-alone device that may be in wireless communication with processor **312**, or may be completely integrated with processor **312**.

Processor **312** may be coupled to a calibration device that may generate, or receive as input, reference measurements for use in calibration calculations. This coupling may occur through a recalibration signal transmitted via a wired or wireless communications path. In an embodiment, processor **312** is capable of transmitting a command to calibration device **80** to initiate a recalibration procedure.

Processor **312** may be coupled to output **314**. Output **314** may be any suitable output device such as one or more medical devices (e.g., a medical monitor that displays various physiological parameters, a medical alarm, or any other suitable medical device that either displays physiological parameters or uses the output of processor **312** as an input), one or more display devices (e.g., monitor, PDA, mobile phone, any other suitable display device, or any combination thereof), one or more audio devices, one or more memory devices (e.g., hard disk drive, flash memory, RAM, optical disk, any other suitable memory device, or any combination thereof), one or more printing devices, any other suitable output device, or any combination thereof.

It will be understood that system **300** may be incorporated into system **10** (FIGS. **1** and **2**) in which, for example, input signal generator **310** may be implemented as parts of sensor units **12** and **13** (FIGS. **1** and **2**) and monitor **14** (FIGS. **1** and **2**) and processor **312** may be implemented as part of monitor **14** (FIGS. **1** and **2**). In some embodiments, portions of system **300** may be configured to be portable. For example, all or part of system **300** may be embedded in a small, compact object carried with or attached to the patient (e.g., a watch, other piece of jewelry, or a cellular telephone). In such embodiments, a wireless transceiver (not shown) may also be included in system **300** to enable wireless communication with other components of system **10** (FIGS. **1** and **2**). As such, system **10** (FIGS. **1** and **2**) may be part of a fully portable and continuous patient monitoring solution. In such embodiments, a wireless transceiver (not shown) may also be

included in system **300** to enable wireless communication with other components of system **10**. For example, pre-processor **320** may output signal **316** over BLUETOOTH, 802.11, WiFi, WiMax, cable, satellite, Infrared, or any other suitable transmission scheme. In an embodiment, a wireless transmission scheme may be used between any communicating components of system **300**.

Pre-processor **320** or processor **312** may determine the locations of pulses within a periodic signal **316** (e.g., a PPG signal) using a pulse detection technique. For ease of illustration, the following pulse detection techniques will be described as performed by processor **312**, but any suitable processing device (e.g., pre-processor **320**) may be used to implement any of the techniques described herein.

An illustrative PPG signal **400** is depicted in FIG. **4**. Processor **312** may receive PPG signal **400**, and may identify local minimum point **410**, local maximum point **412**, local minimum point **420**, and local maximum point **422** in the PPG signal **400**. Processor **312** may pair each local minimum point with an adjacent maximum point. For example, processor **312** may pair points **410** and **412** to identify one segment, points **412** and **420** to identify a second segment, points **420** and **422** to identify a third segment and points **422** and **430** to identify a fourth segment. The slope of each segment may be measured to determine whether the segment corresponds to an upstroke portion of the pulse (e.g., a positive slope) or a downstroke portion of the pulse (e.g., a negative slope) portion of the pulse. A pulse may be defined as a combination of at least one upstroke and one downstroke. For example, the segment identified by points **410** and **412** and the segment identified by points **412** and **430** may define a pulse.

According to an embodiment, PPG signal **400** may include a dichrotic notch **450** or other notches (not shown) in different sections of the pulse (e.g., at the beginning (referred to as an ankle notch), in the middle (referred to as a dichrotic notch), or near the top (referred to as a shoulder notch)). Notches (e.g., dichrotic notches) may refer to secondary turning points of pulse waves as well as inflection points of pulse waves. Processor **312** may identify notches and either utilize or ignore them when detecting the pulse locations. In some embodiments, processor **312** may compute the second derivative of the PPG signal to find the local minima and maxima points and may use this information to determine a location of, for example, a dichrotic notch. Additionally, processor **312** may interpolate between points in signal **316** or between points in a processed signal using any interpolation technique (e.g., zero-order hold, linear interpolation, and/or higher-order interpolation techniques). Some pulse detection techniques that may be performed by processor **312** are described in more detail in co-pending, commonly assigned U.S. patent application Ser. No. 12/242,908, filed Sep. 30, 2008 and entitled "SYSTEMS AND METHODS FOR DETECTING PULSES IN A PPG SIGNAL," which is incorporated by reference herein in its entirety.

