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(54) **SYSTEM FOR DETERMINING CONFIDENCE IN RESPIRATORY RATE MEASUREMENTS**

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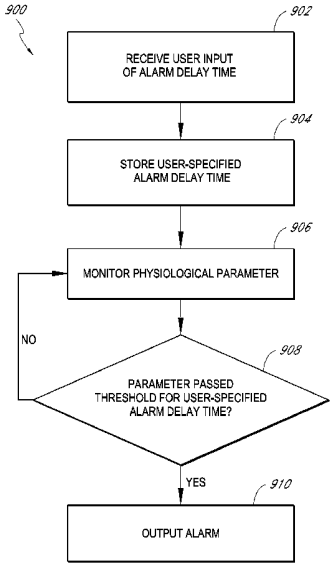
(57) **ABSTRACT**

This disclosure describes, among other features, systems and methods for using multiple physiological parameter inputs to determine multiparameter confidence in respiratory rate measurements. For example, a patient monitoring system can programmatically determine multiparameter confidence in respiratory rate measurements obtained from an acoustic sensor based at least partly on inputs obtained from other non-acoustic sensors or monitors. The patient monitoring system can output a multiparameter confidence indication reflective of the programmatically-determined multiparameter confidence. The multiparameter confidence indication can assist a clinician in determining whether or how to treat a patient based on the patient's respiratory rate.

18 Claims, 22 Drawing Sheets



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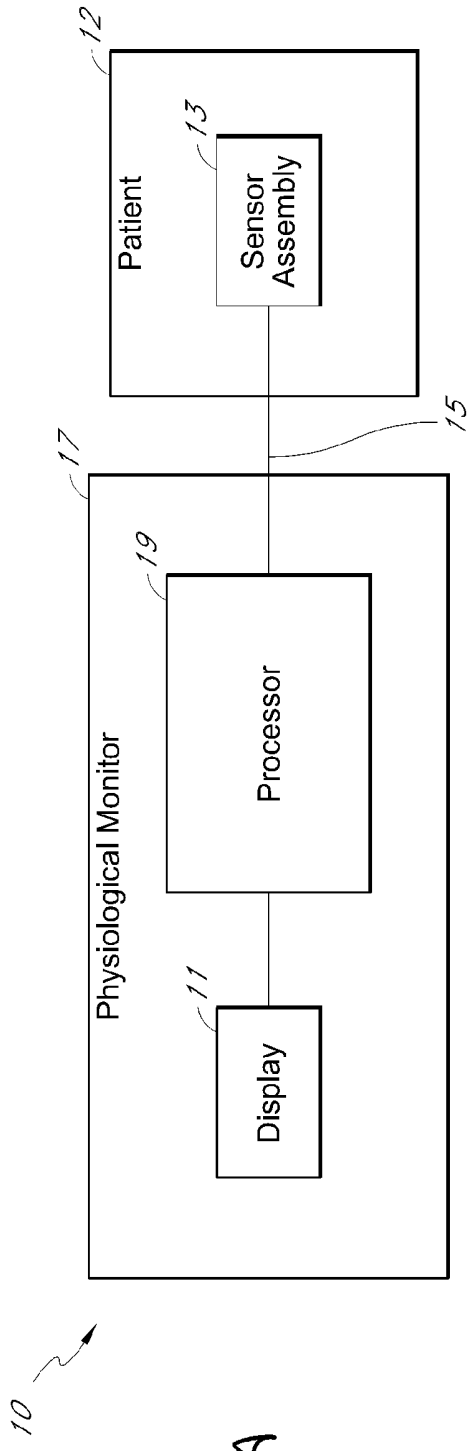
12
Patient
13
Sensor Assembly
15
17
Physiological Monitor
19
Processor
11
Display
10

FIG. 1A

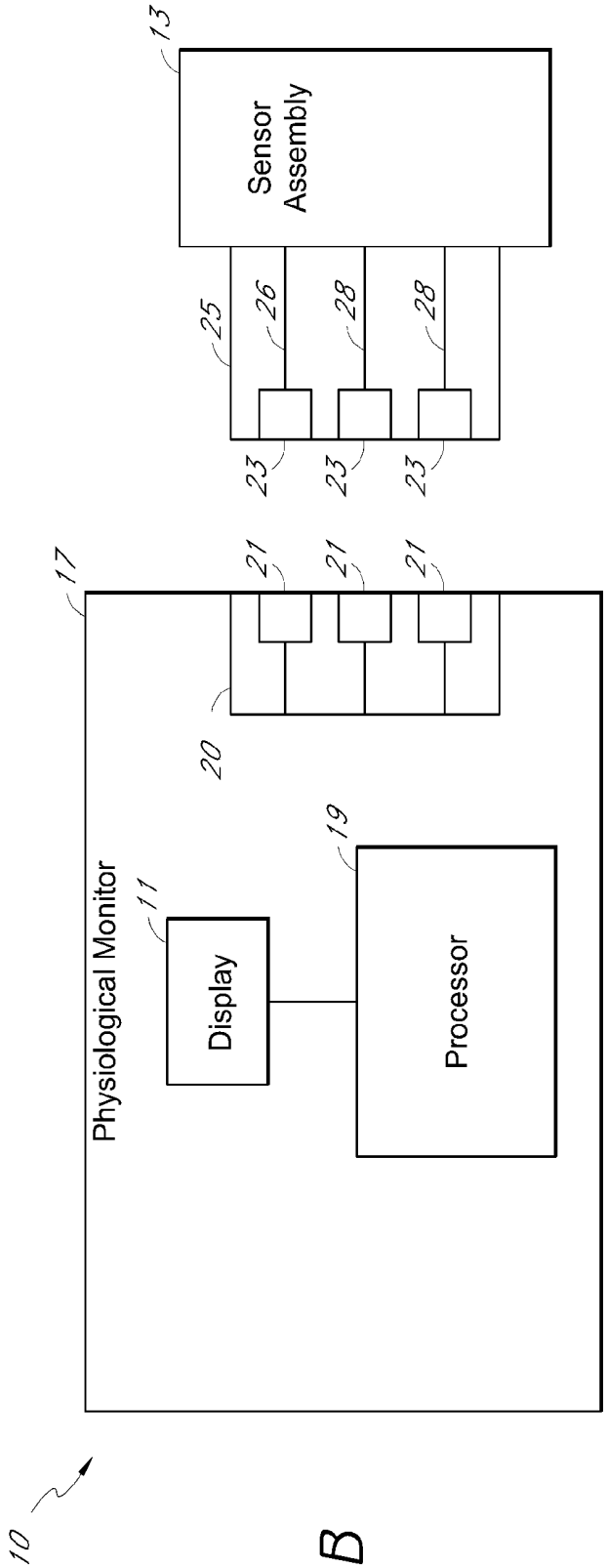
13
Sensor Assembly
25
26
28
28
23
23
23
21
21
21
17
20
Physiological Monitor
19
Processor
11
Display
10

FIG. 1B

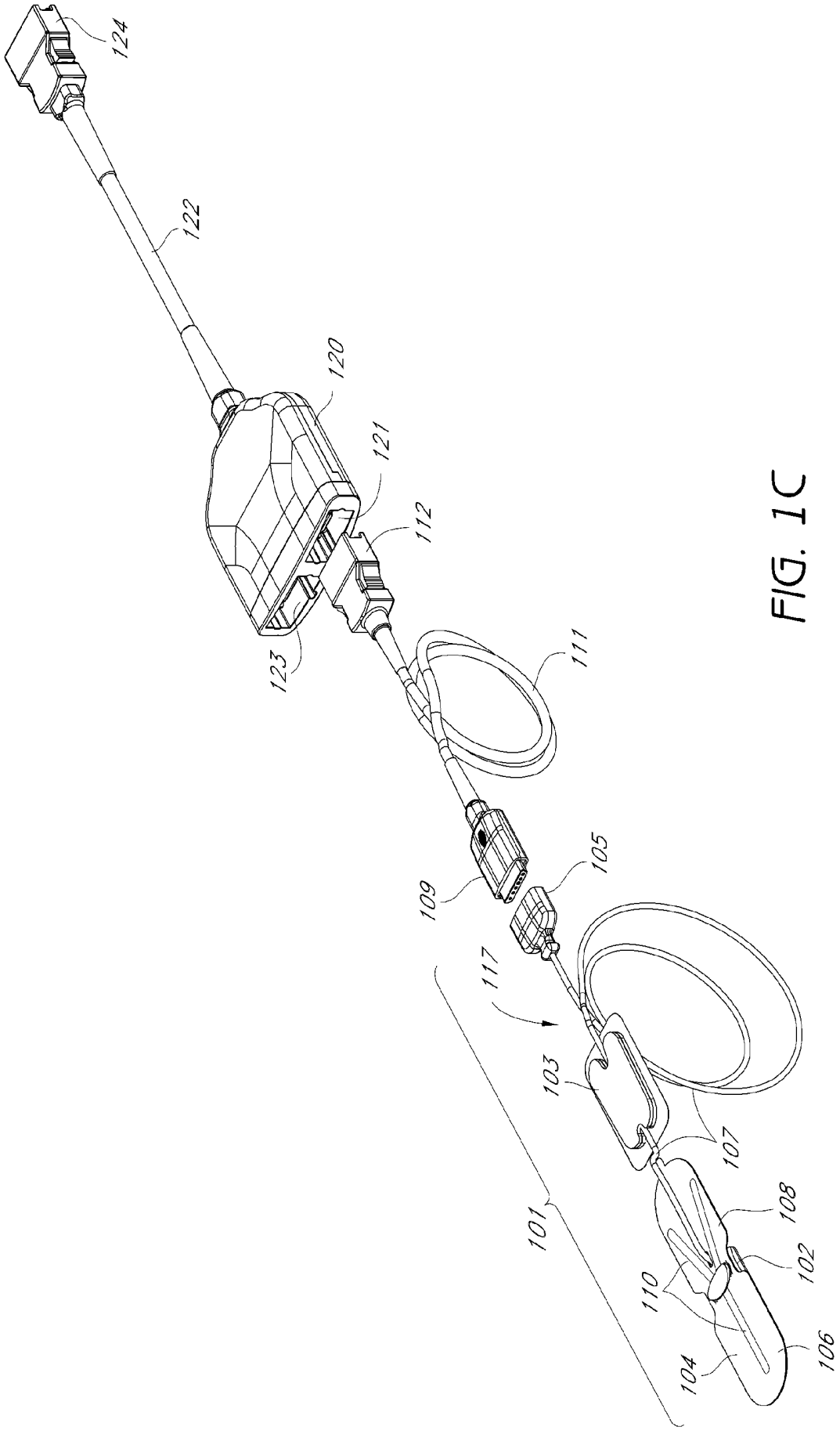
124
122
120
121
112
123
111
109
105
117
103
107
101
108
102
110
104
106

FIG. 1C

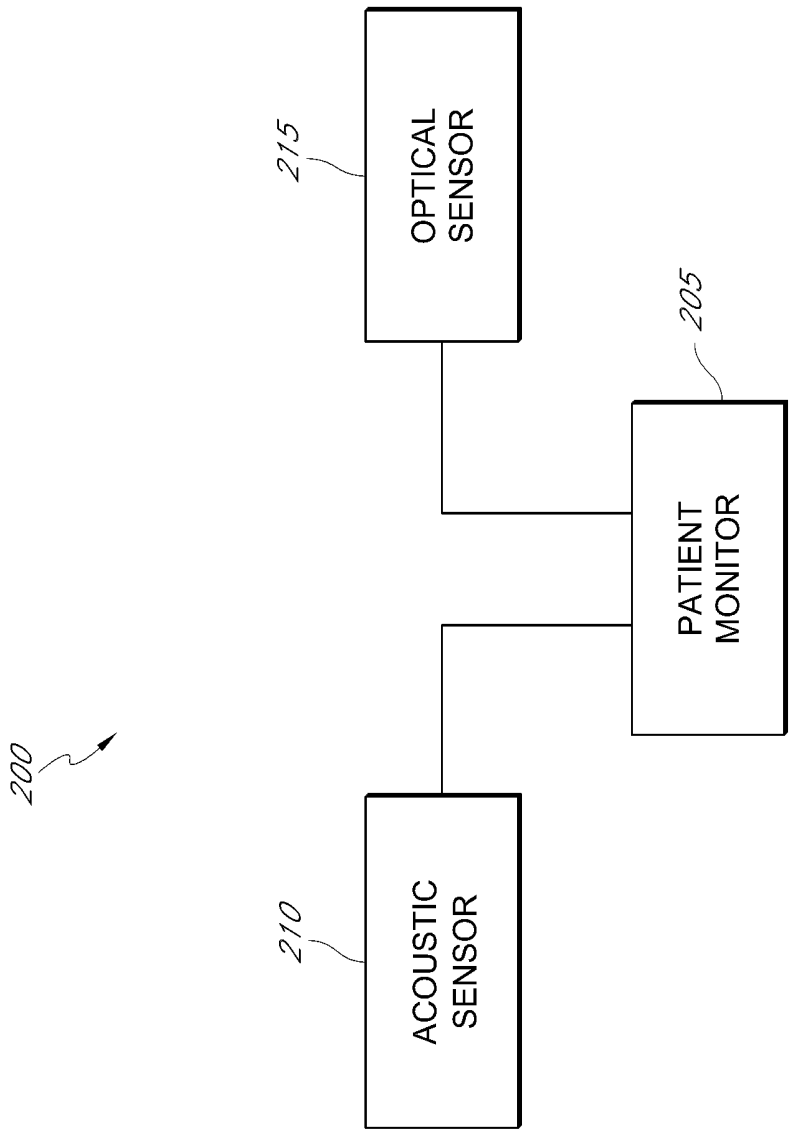
200
215
OPTICAL SENSOR
205
PATIENT MONITOR
210
ACOUSTIC SENSOR