Metrics may be used to characterize or otherwise describe a physiological signal. Metrics may include suitable signal values, signal morphologies, output values from suitable operations performed on a signal or other metric, any other suitable mathematical characterizations, or any suitable combinations thereof. For example, metrics may include pulse wave area (PWA), rate of change computed at one or more points of a time series (e.g., derivative of any suitable order of a signal), statistics of a signal (e.g., mean, moment of any suitable order, regression parameters), offset of a signal from a baseline, interval of portion of a signal (e.g., length of upstroke), relative position of a fiducial point of a signal (e.g., dichrotic notch position), any other suitable metric or change thereof, or any suitable combinations thereof. For example, in some embodiments, the skewness (e.g., the standardized third central moment) of a pulse wave may be monitored.

Metrics may include mathematical manipulations of other metrics such as, for example, the value of an integral of a portion of a blood pressure measurement time series, the skewness of a derivative of a PPG signal, or any other suitable mathematical manipulations. In some embodiments, metrics may be computed from averaged, filtered, scaled, or otherwise processed physiological signals. For example, a derivative may be computed from a suitable ensemble average of pulse waves.

The term "pulse wave" as used herein refers to a portion of a PPG signal corresponding to a physiological pulse.

A patient monitoring system may determine that values of one or more metrics associated with a physiological signal correspond to stored values. The determination may be based at least in part on a comparison of metric values to stored values by, for example, computing a difference. For example, a patient monitoring system may compute a current PWA of a current PPG signal by integrating a suitable portion of the PPG signal. The patient monitoring system may search among stored values of PWA associated with previous PPG signals. The patient monitoring system may compute a difference between the current PWA value and at least one of the stored PWA values. If the patient monitoring system determines that the difference in the current and stored PWA values is below a threshold, then the patient monitoring system may determine that the PWAs correspond to each other. Thresholds may be predetermined, dynamic, constant, or any other suitable type of value, or any suitable combination thereof. For example, in some embodiments, a threshold may be ten percent of a metric value such that if the difference between a value of a monitored metric and a stored value is less than ten percent of the monitored metric, the values are determined to correspond. The selection of this threshold may be determined through consideration of previously acquired empirical data and the required accuracy. In some embodiments, the required accuracy may change with currently reported blood pressure. For example, if a current blood pressure measurement is outside normal physiological ranges, the required accuracy may be tighter and the threshold may be set to encourage a cuff inflation, or true recalibration, rather than rely on an estimate calculated using historical data. In some embodiments, a threshold may be set with respect to a historical variation of the monitored metric, for example, at a fraction (e.g., 0.5) of one standard deviation of the historic values of the monitored metric over a period of time. Any suitable threshold may be used to aid in determining whether values correspond to each other. In some embodiments, the patient monitoring system may determine whether a value of a monitored metric and a stored value to not correspond to one another.

In some embodiments, a difference vector including differences between values of monitored metrics and stored values may be computed by the patient monitoring system. The Euclidean norm, or "norm", of such a vector may provide an indication of how closely the collective values of monitored metrics correspond to stored values. For example, a patient monitoring system may compute differences between monitored values and a set of stored values of PWA, pulse wave skew, and length of pulse wave upstroke, and arrange the difference in each metric value in a difference vector. The patient monitoring system may compute the norm of the difference vector. If the norm is below a threshold value, the patient monitoring system may determine that the current metrics correspond to the stored metrics. Any suitable com-

bination of differences or other comparisons (e.g., norms, conditional probabilities) may be used by a patient monitoring system to determine whether values correspond.

Shown in FIG. **5**(*a*) is illustrative time series **500** of a blood pressure measurement in accordance with some embodiments. Changes in blood pressure, or other suitable physiological metrics, may occur during patient monitoring. Changes in blood pressure, arterial compliance, or other physiological metrics, may result from, for example, administration of vasoactive drugs, changes in patient position, patient activity, any other suitable event which may change the morphology of a physiological signal or metric, or any combination thereof. In some embodiments, a patient monitoring system may be recalibrated in response to changes in, for example, a PPG signal, a metric derived from a PPG signal, any other suitable signal or metric, or any suitable combination thereof.

Time series **500** shown in FIG. **5**(*a*) includes multiple changes in blood pressure such as, for example, those referenced by illustrative points **512**, **514**, and **516**. Time series **500** is observed to increase from point **512** to point **514** over a first time interval, and then decrease from point **514** to point **516** over a second time interval. The blood pressure value at point **516** may, for example, substantially correspond to the blood pressure value at point **512**. In some embodiments, a new calibration at the time associated with point **514** may be desired as a result of the blood pressure change from point **512** to point **514**. In some embodiments, a new calibration at the time associated with point **516** may be desired as a result of the blood pressure change from point **512** to point **514**, and then to point **516**. The blood pressure values included in time series **500** may be computed based at least in part on a DPTT measurement, which may be based at least in part on the signals of two PPG sensors placed at suitable locations on a patient.

Shown in illustrative FIGS. **5**(*b*), **5**(*c*), and **5**(*d*) are illustrative graphs showing time series **520**, **540**, and **560**, respectively. Time series **520**, **540**, and **560** may represent portions of one of the particular PPG signals used by the patient monitor to compute DPTT values and the blood pressure values of points **512**, **514**, and **516** of FIG. **5**(*a*), respectively. Time series **520**, **540**, and **560**, may each represent physiological pulses which may have occurred substantially at the times associated with points **512**, **514** and **516**, respectively. The ordinate of the illustrative graphs shown in FIGS. **5**(*b*), **5**(*c*), and **5**(*d*) may be scaled in arbitrary units, while the abscissa of each of the graphs may be a normalized time variable. For example, an abscissa value of zero represents the onset of a particular pulse, and an abscissa value of one represents the end of a particular pulse, with reference to FIGS. **5**(*b*), **5**(*c*), and **5**(*d*).

Time series **520**, **540**, **560** may each have different morphologies due to, for example, physiological changes. In some embodiments, time series **520** and **560** may have substantially similar morphologies as each other, while time series **540** may have a relatively different morphology from both time series **520** and **560**. Shown in FIG. **6** is superposition **600** of time series **520**, **540**, and **560** of FIGS. **5**(*b*), **5**(*c*), and **5**(*d*), respectively. It can be seen in FIG. **6**, that time series **520** and **560** have substantially similar morphologies to each other. It can also be seen in FIG. **6**, that time series **540** has a substantially different morphology from both time series **520** and **560**. For example, centroids **522** and **562** derived from time series **520** and **560**, respectively, are substantially coincident with each other, and are both substantially different from centroid **542** derived from time series **540**. In a further example, the dichrotic notches of time series **520** and **560** both lie substantially in notch region **524**. The dichrotic notch of time series **540** lies substantially in notch region **544**, located substantially apart from notch region **524**.

Differences in metrics of one or more physiological signals such as, for example, centroids (e.g., centroids **522**, **542**, and **562**) or dichrotic notch positions (e.g., within notch regions **524** or **544**) of pulse waves of a PPG signal, may be monitored to determine when recalibration may be desirous. For example, a patient monitoring system may have particular calibration parameters at a time corresponding to point **512** of FIG. **5**(*a*). Changes in arterial compliance, for example, may cause a change in blood pressure represented by the transition from point **512** to point **514** in FIG. **5**(*a*). The transition from point **514** to point **516** may, in some embodiments, represent a return by the patient to a similar physiological state as that of point **512**, indicated by the similar blood pressure values displayed at points **512** and **516**.

The patient monitoring system may determine that the physiological state of the patient at point **516** is substantially similar to the physiological state of the patient at point **512**. This determination may be based at least in part on the difference between the blood pressure values of points **512** and **516**. For example, the patient monitoring system may compare the difference between the blood pressure values of points **512** and **516** to a threshold. If the difference is less than the threshold, the patient monitoring system may determine that the values correspond. The patient monitoring system may determine that the physiological states correspond based at least in part on the determination that the values correspond. The patient monitoring system may determine that the physiological states of the patient at points **512** and **516** correspond, and the patient monitoring system may not perform a calibration (e.g., a cuff inflation) at a time corresponding to point **516**. Any suitable metrics, or combinations thereof, may be used to determine whether physiological states of a patient correspond.

In some embodiments, metrics associated with the blood pressure pattern from point **512** to point **514** to point **516** may be stored for later reference. For example, administration of a particular drug to a patient may cause the blood pressure change from point **512** to point **514**, and then to point **516**. Metrics associated with this blood pressure change such as, for example, the time interval between points **512** and **516**, peak to peak difference, slope of the time series **500** computed at suitable points, any other suitable metrics, or any suitable combinations thereof, may be stored for future reference. For example, if the same drug is administered at a new time, a new calibration may not be required because stored calibration parameters corresponding to a previous calibration, performed during a previous drug administration, may be recalled. Because the previous calibration may have been performed during a similar physiological state (e.g., for a similar drug administration), the physiological signals may exhibit similar values of suitable metrics. In some embodiments, storing metrics associated with a physiological signal may reduce the desired number of calibrations of the patient monitoring system.

In reference to FIG. **6**, a patient monitoring system may store one or more metrics associated with time trace **520** such as, for example, the position (abscissa and ordinate values) of centroid **522**. The patient monitoring system may monitor a metric associated with a PPG signal such as, for example, the position of the centroid of a pulse wave. The relative centroid position may change from centroid **522** to centroid **542** then to centroid **562**, as shown in FIG. **6**. The position of centroid **562** may be determined by the patient monitoring system to correspond to the position of centroid **522**. The determination

may be based at least in part on, for example, differences between the abscissa and ordinate values of centroids **522** and **562**. For example, the patient monitoring system may determine that the difference between both the abscissa and ordinate values of centroids **522** and **562** are both within a threshold (e.g., five percent), and accordingly that centroids **522** and **562** correspond to each other.