FIG. 2

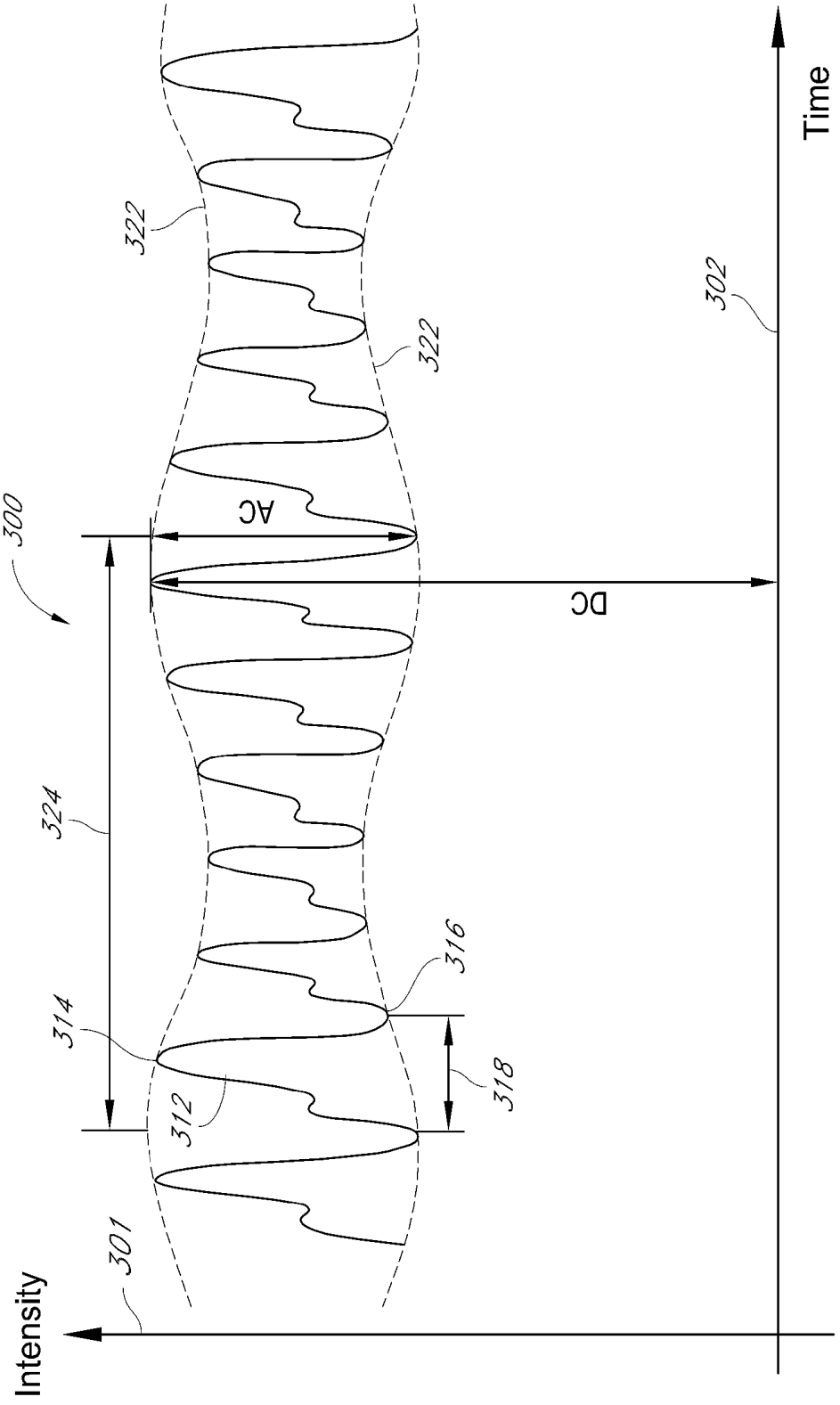

FIG. 3A

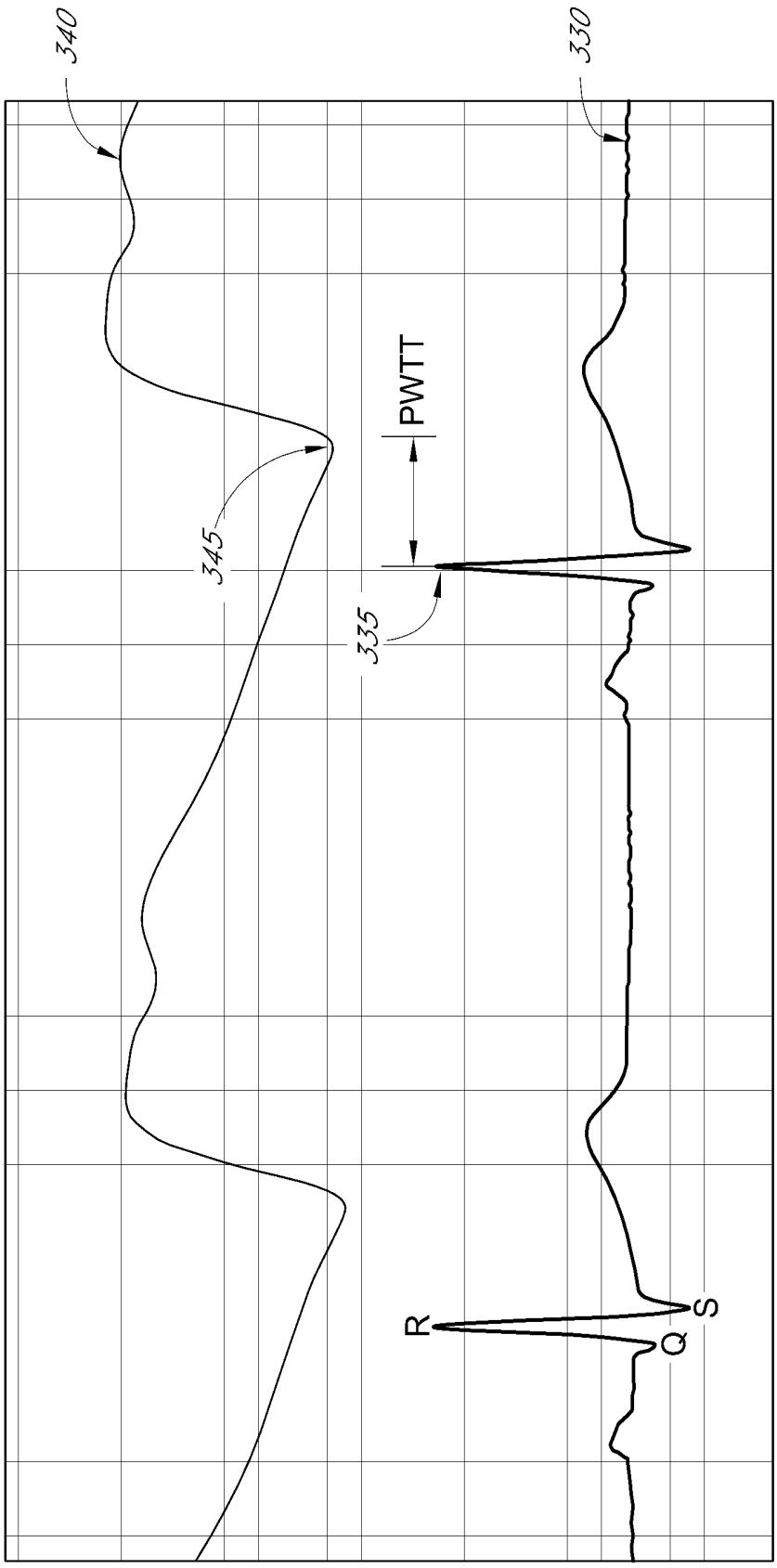

FIG. 3B

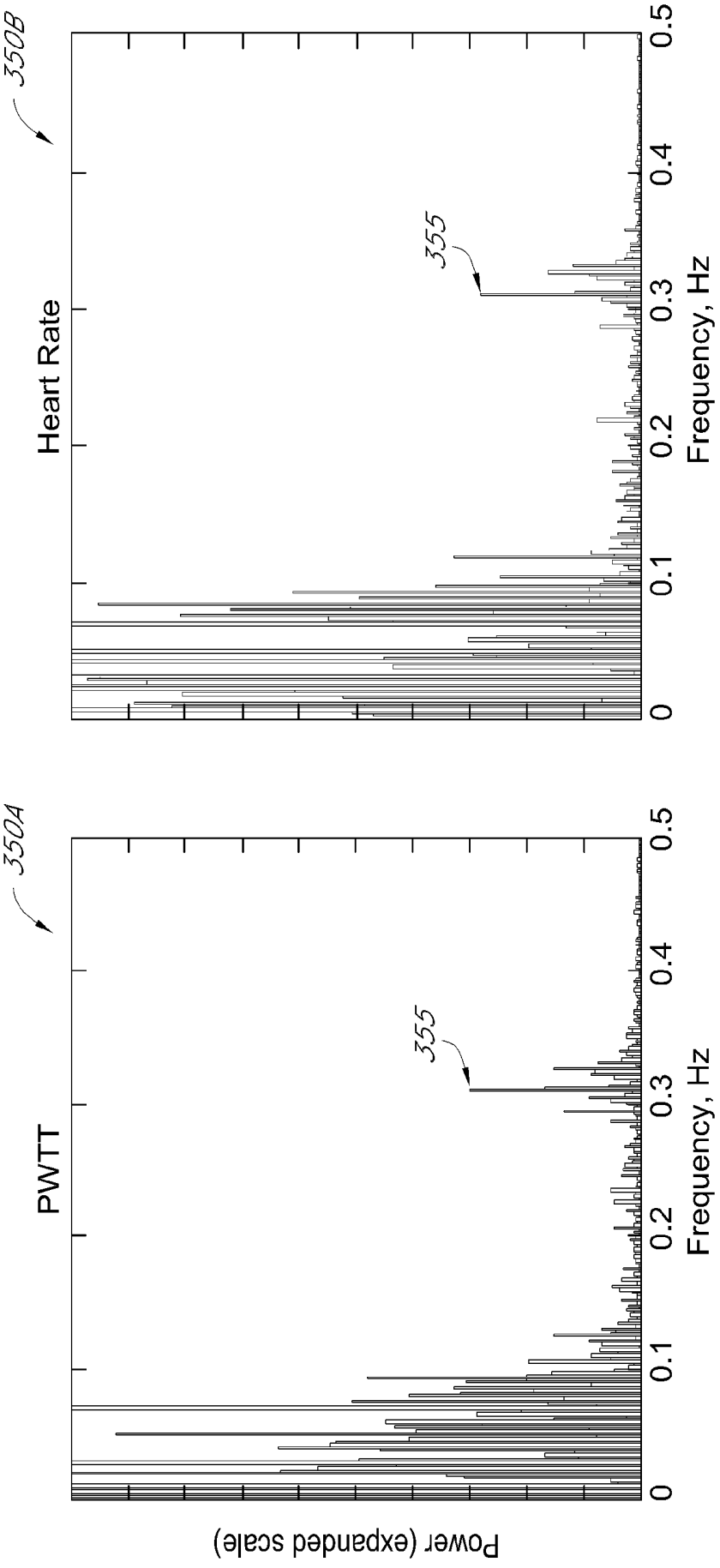
350B
Heart Rate
355
0
0.1
0.2
0.3
0.4
0.5
Frequency, Hz
350A
PWTT
355
0
0.1
0.2
0.3
0.4
0.5
Frequency, Hz
Power (expanded scale)