Shown in FIG. **7** is a block diagram of an illustrative database of stored values **700** in accordance with some embodiments. Stored values **700** may include PPG data **702**, blood pressure data **704**, metrics **706** derived from one or more PPG signals, patient monitoring system calibration parameters **708**, patient information **710** (e.g., physiological information, patient history, multi-patient sample statistics), mappings **712**, any other suitable data which may be stored in any suitable arrangement, or any suitable combinations thereof.

For example, PPG data **702** may include one or more data points sampled from a PPG signal, and stored in any suitable data format. PPG data **702** may include data sampled at any suitable sampling frequency, data sampled at irregular intervals, or both. In some embodiments, PPG data **702** may undergo mathematical manipulation such as, for example, smoothing, averaging (e.g., computing a moving average), re-sampling (e.g., sampling a subset of all data points), converting (e.g., non-dimensionalizing, normalized, offset shifted), any other suitable data processing technique, or any suitable combination thereof, prior to storage.

Blood pressure data **704** may include blood pressure measurements (e.g., a time series) computed from one or more received signals (e.g., invasive arterial sensors, PPG sensors, inflatable cuff sensors). Blood pressure data **704** may include, for example, systolic blood pressure, diastolic blood pressure, or both, or any suitable manipulation of any suitable blood pressure value. In some embodiments, blood pressure data **704** may be smoothed, averaged, re-sampled, converted, mathematically manipulated by any other suitable data processing technique or any combinations thereof.

Metrics **706** may include any suitable value which may be derived from any suitable signal (e.g., a PPG signal). For example, metrics **706** may include derivatives of any suitable order, integrals, statistics (e.g., mean, standard deviation, skew, kurtosis), regressions of any form and order, ordinate values, abscissa values, any other suitable metrics, evaluated at any suitable point or combination of points, which may be computed from a suitable signal, or any suitable combinations thereof. For example, in some embodiments, metrics **706** may include pulse rate, pulse wave area, dichrotic notch position, skew of a portion of a PPG signal, skew of the derivative of a portion of a PPG signal, upstroke length of a pulse wave, pulse wave height, pulse wave full width at half maximum (FWHM), any other suitable metric, or any suitable combinations thereof.

In some embodiments, PPG signals, data derived from any suitable signal, or combinations thereof, may be approximated by any suitable continuous or non-continuous function, basis set (e.g., orthogonal functions), expression, or suitable combination thereof in any suitable variable space. In some embodiments, for example, metrics **706** may include values, parameters, coefficients, boundary conditions, or other descriptors associated with a Fourier series, Fourier integral, Bessel function, Legendre polynomial, Chebyshev polynomial, Laguerre polynomial, discrete or continuous transform (e.g., Laplace, Fourier, wavelet), any other suitable basis set, expression, transform, or function, or any suitable combinations thereof. For example, the output of a fast Fourier transform (FFT) of portions of a sampled (e.g., discreet) PPG signal may be stored in accordance with metrics **706**. In some embodiments, metrics **706** may include the coefficients A_i (e.g., weighting functions, constants) of any suitable superposition (e.g., linear combination over index i) of expressions $f(x_j)$ depending on any suitable number of variables x_j, which may be used to approximate one or more values M of a metric, as illustratively shown by

$$M \approx \sum_{i=1}^{N} A_i f_i(x_j). \tag{19}$$

A summation, such as that given by Eq. 19, may be used to approximate a portion of a signal (e.g., a signal feature corresponding to a physiological pulse), a metric time series, any other suitable values, or any combination thereof. It will be understood that the approximation sign in Eq. 19 may be replaced with an equal sign in suitable circumstances. In some embodiments, with reference to Eq. 19, more than one summation may be performed over any suitable number of indices.

Stored values **700** may include calibration parameters **708**, which may be used to calibrate any suitable device (e.g., a sensor), system (e.g., a patient monitoring system), process, any other suitable hardware or software which may be used to perform a measurement, or any suitable combinations thereof. For example, in some embodiments, calibration parameters **708** may include a, b, and c_i of Eqs. 14-18. Calibration parameters **708** may, for example, be stored and indexed with metrics computed substantially at a time when the calibration was performed.

Stored values **700** may include patient information **710**, which may include inter-patient information, intra-patient information, patient histories, statistical information, any other information associated with one or more patients, or any combination of information thereof. For example, in some embodiments, patient information **710** may include patient medical histories, medication information, patient allergies, patient monitoring histories (e.g., previous physiological state information), patient identification information, any other suitable information, or any combination thereof.