FIG. 3C

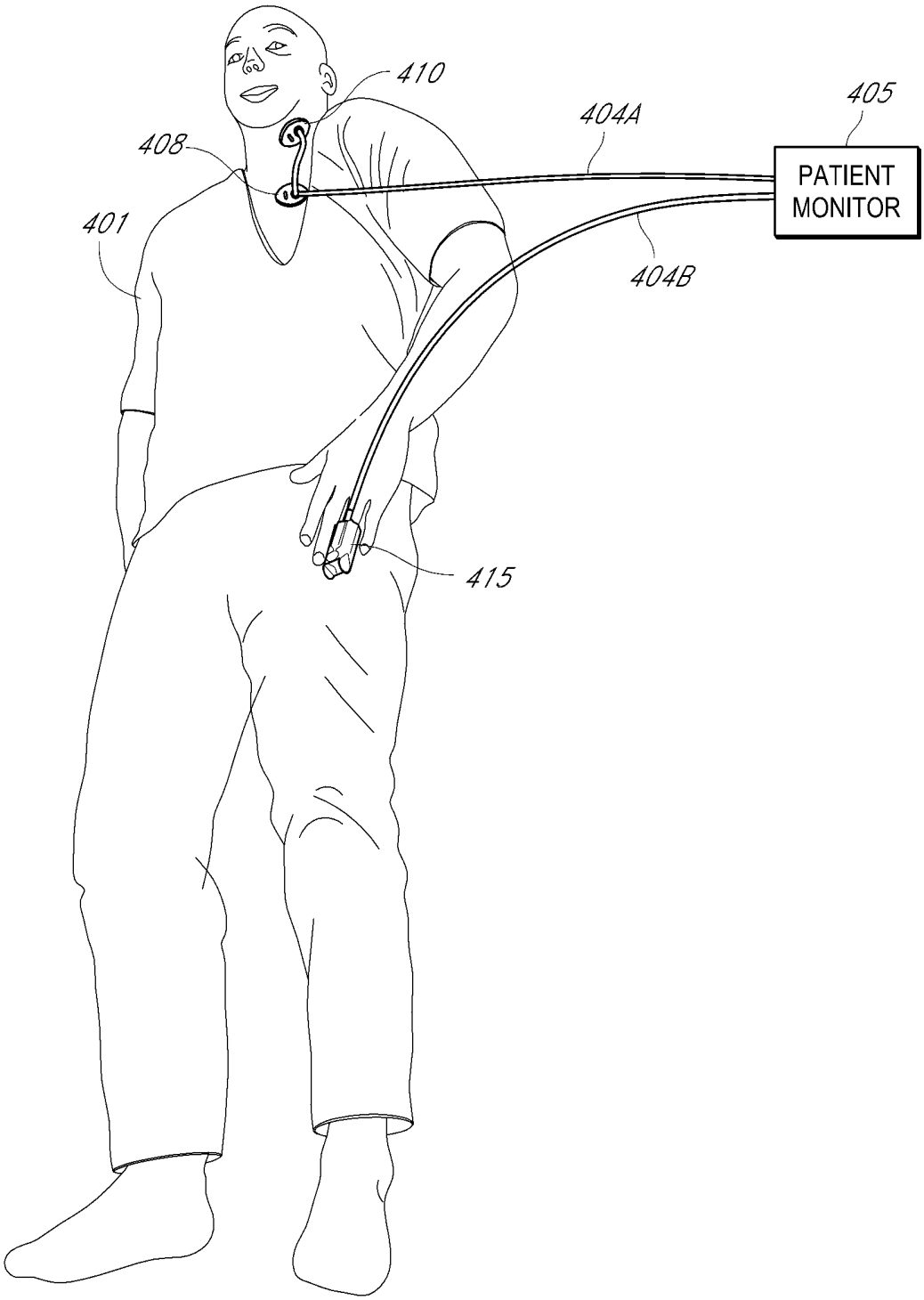

FIG. 4

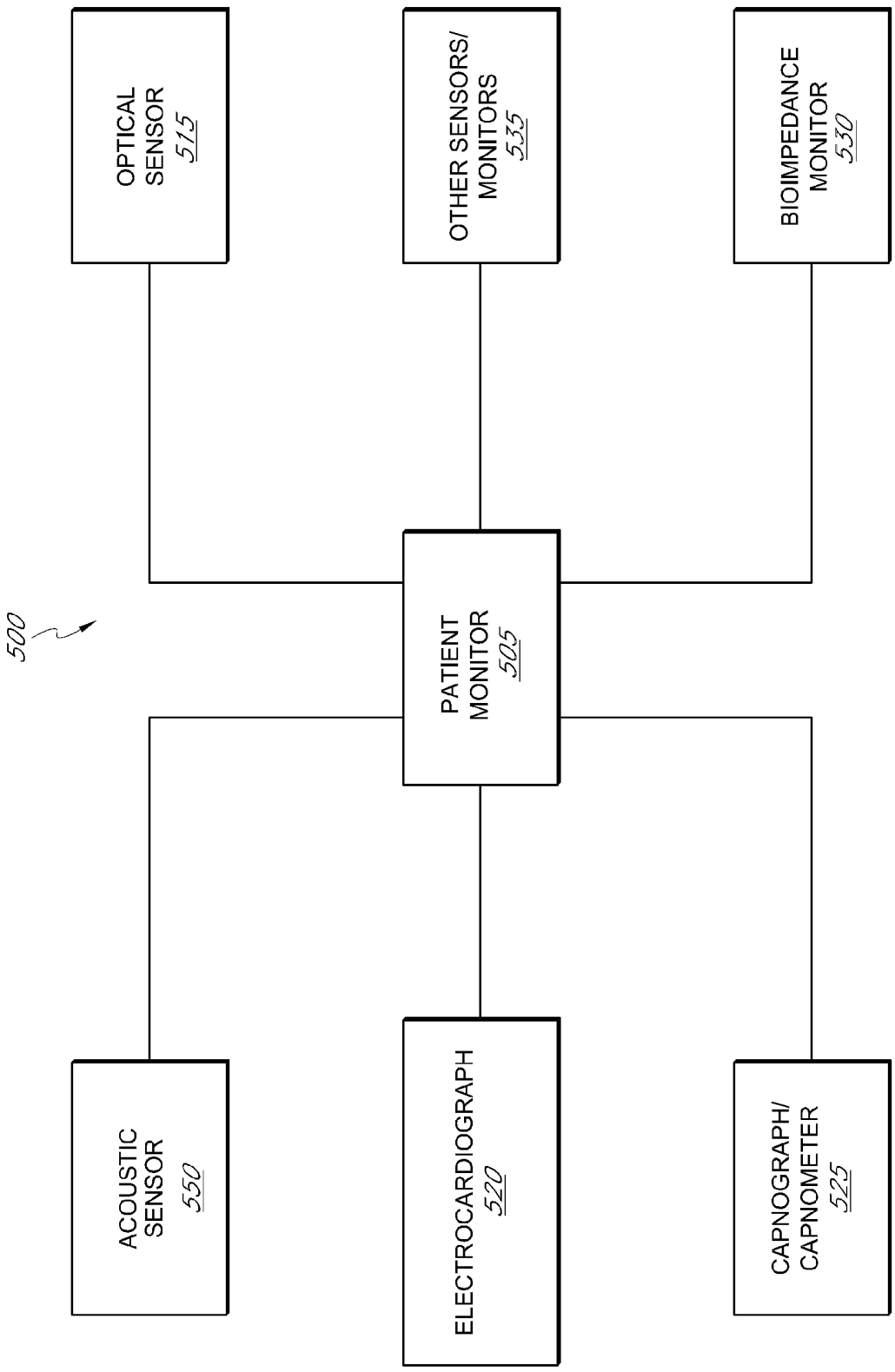
500
PATIENT MONITOR 505
OPTICAL SENSOR 515
OTHER SENSORS/ MONITORS 535
BIOIMPEDANCE MONITOR 530
ACOUSTIC SENSOR 550
ELECTROCARDIOGRAPH 520
CAPNOGRAPH/ CAPNOMETER 525

FIG. 5

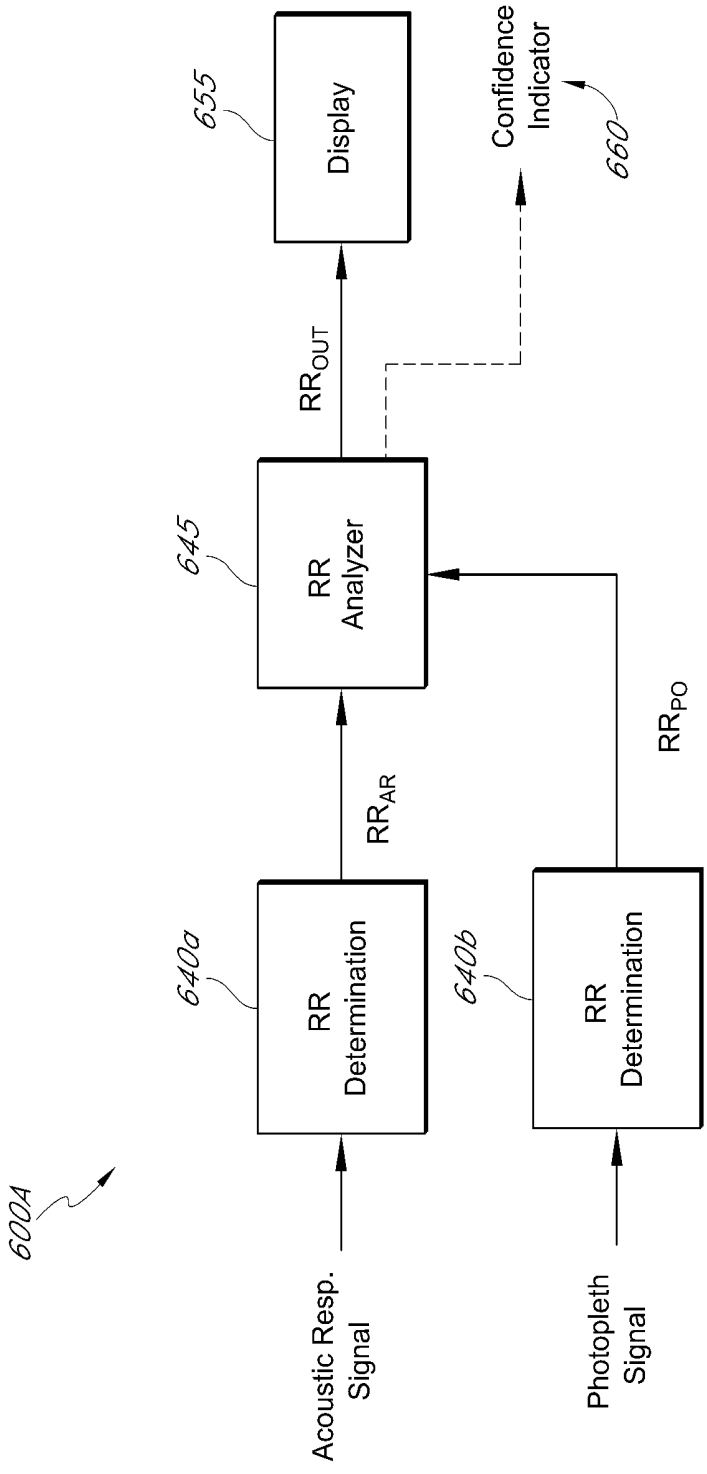
600A
Acoustic Resp. Signal
Photopleth Signal
640a
RR Determination
640b
RR Determination
RR_AR
RR_PO
645
RR Analyzer
RR_OUT
655
Display
Confidence Indicator
660

FIG. 6A

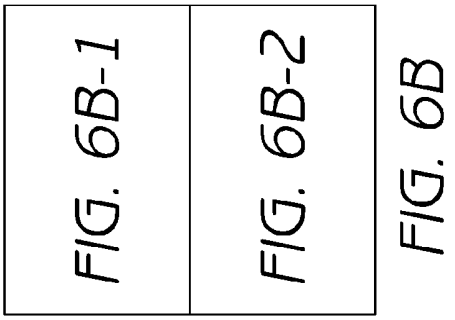

FIG. 6B

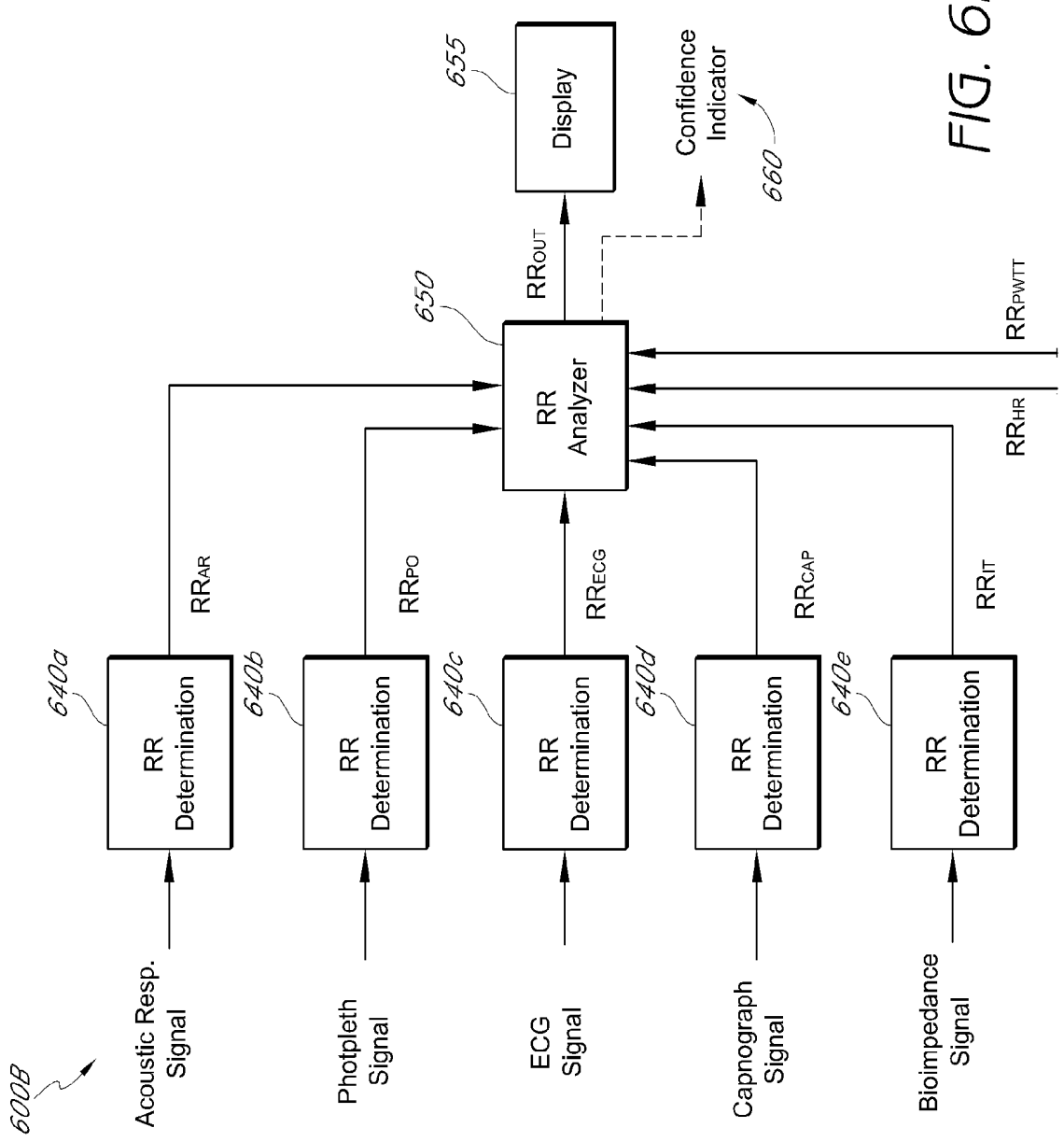

FIG. 6B-1

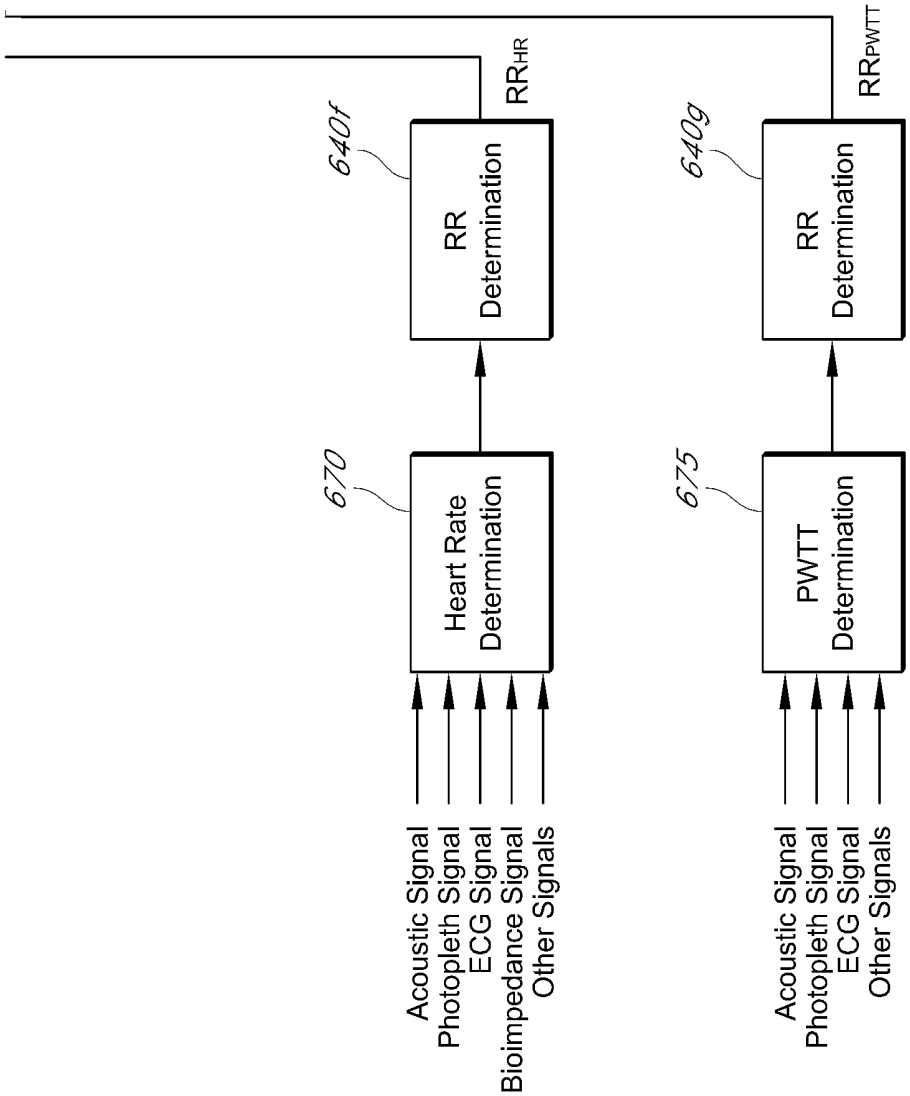
Acoustic Signal
Photopleth Signal
ECG Signal
Bioimpedance Signal
Other Signals
670
Heart Rate Determination
640f
RR Determination
RRHR
Acoustic Signal
Photopleth Signal
ECG Signal
Other Signals
675
PWTT Determination
640g
RR Determination
RRPWTT

FIG. 6B-2

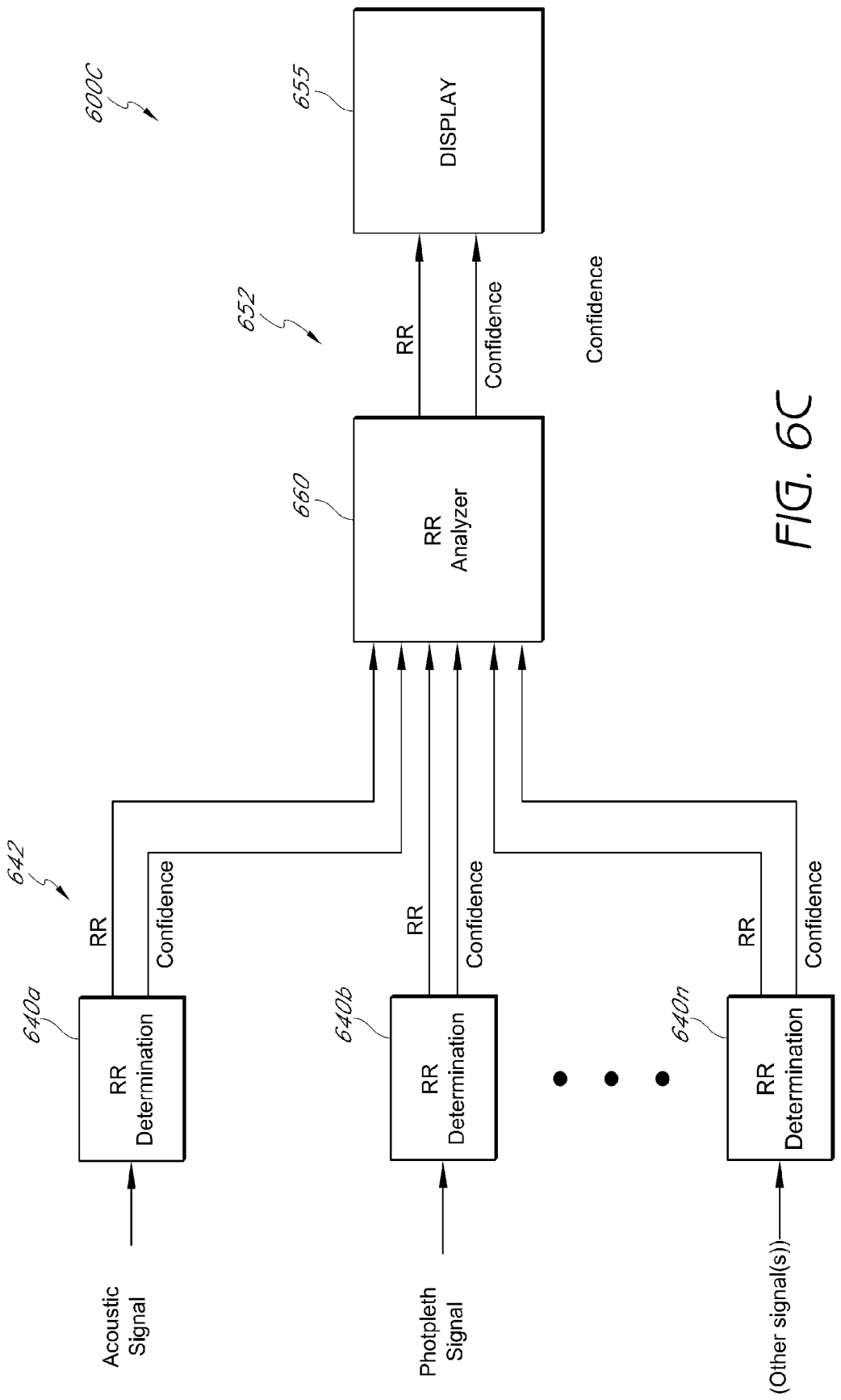
600C
655
DISPLAY
652
RR
Confidence
Confidence
660
RR Analyzer
642
RR
Confidence
RR
Confidence
RR
Confidence
640a
RR Determination
640b
RR Determination
640n
RR Determination
Acoustic Signal
Photpleth Signal
(Other signal(s))

FIG. 6C

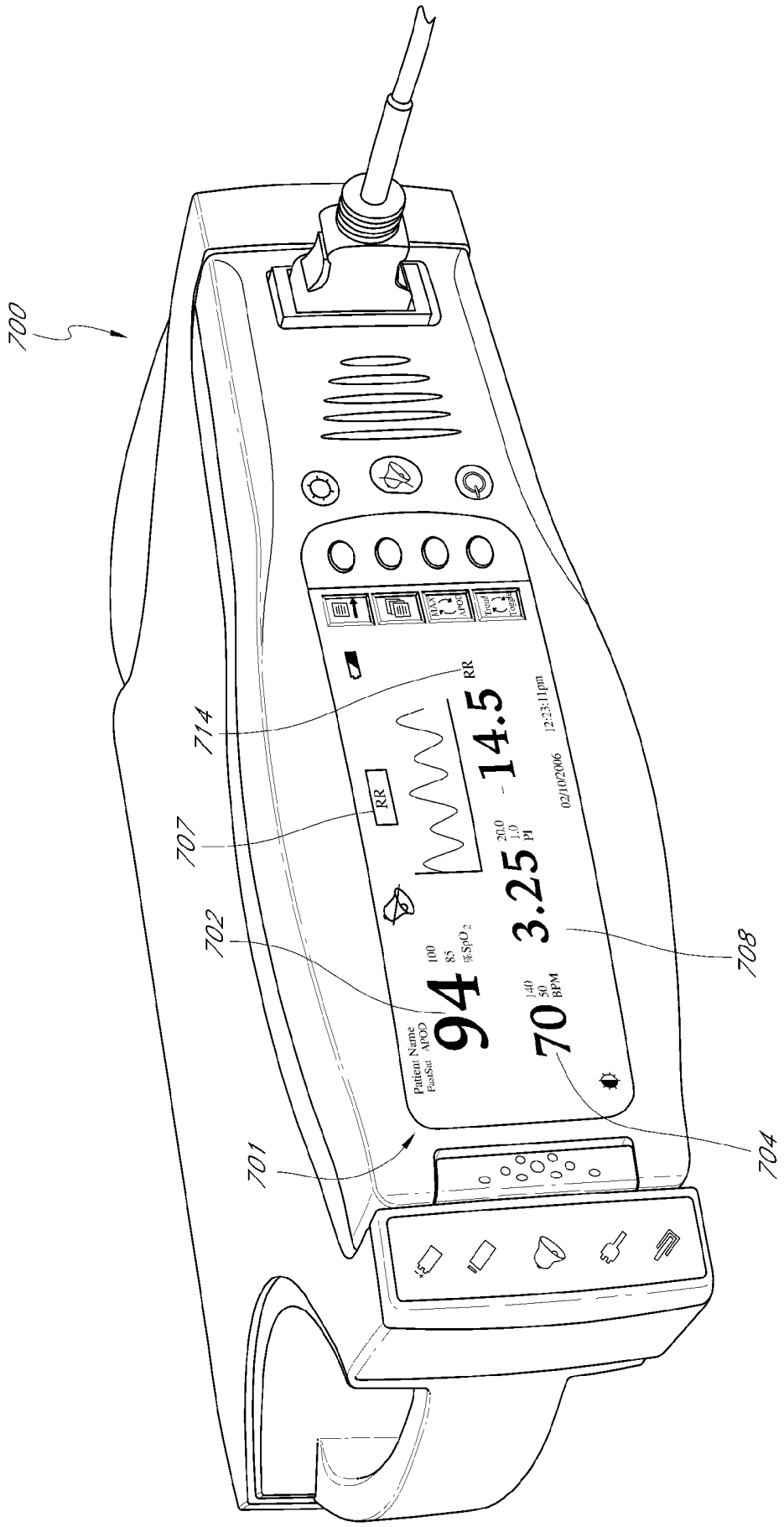
700
701
702
704
707
708
714
RR
14.5
3.25
94
70
%SpO2
BPM
PI
02/10/2006
12:23:11pm
Patient Name
APOD

FIG. 7

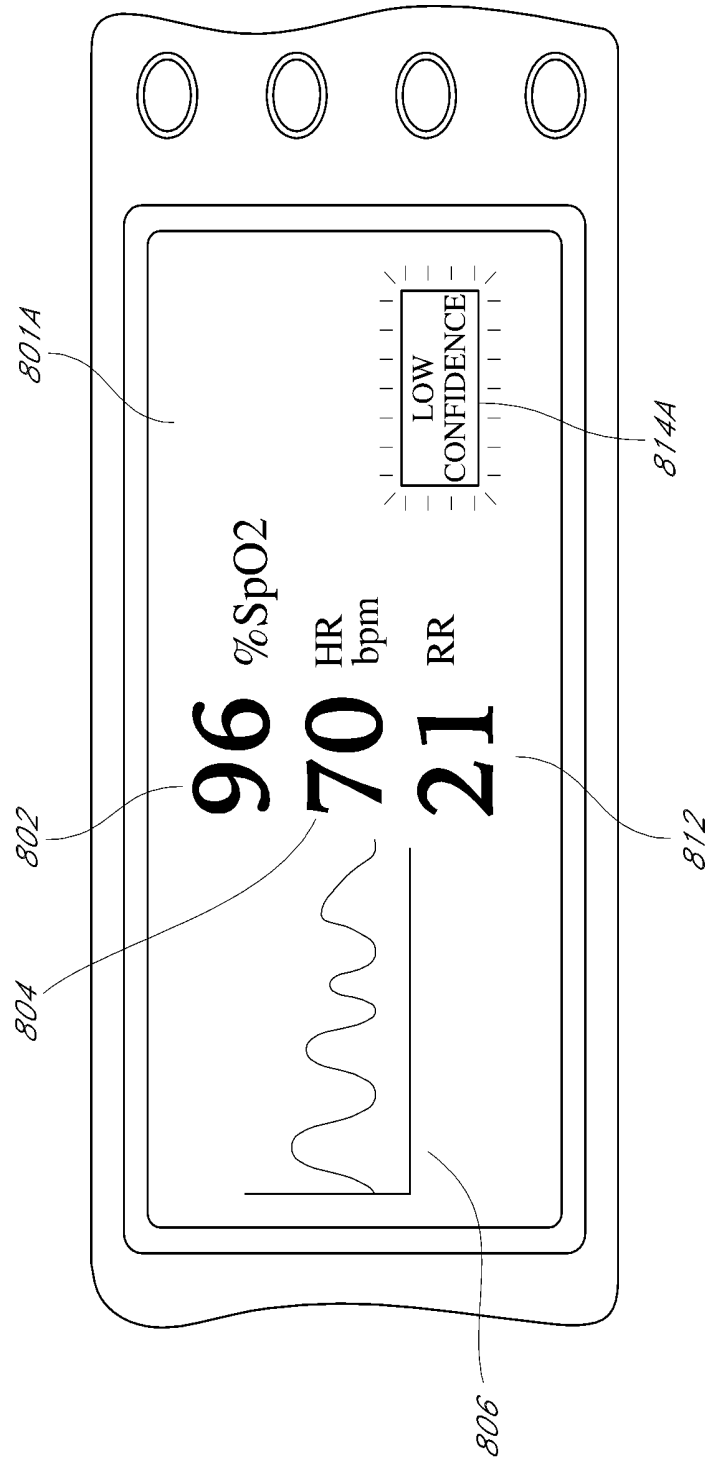
801A
LOW
CONFIDENCE
814A
96
%SpO2
HR
bpm
70
RR
21
802
804
812
806