Stored values **700** may include mappings **712**, which may include any suitable type of distribution functions, functions with any suitable number of variables, expressions with any suitable number of variables, any other suitable correlations, or any suitable combinations thereof. In some embodiments, mappings **712** may include a probability distribution function (PDF), cumulative distribution function (CDF), conditional PDF, conditional CDF, multivariable function, differential equation, cross correlation, interpolation, any other suitable mathematical or computational tool for relating sets or variables, or any combinations thereof. For example, in some embodiments, mappings **712** may include a function such as that given by

$$M \approx f(x_1, x_2, \ldots x_N), \tag{20}$$

wherein x_i may be suitable parameters, metrics, or other values, and M may be any suitable metric value. In a further example, only discreet values of values x_i may be defined (e.g., only integers, evenly spaced discreet values), and a suitable interpolation may be used to determine M values based on x_i values intermediate to the discreet x_i values. It will be understood that the approximation sign in Eq. 20 may be replaced with an equal sign in suitable circumstances.

Stored values **700** may be stored in any suitable memory device or combination of memory devices. Stored values **700**

may be stored remotely (e.g., in remote memory **90** of FIG. **1**), locally (e.g., in ROM **52** of FIG. **1**), or any suitable combination thereof. For example, in some embodiments, a database of stored values **700** may be catalogued and indexed as a lookup table, in which stored values **700** may be stored in one or more memory devices. Any suitable data structure may be used to index stored values **700**, including, for example, tree structures, array structures (e.g., vectors, images), mappings, any other suitable data structure, or any suitable combinations thereof. Any of stored values **700** may be associated, indexed, catalogued, or otherwise related to any other of stored values **700**. For example, a particular value of metric **706** may be associated with a particular set of calibration parameters **708**. The particular set calibration parameters **708** may be recalled by the patient monitoring system if a monitored metric is determined to substantially correspond to the particular value of metric **706**.

In some embodiments, a patient monitoring system may decide not to perform a calibration if it determines that a monitored metric corresponds to a particular value of a stored metric **706**. In some embodiments, a patient monitoring system may determine that the current calibration parameters are appropriate based at least in part on values of one or more monitored metrics. For example, a patient monitoring system may determine that a patient's current physiological state corresponds to a previous physiological state of the patient. If, for example, the current calibration parameters were taken during the previous physiological state, and are still appropriate, the patient monitoring system may determine that a recalibration is not desired.

Shown in FIG. **8** is flow diagram **800** of an illustrative process for updating monitoring system calibration parameters in accordance with an embodiment. Illustrative step **802** may include receiving at least one signal to the signal input of a patient monitoring system (e.g., patient monitoring system **10** of FIG. **1**). Illustrative step **804** may include monitoring the value of at least one metric derived from the received signal (e.g., a PPG signal). Illustrative step **806** may include comparing the monitored metric value to a stored value (e.g., any of stored values **700** of FIG. **7**). Illustrative determination step **808** may include determining whether the monitored metric value corresponds to the stored value. Illustrative step **810** may include updating calibration parameters of a patient monitoring system (e.g., patient monitoring system **10** of FIG. **1**).

Step **802** of FIG. **8** may include receiving any suitable physiological signal such as, for example, a PPG signal. In some embodiments, the signal may be sampled at any suitable sampling frequency by a patient monitoring system. In some embodiments, more than one signal may be received in accordance with step **802**. For example, in some embodiments, two PPG signals may be received by a patient monitoring system (e.g., to calculate a DPTT value).

Step **804** of FIG. **8** may include monitoring any suitable metric value which may be derived from a received signal (e.g., the signal of step **802**). For example, the value of metrics such as blood pressure, heart rate, DPTT, signal morphology (e.g., pulse wave area, pulse wave moment, relative fiducial point position), any other suitable metrics, or any suitable combinations thereof, may be monitored by a patient monitoring system at step **804**. In some embodiments, step **804** may include a patient monitoring system storing, recalling, deleting, displaying or otherwise managing metric values derived from any suitable received signal. For example, in some embodiments, a patient monitoring system may store a metric value in queue (e.g., in a suitable memory device), and replace the value with a new value at a later time.

Step **806** of FIG. **8** may include comparing a monitored metric value (e.g., metric value of step **804**) to a stored value (e.g., any of stored values **700** of FIG. **7**). In some embodiments, step **806** may include determining a difference between a monitored metric value and a stored value. The difference may include computations such as subtraction, normalization, division, any other suitable operation, or any suitable combination thereof, of the monitored metric value and the stored value. In some embodiments, a difference may be compared to a threshold value. The threshold value may, for example, be a stored value, a user defined value, a substantially real-time value computed based at least in part on a received signal, a monitored metric, a value derived from any other formulation, or any suitable combination thereof. In some embodiments, the stored value may be recalled from any suitable database(s) stored in suitable memory device(s), as shown illustratively by step **850**. Step **850** may include parsing data, interpolating data, requesting values, searching data structures, traversing data structures (e.g., arrays, trees, multimaps), any other suitable technique for accessing a stored value, or any suitable combination thereof.