FIG. 8A

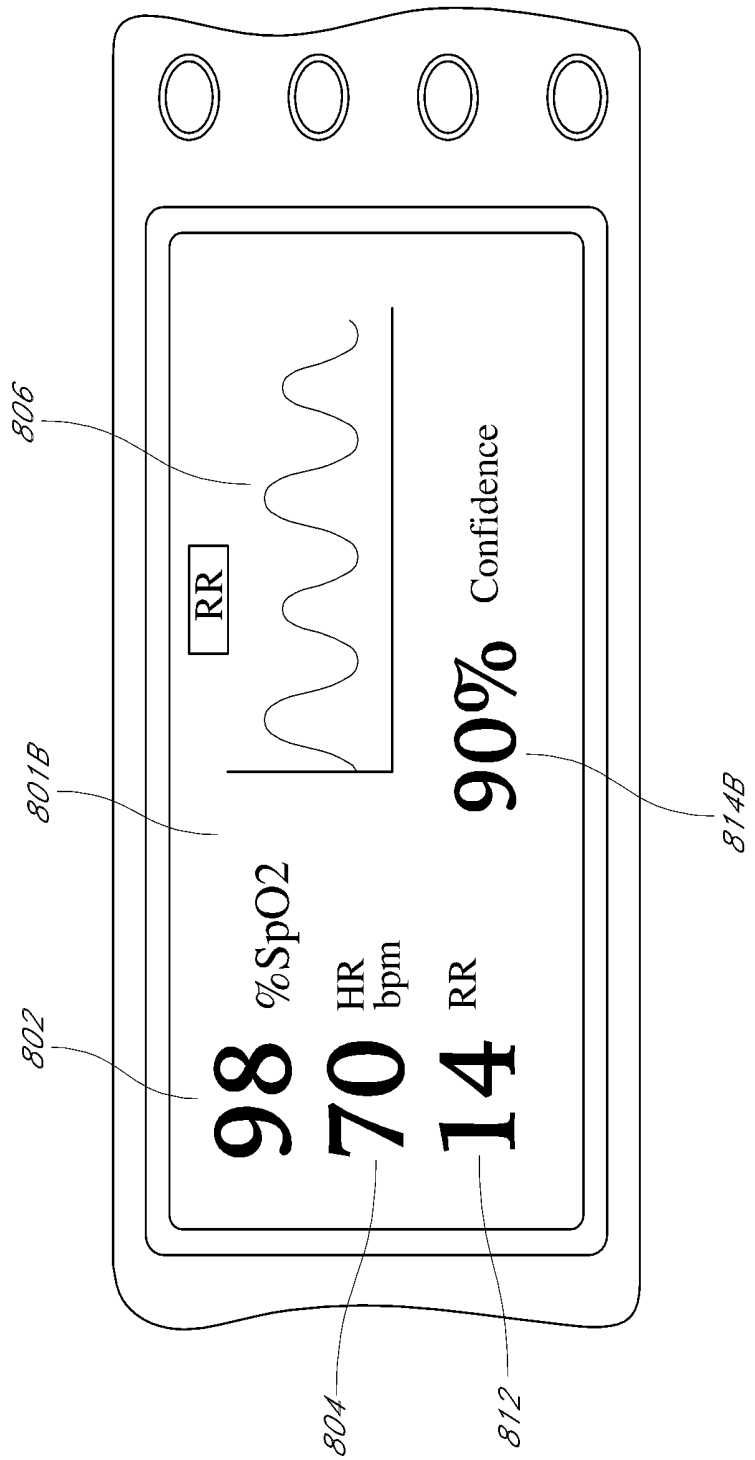
806
801B
802
804
812
814B
RR
98
%SpO2
70
HR
bpm
14
RR
90%
Confidence

FIG. 8B

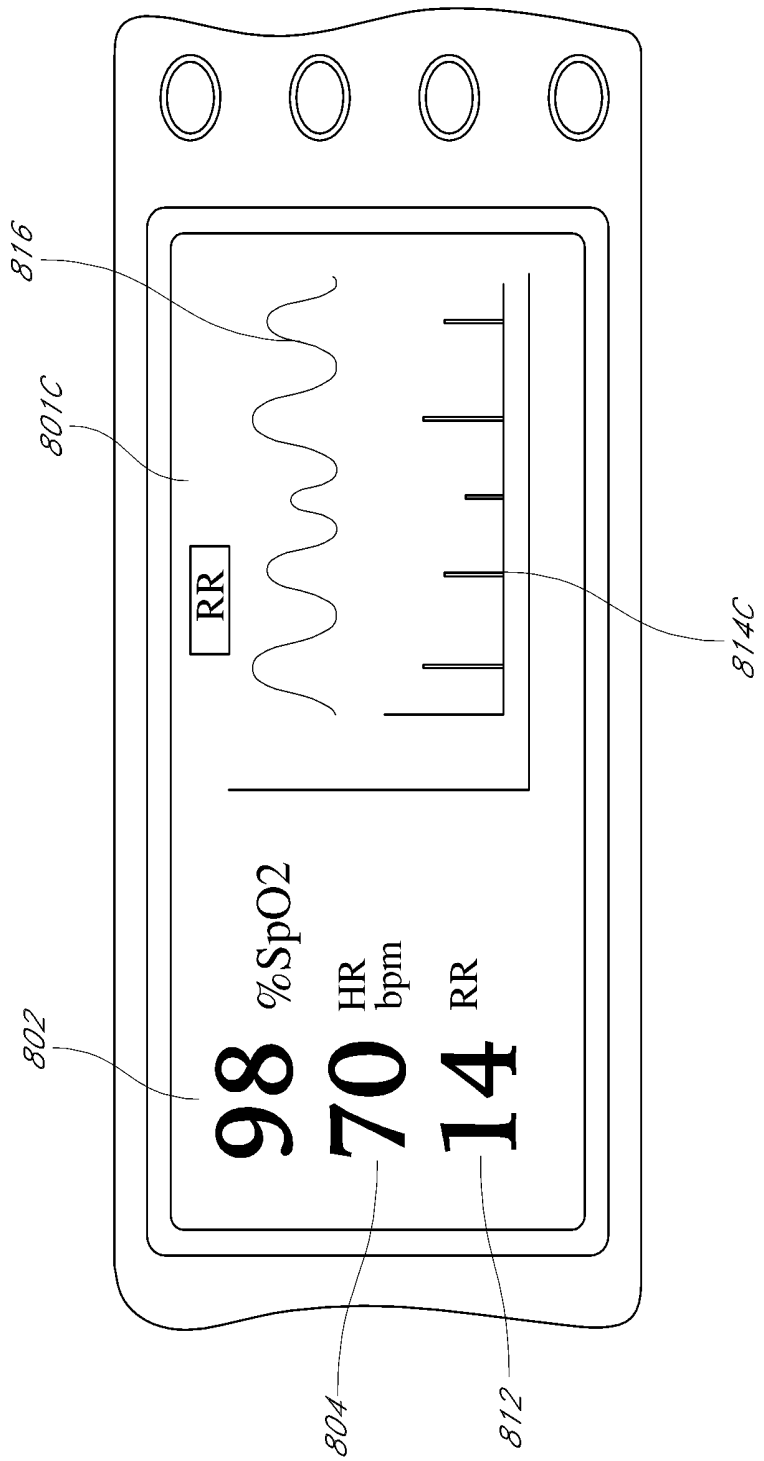

FIG. 8C

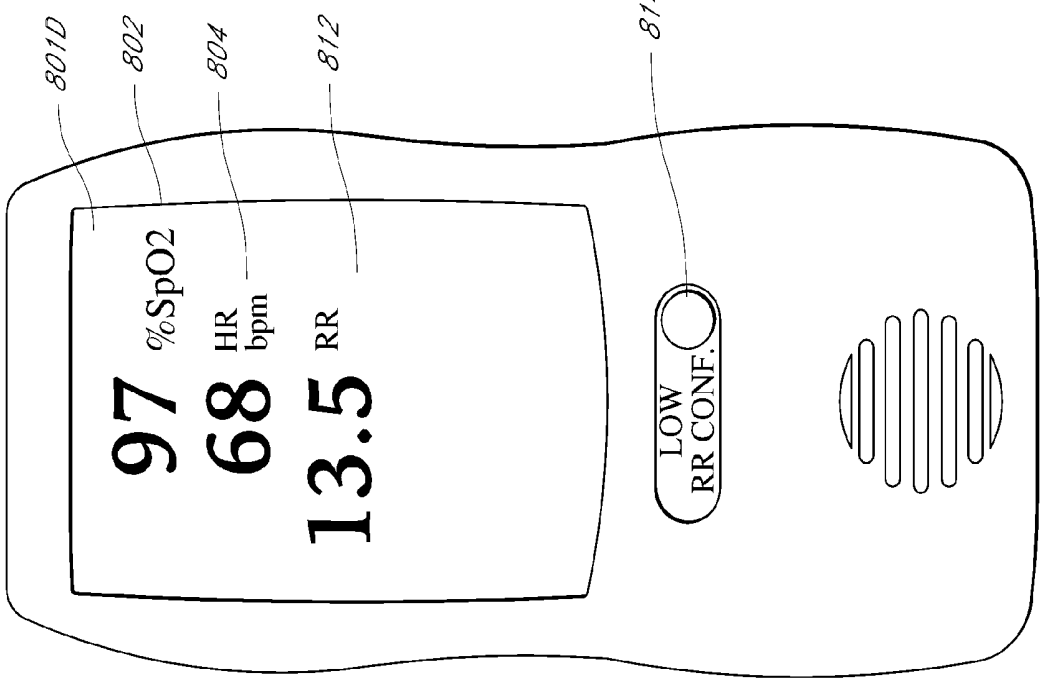

FIG. 8D

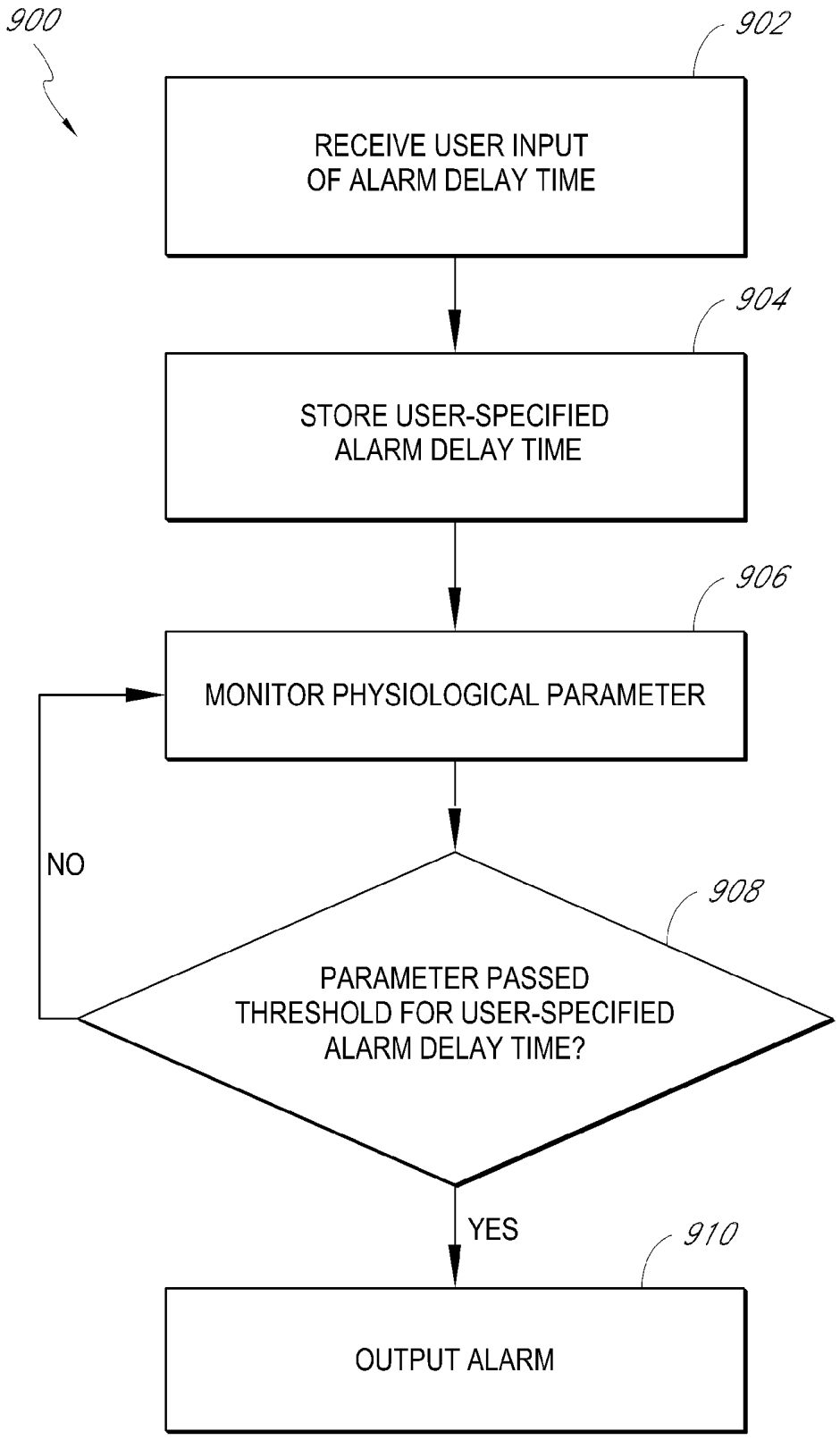
900
902
RECEIVE USER INPUT OF ALARM DELAY TIME
904
STORE USER-SPECIFIED ALARM DELAY TIME
906
MONITOR PHYSIOLOGICAL PARAMETER
NO
908
PARAMETER PASSED THRESHOLD FOR USER-SPECIFIED ALARM DELAY TIME?
YES
910
OUTPUT ALARM

FIG. 9

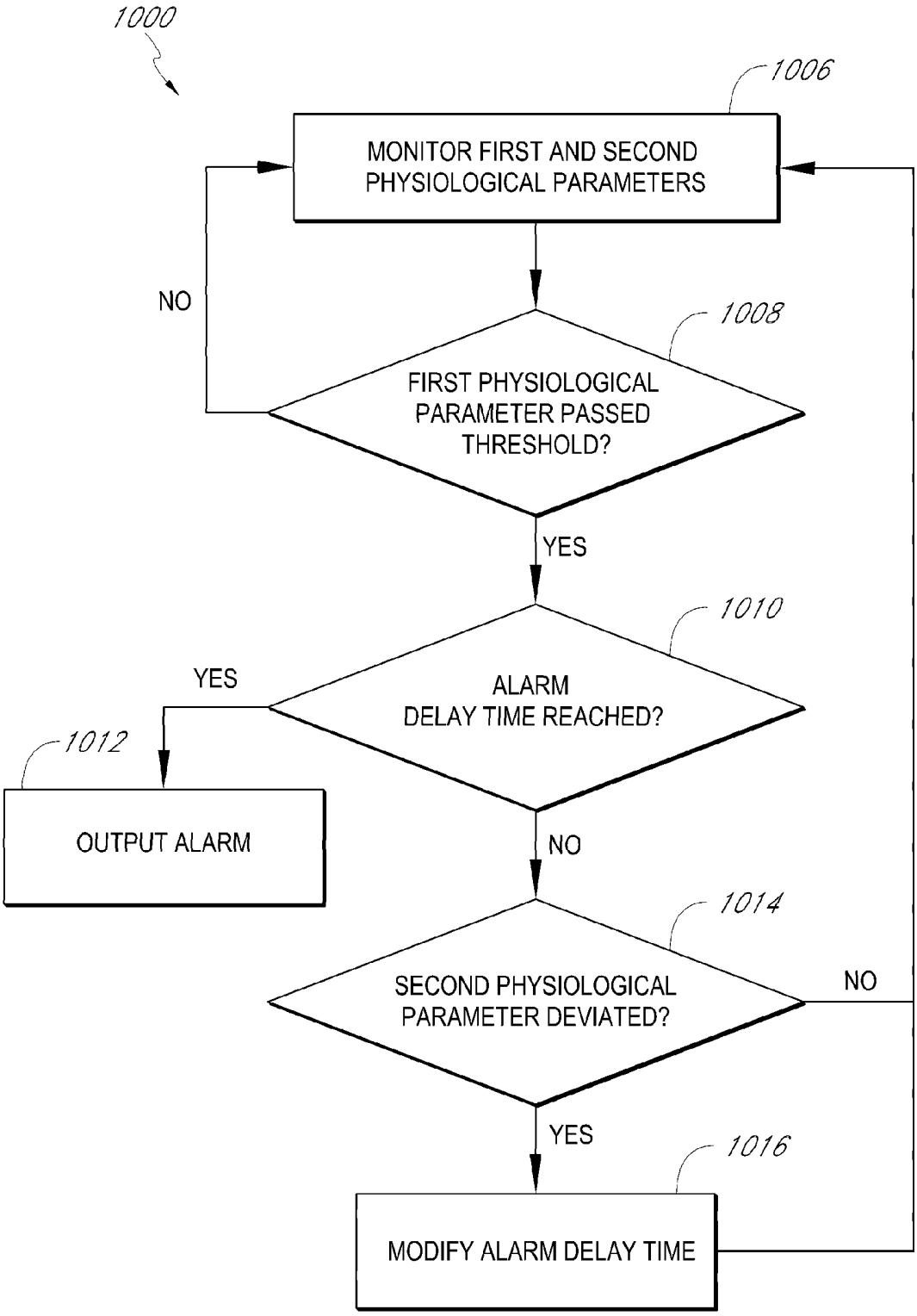
1000
1006
MONITOR FIRST AND SECOND PHYSIOLOGICAL PARAMETERS
NO
1008
FIRST PHYSIOLOGICAL PARAMETER PASSED THRESHOLD?
YES
1010
YES
ALARM DELAY TIME REACHED?
1012
OUTPUT ALARM
NO
1014
SECOND PHYSIOLOGICAL PARAMETER DEVIATED?
NO
YES
1016
MODIFY ALARM DELAY TIME

FIG. 10

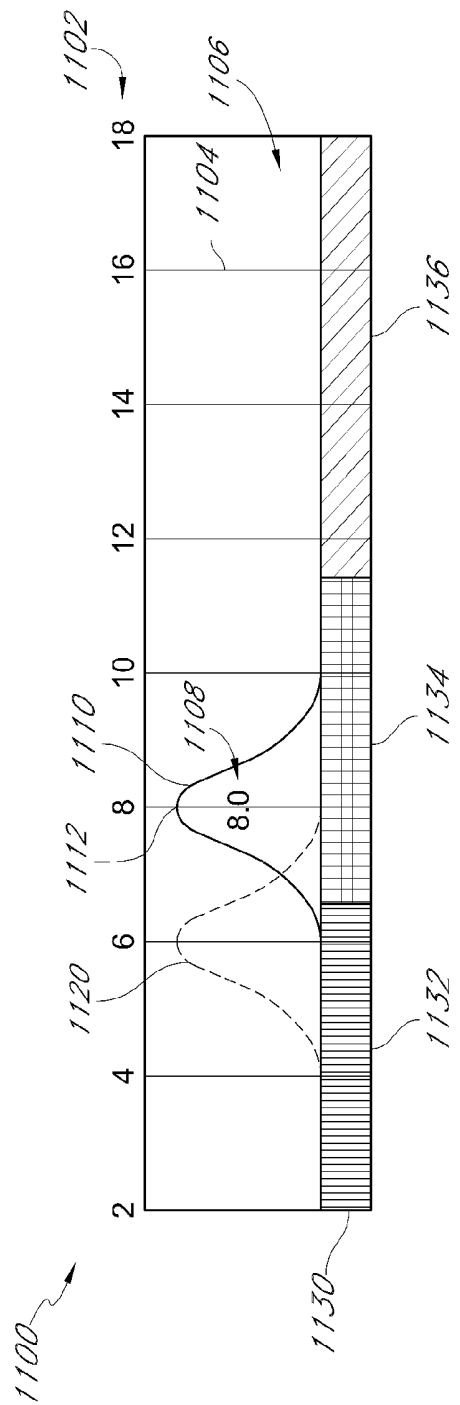

FIG. 11

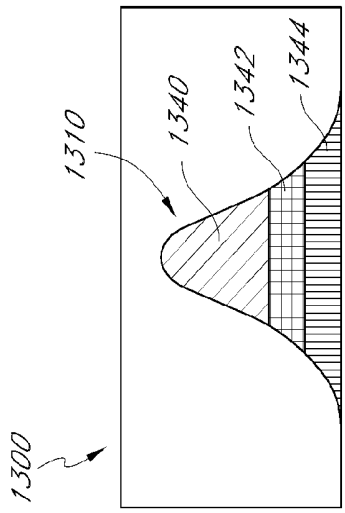

FIG. 13

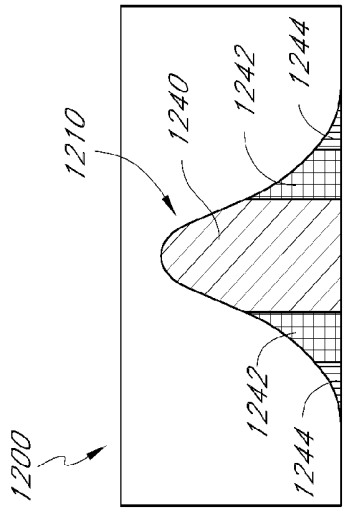

FIG. 12

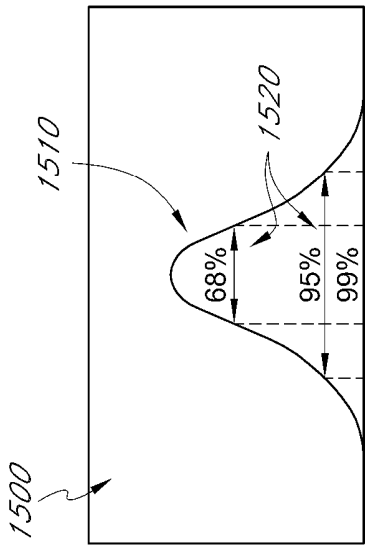

FIG. 15

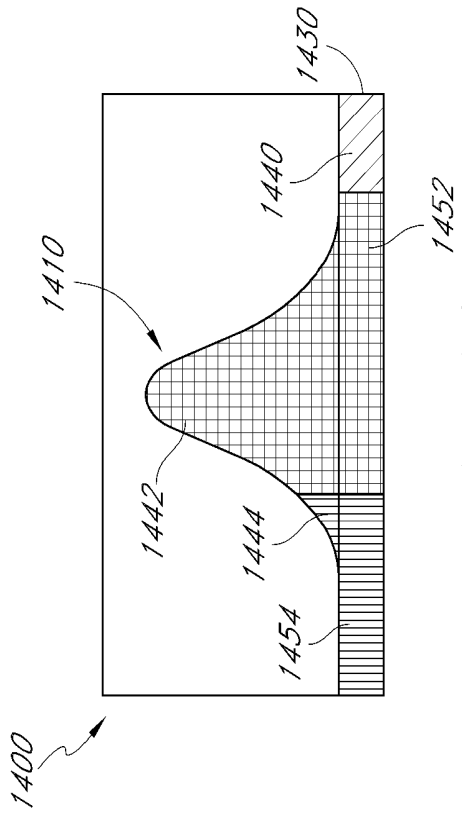

FIG. 14

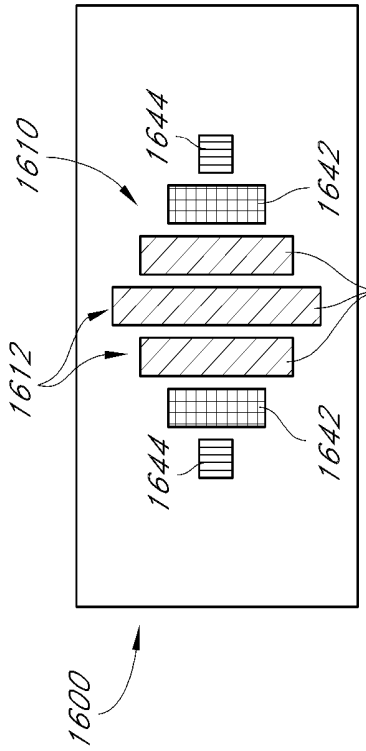

FIG. 16

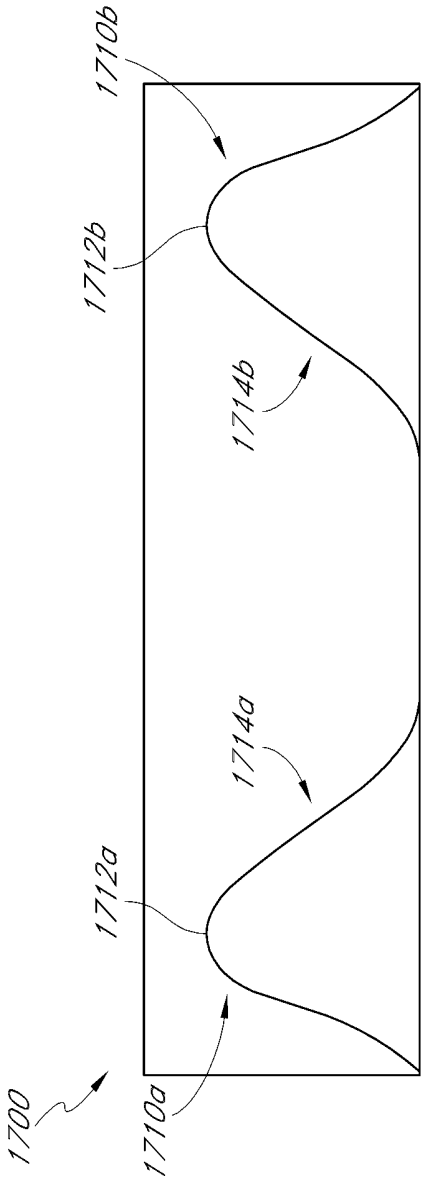

FIG. 17

SYSTEM FOR DETERMINING CONFIDENCE IN RESPIRATORY RATE MEASUREMENTS

RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/905,449, filed Oct. 15, 2010, entitled "SYSTEM FOR DETERMINING CONFIDENCE IN RESPIRATORY RATE MEASUREMENTS," which claims priority from U.S. Provisional Patent Application No. 61/252,086 filed Oct. 15, 2009, entitled "Pulse Oximetry System for Determining Confidence in Respiratory Rate Measurements," from U.S. Provisional Patent Application No. 61/261,199, filed Nov. 13, 2009, entitled "Pulse Oximetry System with Adjustable Alarm Delay," and from U.S. Provisional Patent Application No. 61/366,866, filed Jul. 22, 2010, entitled "Pulse Oximetry System for Determining Confidence in Respiratory Rate Measurements," the disclosures of which are hereby incorporated by reference in their entirety.