In some embodiments, any suitable pattern matching technique, pattern recognition technique, or other classification technique, or combination of techniques, may be used to compare metrics at step **806** of FIG. **8**. For example, templates, classifications (e.g., k-nearest neighbor algorithms, decision trees), regressions (e.g., neural networks), any other pattern recognition techniques, or any suitable combination thereof may be used to compare or match the value of a monitored metric to a stored value.

If the patient monitoring system does not locate a suitable stored value, step **860** may be performed (see step **1060** of flow diagram **1000** of FIG. **10**). Step **860** may include determining a morphology change, performing a calibration, storing values in memory, any other suitable actions, or any combination thereof. For example, if the patient monitoring system cannot locate a suitable stored value for comparison, the patient monitoring system may store one or more current metric values so that stored metric values may be available in the future.

Determination step **808** of FIG. **8** may include, for example, determining whether a monitored metric value corresponds to a stored metric value. In some embodiments, a comparison of the monitored metric value and the stored value may be used at determination step **808**. For example, in some embodiments, a monitored metric value may be determined to correspond to a stored value if a computed difference between the two values is less than a particular threshold value.

It may be determined, for example, at determination step **808** that a monitored metric does not correspond to a stored value. In response to such a determination, the patient monitoring system may, in some embodiments, initiate step **802**, **804**, or **806**. In some embodiments, the monitored metric value may be compared to further stored values at step **808**. In some embodiments, the patient monitoring system may compute a new value for the monitored metric and compare the new value to a stored value at determination step **808**.

In some embodiments, the patient monitoring system may determine that a monitored metric does not correspond to a stored value. In response to such a determination, the patient monitoring system may, in some embodiments, perform step **860** (see step **1060** of flow diagram **1000** of FIG. **10**). For example, the patient monitoring system may determine that the monitored metric does not correspond to a stored value,

and that a calibration is desired. One or more metric values corresponding to the calibration may be stored for future reference as stored values.

If the value of a monitored metric is determined to correspond to a stored value, calibration parameters may be updated in accordance with step **810** of FIG. **8**. Step **810** may include, for example, recalling calibration parameters (e.g., a, b and/or c_i of Eqs. 14-18) from a memory device, replacing calibration parameters with stored calibration parameters, determining a blood pressure measurement based on stored calibration parameters, any other suitable process, or any suitable combination thereof. In some embodiments, calibration parameters associated with the stored value may be recalled and used in the current calibration.

In an illustrative example, two PPG signals may be received by a patient monitoring system (e.g., patient monitoring system **10** of FIG. **1**) at step **802** of FIG. **8**. A metric such as, for example, the DPTT derived from the received signals may be computed as a time series by the patient monitoring system at step **804** of FIG. **8**. The patient monitoring system may compare one or more DPTT values to a suitable stored DPTT value in a suitable memory device (e.g., ROM **52**, remote memory **90**, or both, of FIG. **1**). The stored DPTT value may be recalled by the patient monitoring system by suitable searching of a catalogue of stored metric values stored in a suitable database. If the patient monitoring system determines that the monitored DPTT value corresponds substantially to a stored DPTT value, the patient monitoring system may recall calibration parameters associated with the stored DPTT value. The patient monitoring system may update the current blood pressure calibration values (e.g., a, b and/or c_i of Eqs. 14-18) with the blood pressure calibration values associated with the stored DPTT value. Although the previous example discloses monitoring a DPTT value and updating blood pressure calibration parameters, the value of any suitable metric may be monitored, and any suitable calibration parameters may be updated.

Shown in FIG. **9** is flow diagram **900** of an illustrative process for storing physiological signals, metrics, or both, in accordance with an embodiment. Illustrative step **902** may include a patient monitoring system (e.g., patient monitoring system **10** of FIG. **1**) receiving at least one signal. Illustrative step **904** may include computing the value of at least one metric based at least in part on the received signal (e.g., a PPG signal). Illustrative step **906** may include storing the monitored metric value in any suitable memory device (e.g., ROM **52**, remote memory **90**, or both, of FIG. **1**). Illustrative determination step **908** may include cataloguing the stored metric value in a suitable database.

Step **902** of FIG. **9** may include receiving any suitable physiological signal such as, for example, a PPG signal. In some embodiments, the signal may be sampled at any suitable sampling frequency allowing the signal to be monitored by a patient monitoring system. In some embodiments, more than one signal may be received at step **902**. For example, in some embodiments, two PPG signals may be received by a patient monitoring system.