BACKGROUND

Hospitals, nursing homes, and other patient care facilities typically include patient monitoring devices at one or more bedsides in the facility. Patient monitoring devices generally include sensors, processing equipment, and displays for obtaining and analyzing a patient's physiological parameters. Physiological parameters include, for example, blood pressure, respiratory rate, oxygen saturation (SpO_2) level, other blood constitutions and combinations of constitutions, and pulse, among others. Clinicians, including doctors, nurses, and certain other caregiver personnel use the physiological parameters obtained from the patient to diagnose illnesses and to prescribe treatments. Clinicians can also use the physiological parameters to monitor a patient during various clinical situations to determine whether to increase the level of care given to the patient. Various patient monitoring devices are commercially available from Masimo Corporation ("Masimo") of Irvine, Calif.

During and after surgery and in other care situations, respiratory rate is a frequently monitored physiological parameter of a patient. Respiratory rate can be indicated as the number of breaths a person takes within a certain amount of time, such as breaths per minute. For example, a clinician (such as a nurse, doctor, or the like) can use respiratory rate measurements to determine whether a patient is experiencing respiratory distress and/or dysfunction.

SUMMARY OF DISCLOSURE

A system for determining multiparameter confidence in a respiratory rate measurement from a medical patient, the system comprising: an optical sensor comprising: a light emitter configured to impinge light on body tissue of a living patient, the body tissue comprising pulsating blood, and a detector responsive to the light after attenuation by the body tissue, wherein the detector is configured to generate a photoplethysmographic signal indicative of a physiological characteristic of the living patient; an ECG sensor configured to obtain an electrical signal from the living patient; an acoustic sensor, the acoustic sensor configured to obtain an acoustic respiratory signal from the living patient; and a processor configured to: derive a first respiratory rate measurement from the acoustic respiratory signal, derive a second respiratory rate measurement from one or both of the photoplethysmographic signal and the electrical signal, and use the second respiratory rate measurement to calculate a confidence in the first respiratory rate measurement.

A system for determining confidence in a respiratory rate measurement from a medical patient, the system comprising: a first physiological sensor configured to obtain a physiological signal from a patient, the first physiological sensor comprising at least one of the following: an ECG sensor, a bioimpedance sensor, and a capnography sensor; an acoustic sensor configured to obtain an acoustic respiratory signal from the living patient; and a processor configured to: obtain a first respiratory rate measurement from the physiological signal, obtain a second respiratory rate measurement from the acoustic respiratory signal, and calculate a confidence in the first respiratory rate measurement responsive to the first and second respiratory rate measurements.

A method of analyzing respiratory rate monitoring parameters to determine confidence in a measured respiratory rate, the method comprising: obtaining a first respiratory measurement from a first physiological device, the first physiological device comprising an acoustic sensor; obtaining a second respiratory measurement from a second physiological device; determining a third respiratory rate measurement based at least in part on the first and second respiratory rate measurements; and outputting the third respiratory rate measurement.

For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the inventions have been described herein. It is to be understood that not necessarily all such advantages can be achieved in accordance with any particular embodiment of the inventions disclosed herein. Thus, the inventions disclosed herein can be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as can be taught or suggested herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Throughout the drawings, reference numbers can be reused to indicate correspondence between referenced elements. The drawings are provided to illustrate embodiments of the inventions described herein and not to limit the scope thereof.

FIGS. **1**A-B are block diagrams illustrating physiological monitoring systems in accordance with embodiments of the disclosure;

FIG. **1**C is a top perspective view illustrating portions of a sensor assembly in accordance with an embodiment of the disclosure;

FIG. **2** illustrates a block diagram of an embodiment of a multiparameter patient monitoring system that includes an acoustic respiratory monitoring (ARM) sensor and an optical sensor.

FIG. **3**A illustrates an embodiment of an envelope of a photoplethysmograph waveform.

FIG. **3**B schematically illustrates an example calculation of pulse wave transit time from two physiological signal inputs.

FIG. **3**C illustrates example power spectrum plots of pulse wave transit time variability and heart rate variability for determining respiratory rate measurements.

FIG. **4** illustrates an embodiment of the multiparameter patient monitoring system of FIG. **2** coupled to a patient.

FIG. **5** illustrates a block diagram of an embodiment of a multiparameter patient monitoring system.

FIGS. **6**A through **6**C illustrate block diagrams of embodiments of respiratory rate measurement calculation systems.

FIG. **7** illustrates an example multiparameter physiological monitor.

FIGS. **8**A through **8**D illustrate example multiparameter physiological monitor displays.

FIG. **9** illustrates an embodiment of a patient monitoring process in which a user can specify a delay time for an alarm to be triggered.

FIG. **10** illustrates an embodiment of a multiparameter patient monitoring process that allows for dynamic modification of an alarm delay.

FIGS. **11** through **17** illustrate embodiments of parameter confidence displays.

DETAILED DESCRIPTION

Acoustic sensors, including piezoelectric acoustic sensors, can be used to measure breath sounds and other biological sounds of a patient. Breath sounds obtained from an acoustic sensor placed on the neck, chest, and/or other suitable location can be processed by a patient monitor to derive one or more physiological parameters of a patient, including respiratory rate. Respiratory rate can also be determined from other physiological signals (for example, an ECG signal, a plethysmographic signal, a bioimpedance signal, and/or the like) obtained using other sensors and/or instruments.

Respiratory rate measurements derived from a single sensor or sensor type can be less accurate at times due to noise, sensor limitations, body movement, and/or other reasons. Accordingly, improved multiparameter respiratory rate measurements can be obtained by jointly processing multiple physiological signals from multiple sensors and/or sensor types. Alternately, or in addition, respiratory rate measurements derived from a physiological signal obtained from one type of sensor can be used to continuously or periodically refine or assess confidence in the respiratory rate measurements derived from a physiological signal obtained from another type of sensor. For example, in certain embodiments, respiratory rate measurements derived from a plethysmographic signal obtained by an optical sensor can be used to improve or determine confidence in the respiratory rate derived from an acoustic signal obtained by an acoustic sensor.

This disclosure describes, among other features, systems and methods for using multiple physiological signals to improve respiratory or other physiological parameter measurements reflective of a patient's condition and/or to determine confidence in these physiological parameter measurements. In certain embodiments, a patient monitoring system comprises one or more physiological sensors applied to a living patient and a processor to monitor the physiological signals received from physiological sensors. The physiological sensors can include, for example, acoustic sensors for acquiring breath and/or heart sounds, electrodes for acquiring ECG and/or bioimpedance signals, and noninvasive optical sensors to perform pulse oximetry and related noninvasive analysis of blood constituents.

In particular, in certain embodiments, a patient monitoring system can programmatically determine multiparameter confidence in respiratory rate measurements obtained from an acoustic sensor based at least partly on inputs obtained from other non-acoustic sensors or monitors. The patient monitoring system can output a multiparameter confidence indication reflective of the programmatically-determined multiparameter confidence. The multiparameter confidence indication can assist a clinician in determining whether or how to treat a patient based on the patient's respiratory rate.

In certain embodiments, the patient monitoring system can determine the multiparameter confidence at least in part by receiving signals from multiple physiological parameter monitoring devices that are reflective of respiratory rate. For example, a multiparameter patient monitoring unit can receive a signal reflective of a respiratory rate from both an acoustic sensor and an optical sensor. Respiratory rate measurements can be extracted and/or derived from each of the physiological parameter signals. The respiratory rate measurement from the acoustic sensor can be compared with the respiratory rate measurement derived from the optical sensor signal. Based at least partly on this comparison, a determination of multiparameter confidence in the acoustically-derived respiratory rate can be made. A visual or audible indicator corresponding to this multiparameter confidence determination, including possibly an alarm, can be output for presentation to a clinician.

Additionally, in certain embodiments, the respiratory rate measurement output to the clinician can be generated based at least partly on a combination of the multiple respiratory rate measurements. For example, a respiratory rate measurement derived from an optical sensor signal can be combined with a respiratory rate measurement derived from an acoustic sensor signal to produce an overall respiratory rate. The overall respiratory rate measurement can be output to the patient monitor display and/or can be output over a network to another device.

Moreover, in certain embodiments, the patient monitoring systems and methods disclosed herein can assess multiparameter confidence and/or determine respiratory rate based at least partly on signals received from other physiological parameter monitoring devices. For example, various measurements obtained from a capnograph, an electrocardiograph (ECG), a bioimpedance device, or from other monitoring devices or sensors can be used to assess multiparameter confidence in acoustic respiratory rate measurements and/or to determine an overall respiratory rate output.

For purposes of illustration, this disclosure is described primarily in the context of respiratory rate. However, the features described herein can be applied to other respiratory parameters, including, for example, inspiratory time, expiratory time, inspiratory to expiratory ratio, inspiratory flow, expiratory flow, tidal volume, minute volume, apnea duration, breath sounds (including, e.g., rales, rhonchi, or stridor), changes in breath sounds, and the like. Moreover, the features described herein can also be applied to other physiological parameters and/or vital signs. For example, outputs from multiple monitoring devices or sensors (e.g., an optical sensor and an ECG monitor) can be used to assess multiparameter confidence in heart rate measurements, among other parameters.

Referring to the drawings, FIGS. **1**A through **1**C illustrate example patient monitoring systems, sensors, and cables that can be used to derive a respiratory rate measurement from a patient. FIGS. **2** through **8** illustrate multiparameter respiratory rate embodiments. The embodiments of FIGS. **2** through **8** can be implemented at least in part using the systems and sensors described in FIGS. **1**A through **1**C.

Turning to FIG. **1**A, an embodiment of a physiological monitoring system **10** is shown. In the physiological monitoring system **10**, a medical patient **12** is monitored using one or more sensor assemblies **13**, each of which transmits a signal over a cable **15** or other communication link or

medium to a physiological monitor **17**. The physiological monitor **17** includes a processor **19** and, optionally, a display **11**. The one or more sensors **13** include sensing elements such as, for example, acoustic piezoelectric devices, electrical ECG leads, optical sensors, or the like. The sensors **13** can generate respective signals by measuring a physiological parameter of the patient **12**. The signals are then processed by one or more processors **19**. The one or more processors **19** then communicate the processed signal to the display **11**. In an embodiment, the display **11** is incorporated in the physiological monitor **17**. In another embodiment, the display **11** is separate from the physiological monitor **17**. In one embodiment, the monitoring system **10** is a portable monitoring system. In another embodiment, the monitoring system **10** is a pod, without a display, that is adapted to provide physiological parameter data to a display.

For clarity, a single block is used to illustrate the one or more sensors **13** shown in FIG. **1**A. It should be understood that the sensor **13** shown is intended to represent one or more sensors. In an embodiment, the one or more sensors **13** include a single sensor of one of the types described below. In another embodiment, the one or more sensors **13** include one or more acoustic sensors. In still another embodiment, the one or more sensors **13** include one or more acoustic sensors and one or more ECG sensors, optical sensors, bioimpedance sensors, capnography sensors, and the like. In each of the foregoing embodiments, additional sensors of different types are also optionally included. Other combinations of numbers and types of sensors are also suitable for use with the physiological monitoring system **10**.

In some embodiments of the system shown in FIG. **1**A, all of the hardware used to receive and process signals from the sensors are housed within the same housing. In other embodiments, some of the hardware used to receive and process signals is housed within a separate housing. In addition, the physiological monitor **17** of certain embodiments includes hardware, software, or both hardware and software, whether in one housing or multiple housings, used to receive and process the signals transmitted by the sensors **13**.

As shown in FIG. **1**B, the acoustic sensor assembly **13** can include a cable **25**. The cable **25** can include three conductors within an electrical shielding. One conductor **26** can provide power to a physiological sensor **13**, one conductor **28** can provide a ground signal from the physiological monitor **17**, and one conductor **28** can transmit signals from the sensor **13** to the physiological monitor **17**. For multiple sensors **13**, one or possibly more cables **13** can be provided.

In some embodiments, the ground signal is an earth ground, but in other embodiments, the ground signal is a patient ground, sometimes referred to as a patient reference, a patient reference signal, a return, or a patient return. In some embodiments, the cable **25** carries two conductors within an electrical shielding layer, and the shielding layer acts as the ground conductor. Electrical interfaces **23** in the cable **25** can enable the cable to electrically connect to electrical interfaces **21** in a connector **20** of the physiological monitor **17**. In another embodiment, the sensor assembly **13** and the physiological monitor **17** communicate wirelessly.