Step **904** of FIG. **9** may include determining (e.g., computing) any suitable metric value that may be derived from a received signal of step **902**. For example, the value of metrics such as blood pressure, pulse rate, DPTT, signal morphologies (e.g., pulse wave area, pulse wave moment, relative fiducial point position, skewness, kurtosis), any other suitable metrics, or any combinations thereof, may be monitored by a suitable patient monitoring system at step **904**. In some embodiments, a patient monitoring system may store (e.g., to a queue), recall (e.g., from a queue), delete, display or otherwise manage one or more metric values derived at least in part from any suitable received signal at step **904**.

Step **906** of FIG. **9** may include storing, cataloguing, or both, any suitable metric value in any suitable memory storage device. For example, in some embodiments, a patient monitoring system may create or addend a database any of stored values **700** of FIG. **7**. For example, in some embodiments, patient information **710** may be appended with information regarding a new patient. In a further example, multiple values of a particular metric may be stored and used as a training set on which a correlation or PDF may be based.

In some embodiments, metric values may be stored and then catalogued (e.g., indexed by value and storage location). In some embodiments, metric values may be catalogued and then stored (e.g., stored in particular locations based at least in part on metric value). Metric values may be associated with any of stored values **700** during cataloguing, in some embodiments.

In some embodiments, step **950** of FIG. **9** may correspond substantially to step **850** of FIG. **8**. For example, values catalogued, stored, or both, at step **906** of FIG. **9** may be recalled or otherwise identified at step **806** of FIG. **8**. In some embodiments, a suitable combination of steps **850** and **950** may allow a suitable database to be created, appended, or otherwise maintained, and any data stored within to be recalled at a suitable time (e.g., in response to a request).

Shown in FIG. **10** is flow diagram **1000** of an illustrative process for storing physiological signals, metrics, or both, corresponding to a calibration in accordance with an embodiment. Illustrative step **1002** may include a patient monitoring system (e.g., patient monitoring system **10** of FIG. **1**) receiving at least one signal. Illustrative step **1004** may include computing the value of at least one metric based at least in part on the at least one received signal (e.g., a PPG signal). Illustrative determination step **1006** may include determining a change in one or more metric values. Illustrative determination step **1008** may include calibrating one or more sensors of a patient monitoring system. Illustrative step **1010** may include storing one or more metric value in any suitable memory device (e.g., ROM **52**, remote memory **90**, or both, of FIG. **1**).

Step **1002** of FIG. **10** may include receiving any suitable physiological signal such as, for example, a PPG signal. In some embodiments, the signal may be sampled at any suitable sampling frequency allowing the signal to be monitored by a patient monitoring system. In some embodiments, more than one signal may be received at step **1002**. For example, in some embodiments, two PPG signals may be received by a patient monitoring system.

Step **1004** of FIG. **10** may include determining (e.g., computing) any suitable metric value that may be derived from a received signal of step **1002**. For example, the value of metrics such as blood pressure, pulse rate, DPTT, signal morphologies (e.g., pulse wave area, pulse wave moment, relative fiducial point position, skewness, kurtosis), any other suitable metrics, or any combinations thereof, may be monitored by a suitable patient monitoring system at step **1004**. In some embodiments, a patient monitoring system may store (e.g., to a queue), recall (e.g., from a queue), delete, display or otherwise manage one or more metric values derived at least in part from any suitable received signal at step **1004**.

Step **1006** may include determining a change in one or more metric values. In some embodiments, a change in one or metric values may be a change from a constant or historical metric values. In some embodiments, a change in metric value may be a change in a derivative of one or more metrics. The value of one or more metrics may be compared to a

threshold to aid in determining whether the metric value has changed. For example, if the difference between a monitored metric value and threshold value is computed to be greater than ten percent of the monitored metric value, the patient monitoring system may determine that the monitored metric has changed. In some embodiments, a user (e.g., a clinician) may determine that a metric value has changed and the patient monitoring system may receive user input indicating the change.

In some embodiments, a stored value may not be available at step **1006** to aid in determining whether a metric has changed. For example, the patient monitoring system may determine that one or more particular metric values do not correspond to any available stored values. For example, the patient monitoring system may determine that the blood pressure has changed if the blood pressure measurement changes by more than one standard deviation from a historical measurement (e.g., a time series of blood pressure measurements). In some embodiments, step **860** of FIG. **8** may correspond to step **1060** of FIG. **10**.

Step **1008** of FIG. **10** may include performing a calibration measurement if one or more metric values are determined to have changed. The calibration may include performing a NIBP measurement, updating a measurement (e.g., a displayed blood pressure measurement), calibrating one or more devices (e.g., two PPG sensors), any other suitable action, or any combination thereof.

In some embodiments, step **1008** may be performed in response to a lack of stored values being available. For example, if a particular metric is determined to have changed, but no stored values are available which correspond to the metric value, the patient monitoring system may perform a calibration (e.g., perform a cuff inflation).

Step **1010** of FIG. **10** may include storing metric values, calibration parameters, or both, in any suitable memory storage device. In some embodiments, step **1010** may append a database such as a look-up table with one or more metric values, calibration parameters, signal values, any other suitable values associated with the calibration of step **1008**, or any combination thereof. In some embodiments, step **1010** may allow one or more current metrics to be stored for future reference. For example, in some embodiments, a patient monitoring system may create or addend a database any of stored values **700** of FIG. **7**. For example, in some embodiments, patient information **710** may be appended with information regarding a new patient. In a further example, multiple values of a particular metric may be stored and used as a training set on which a correlation or PDF may be based.

In some embodiments, metric values may be stored and then catalogued (e.g., indexed by value and storage location). In some embodiments, metric values may be catalogued and then stored (e.g., stored in particular locations based at least in part on metric value). Metric values may be associated with any of stored values **700** during cataloguing, in some embodiments.

It will be understood that the steps of flow diagrams **800**, **900**, and **1000** of FIGS. **8-10**, respectively, are illustrative. Any of the steps of flow diagrams **800**, **900**, and **1000** may be modified, omitted, rearranged, combined with other steps of flow diagrams **800**, **900**, and **1000**, or supplemented with additional steps, without departing from the scope of the present disclosure.

What is claimed is:

1. A method for calibrating a blood pressure monitor, the method comprising:

receiving a photoplethysmograph (PPG) signal;

monitoring a value of at least one metric derived at least in part from the PPG signal;

comparing the value of the metric to a stored value;

determining based at least in part on the comparison whether the value of the metric corresponds to the stored value; and

determining, using a processor, whether to update current calibration parameters of the blood pressure monitor based at least in part on the comparison, wherein the calibration parameters are used for calculating blood pressure values.

2. The method of claim **1**, wherein the determining whether to update current calibration parameters further comprises determining whether to update the current calibration parameters based further at least in part on whether current calibration parameters correspond to stored calibration parameters associated with the stored value, the method further comprising:

updating the current calibration parameters with the stored calibration parameters if it is determined that the current calibration parameters do not correspond to the stored calibration parameters; and

retaining the current calibration parameters if it is determined that the current calibration parameters correspond to the stored calibration parameters.

3. The method of claim **2**, wherein updating the calibration parameter further comprises recalling previous calibration parameters.

4. The method of claim **1**, wherein the stored value is catalogued in the database.

5. The method of claim **1**, wherein the stored value is stored at time when a calibration of the blood pressure monitor is performed.

6. The method of claim **1**, wherein the at least one feature is based at least in part on PPG signal morphology.

7. The method of claim **1**, wherein the PPG signal morphology comprises a derivative, integral, moment, domain, range, peak value and/or coefficients of a signal transform, and/or a combination thereof.

8. The method of claim **1**, wherein comparing the value of the metric and the stored value further comprises using a pattern matching technique.

9. The method of claim **1**, wherein comparing the value of the metric and the stored value further comprises comparing a threshold to a difference between the value of the at least one monitored metric and the stored value.

10. The method of claim **1**, further comprising receiving an auxiliary PPG signal, wherein the metric corresponds to a time difference between at least one portion of the PPG signal and at least one portion of the auxiliary PPG signal.

11. A system for determining physiological information about a subject, the system comprising:

a signal input configured to receive at least one PPG signal of a subject from at least one sensing device;

at least one processing device coupled to the signal input, wherein the at least one processing device is configured to:

monitor a value of at least one metric derived at least in part from the at least one PPG signal;

compare the value of the at least one metric to a stored value;

determine based at least in part on the comparison whether the value of the metric corresponds to the stored value; and

determine whether to update calibration parameters of the blood pressure monitor based at least in part on the comparison, wherein the calibration parameters are used for calculating blood pressure values.

12. The system of claim **11**, wherein the at least one processing device comprises a memory device.

13. The system of claim **11**, wherein the at least one processing device is coupled to at least one memory device.

14. The system of claim **11**, wherein the at least one PPG signal comprises two PPG signals measured at two different sites of the subject.

15. The system of claim **11**, wherein the at least one metric comprises a differential pulse transit time, blood pressure, heart rate, PPG signal derivative, PPG signal integral, PPG signal moment, PPG signal domain, PPG signal range, PPG signal peak value and/or coefficients of a PPG signal transform, and/or a combination thereof.

16. The system of claim **11**, wherein comparing the value of the metric to the value stored in the memory device further comprises the at least one processing device being further configured to use a pattern matching technique.

17. The system of claim **11**, wherein the value stored in the memory device is catalogued in a database stored in the memory device.

18. The system of claim **11**, wherein the at least one processing device is further configured to perform a calibration of the system.

19. The system of claim **11**, wherein the at least one processing device is further configured to search for the stored value stored in a memory device based at least in part on the value of the monitored metric.

20. The system of claim **11**, wherein the at least one processing device is further configured to recall the stored value from a memory device.

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