FIG. **1**C illustrates an embodiment of a sensor system **100** including a sensor assembly **101** and a monitor cable **111** suitable for use with any of the physiological monitors shown in FIGS. **1**A and **1**B. The sensor assembly **101** includes a sensor **115**, a cable assembly **117**, and a connector **105**. The sensor **115**, in one embodiment, includes a sensor subassembly **102** and an attachment subassembly **104**. The cable assembly **117** of one embodiment includes a sensor **107** and a patient anchor **103**. A sensor connector subassembly **105** is connected to the sensor cable **107**.

The sensor connector subassembly **105** can be removably attached to an instrument cable **111** via an instrument cable connector **109**. The instrument cable **111** can be attached to a cable hub **120**, which includes a port **121** for receiving a connector **112** of the instrument cable **111** and a second port **123** for receiving another cable. In certain embodiments, the second port **123** can receive a cable connected to an optical sensor or other sensor. In addition, the cable hub **120** could include additional ports in other embodiments for receiving additional cables. The hub includes a cable **122** which terminates in a connector **124** adapted to connect to a physiological monitor (not shown).

The sensor connector subassembly **105** and connector **109** can be configured to allow the sensor connector **105** to be straightforwardly and efficiently joined with and detached from the connector **109**. Embodiments of connectors having connection mechanisms that can be used for the connectors **105**, **109** are described in U.S. patent application Ser. No. 12/248,856 (hereinafter referred to as "the '856 application"), filed on Oct. 9, 2008, which is incorporated in its entirety by reference herein. For example, the sensor connector **105** could include a mating feature (not shown) which mates with a corresponding feature (not shown) on the connector **109**. The mating feature can include a protrusion which engages in a snap fit with a recess on the connector **109**. In certain embodiments, the sensor connector **105** can be detached via one hand operation, for example. Examples of connection mechanisms can be found specifically in paragraphs [0042], [0050], [0051], [0061]-[0068] and [0079], and with respect to FIGS. 8A-F, 13A-E, 19A-F, 23A-D and 24A-C of the '856 application, for example.

The sensor connector subassembly **105** and connector **109** can reduce the amount of unshielded area in and generally provide enhanced shielding of the electrical connection between the sensor and monitor in certain embodiments. Examples of such shielding mechanisms are disclosed in the '856 application in paragraphs [0043]-[0053], [0060] and with respect to FIGS. 9A-C, 11A-E, 13A-E, 14A-B, 15A-C, and 16A-E, for example.

In an embodiment, the acoustic sensor assembly **101** includes a sensing element, such as, for example, a piezoelectric device or other acoustic sensing device. The sensing element can generate a voltage that is responsive to vibrations generated by the patient, and the sensor can include circuitry to transmit the voltage generated by the sensing element to a processor for processing. In an embodiment, the acoustic sensor assembly **101** includes circuitry for detecting and transmitting information related to biological sounds to a physiological monitor. These biological sounds can include heart, breathing, and/or digestive system sounds, in addition to many other physiological phenomena. The acoustic sensor **115** in certain embodiments is a biological sound sensor, such as the sensors described herein. In some embodiments, the biological sound sensor is one of the sensors such as those described in the '883 application. In other embodiments, the acoustic sensor **115** is a biological sound sensor such as those described in U.S. Pat. No. 6,661,161, which is incorporated by reference herein in its entirety. Other embodiments include other suitable acoustic sensors.

The attachment sub-assembly **104** includes first and second elongate portions **106**, **108**. The first and second elongate portions **106**, **108** can include patient adhesive (e.g., in some embodiments, tape, glue, a suction device, etc.). The adhesive on the elongate portions **106**, **108** can be used to

secure the sensor subassembly **102** to a patient's skin. One or more elongate members **110** included in the first and/or second elongate portions **106**, **108** can beneficially bias the sensor subassembly **102** in tension against the patient's skin and reduce stress on the connection between the patient adhesive and the skin. A removable backing can be provided with the patient adhesive to protect the adhesive surface prior to affixing to a patient's skin.

The sensor cable **107** can be electrically coupled to the sensor subassembly **102** via a printed circuit board ("PCB") (not shown) in the sensor subassembly **102**. Through this contact, electrical signals are communicated from the multi-parameter sensor subassembly to the physiological monitor through the sensor cable **107** and the cable **111**.

In various embodiments, not all of the components illustrated in FIG. **1**C are included in the sensor system **100**. For example, in various embodiments, one or more of the patient anchor **103** and the attachment subassembly **104** are not included. In one embodiment, for example, a bandage or tape is used instead of the attachment subassembly **104** to attach the sensor subassembly **102** to the measurement site. Moreover, such bandages or tapes can be a variety of different shapes including generally elongate, circular and oval, for example. In addition, the cable hub **120** need not be included in certain embodiments. For example, multiple cables from different sensors could connect to a monitor directly without using the cable hub **120**.

Additional information relating to acoustic sensors compatible with embodiments described herein, including other embodiments of interfaces with the physiological monitor, are included in U.S. patent application Ser. No. 12/044,883, filed Mar. 7, 2008, entitled "Systems and Methods for Determining a Physiological Condition Using an Acoustic Monitor," (hereinafter referred to as "the '883 application"), the disclosure of which is hereby incorporated by reference in its entirety. An example of an acoustic sensor that can be used with the embodiments described herein is disclosed in U.S. Patent Application No. 61/252,076, filed Oct. 15, 2009, titled "Acoustic Sensor Assembly," the disclosure of which is hereby incorporated by reference in its entirety.

FIG. **2** illustrates an embodiment of a multiparameter patient monitoring system **200**, which can implement any of the features described above. The multiparameter patient monitoring system **200** includes a multiparameter patient monitor **205** that receives signals from multiple physiological parameter measurement devices. The multiparameter patient monitor **205** can use the multiple received signals to determine a confidence value for respiratory rate measurements derived from the signals. The confidence value can advantageously reflect a degree to which the respiratory rate measurements derived from the different signals correspond. In addition, in some embodiments, the multiparameter patient monitor **205** can generate one or more respiratory rate outputs based at least partly on the multiple received signals.

The patient monitor **205** can include any of the features of the physiological monitor **17** described above. The patient monitor **205** can include one or more processors, a display, memory, one or more input/output (I/O) devices (such as input control buttons, speakers, etc), a wireless transceiver, a power supply, and/or processing and filtration circuitry. In certain embodiments, the patient monitor **205** can communicate with external devices, such as processing devices, output devices, mass storage devices, and the like. The patient monitor **205** can communicate with the external devices via a wired and/or wireless connection. The external devices can include a central monitoring station (such as a nurses' monitoring station), a server, a laptop computer, a cell phone, a smart phone, a personal digital assistant, a kiosk, other patient monitors, or other clinician devices. The patient monitor **205** can send physiological data to the external devices.

In the depicted embodiment, the patient monitor **205** is in communication with an acoustic sensor **210** and an optical sensor **210**. The acoustic sensor **210** can be a piezoelectric sensor or the like that obtains physiological information reflective of one or more respiratory parameters of a patient, including respiratory rate, expiratory flow, tidal volume, minute volume, apnea duration, breath sounds, riles, rhonchi, stridor, and changes in breath sounds, such as decreased volume or change in airflow. In addition, in some cases the acoustic sensor **210** can measure other physiological sounds, such as heart rate (e.g., to help with probe-off detection). In certain embodiments, the acoustic sensor **210** can include any of the features described in U.S. Patent Application No. 61/252,076, filed Oct. 15, 2009, titled "Acoustic Sensor Assembly," the disclosure of which is hereby incorporated by reference in its entirety.

The optical sensor **215** can include a noninvasive optical sensor that obtains physiological information reflective of one or more blood parameters of the patient. These parameters can include one or more of the following: a photoplethysmograph, oxygen saturation (SpO_2), HbCO, HBMet, FaO_2, fractional oxygen, total hemoglobin (Hbt), other hemoglobin species, carbon monoxide, carbon dioxide, pulse rate, perfusion index, pleth variability index, and optionally others, including concentrations or actual analyte values of the same. The optical sensor **215** can include one or more emitters capable of irradiating a tissue site (such as a finger) with one or more wavelengths of light, such as red and/or infrared (IR) wavelengths. In one embodiment, the optical sensor **215** is a pulse oximetry sensor. While many optical sensors emit two wavelengths, certain of the features described herein can be implemented by a photoplethysmograph sensor that emits a single wavelength. Further, the optical sensor **215** need not emit red or infrared wavelengths in certain embodiments but can also emit other wavelengths. The optical sensor **215** can also include one or more detectors capable of detecting the light after attenuation by pulsatile blood and tissue at the measurement site. The one or more detectors can generate a signal responsive to the attenuated light, which can be provided to the patient monitor **205**.

The patient monitor **205** can receive signals indicative of one or more physiological parameters from the acoustic sensor **210** and from the optical sensor **215**. The patient monitor **205** can extract and/or derive respiratory rate measurements from signals provided by both the acoustic sensor **210** and the optical sensor **215**. The patient monitor **205** can also output one or more respiratory rate measurements for display based at least in part on the received signals. Example techniques for deriving respiratory rate from the optical sensor measurements are described below with respect to FIG. **3**.

In certain embodiments, the patient monitor **205** can use pulse oximetry respiratory rate measurements to determine a multiparameter confidence in the acoustic respiratory rate measurements. The multiparameter confidence can be a value that reflects a degree of correspondence between the respiratory rate measurements obtained from the two sensors **210**, **215**. A close correspondence (e.g., small difference) between the two respiratory rate measurements can cause the patient monitor **205** to assign a higher multiparameter confidence to the acoustic respiratory rate measurement.

Conversely, a larger difference between the two measurements can result in a lower multiparameter confidence. In certain embodiments, the patient monitor **205** can instead or also use the difference in respiratory rate values to assign a multiparameter confidence to the pulse-oximetry-derived respiratory rate measurement.

More generally, any comparative metric can be used to determine the multiparameter confidence. The comparative metric can be a difference between the measurements of the two sensors **210**, **215** but need not be. Instead, in some embodiments, the comparative metric can be a ratio between the measurements from the sensors **210**, **215**, a percentage derived from such a ratio, or the like. Such a ratio or percentage might be more meaningful than an absolute difference in some situations. Similarly, the comparative metric can be a normalization of the measurements from the two sensors **210**, **215**, such as the following quotient: (the acoustic respiratory rate—the oximeter respiratory rate)/(the acoustic respiratory rate) or the like. Other comparative metrics can also be used.

Additionally, the patient monitor **205** can use pulse oximetry respiratory rate measurements to refine or adjust the acoustic respiratory rate measurements in some implementations. For example, the respiratory rate measurements derived from the two sensors **210**, **215** can be combined to form an overall respiratory measurement. The patient monitor **205** can average the two measurements, for example. The combined respiratory rate measurement can be more accurate than a respiratory rate measurement from either sensor **210**, **215** alone.

The patient monitor **205** can output the respiratory rate measurement derived from either or both of the acoustic and optical sensors **210**, **215**. In addition, the patient monitor **205** can output a multiparameter confidence indicator that reflects the calculated multiparameter confidence. Examples of multiparameter confidence indicators are described in greater detail below.

In certain embodiments, a signal received from the optical sensor **215** can be analyzed to determine a respiratory rate measurement. As an illustration of such a signal, FIG. **3**A depicts an example photoplethysmograph (pleth) waveform **300** derived from an optical sensor. The pleth waveform **300** can be derived from the received signal by the patient monitor **205**. The pleth waveform **300** is plotted on an intensity axis **301** versus a time axis **302**. The pleth waveform **300** has multiple pulses **312**, each with a peak **314** and a valley **316** and extending over a time period **318**. A curve extending along the peaks **314** of the pleth waveform **300** represents an envelope **322** of the pleth waveform **300**.

In certain embodiments, a respiratory rate measurement can be determined from an analysis of the pleth waveform **300**. A respiratory rate measurement can be determined from the pleth waveform **300** in the time domain and/or in the frequency domain. In certain embodiments, a respiratory rate measurement can be determined from the modulation in the amplitude of the pleth waveform **300**. For example, the time-varying frequency of the envelope **322** can correspond to the respiratory rate of the patient. The frequency of the pleth envelope **322** can be determined from the inverse of the period **324** of the envelope **322**. The envelope **322** of the pleth waveform **300** can be detected by an envelope detector. The envelope can be identified using an analog envelope detector such as a diode-based envelope detector or a digital detector employing such techniques as a Hilbert transform, squaring and low-pass filtering, or the like.

The respiratory rate can also be determined from a frequency analysis of the pleth waveform **300**. A frequency spectrum of the pleth waveform **300** can be generated, for example, by performing a Fast Fourier Transform (FFT) or other mathematical transform of the pleth waveform **300**. The respiratory rate can be identified by a peak in the spectrum (e.g., which corresponds to the frequency of the pleth envelope **322**). In certain embodiments, the peak can be identified by identifying the highest peak in a range of typical respiratory rates of a human patient. This range can differ for different patients based on factors such as age, gender, comorbidity, and the like. A respiratory rate value can be derived from the frequency of the selected peak. Additional methods of determining respiratory rate from the pleth waveform **300** and/or an optical signal are also possible.

In certain embodiments, instead of or in addition to analyzing the pleth waveform **300** to obtain respiratory rate, the patient monitor **205** can obtain respiratory rate from variability detected in oxygen saturation measurements obtained from the optical sensor **215**. Variations in the oxygen saturation can track or approximately track the patient's respiratory cycle (e.g., a cycle of recruitment and collapse of alveoli), as is described in greater detail in U.S. Application No. 61/222,087, filed Jun. 30, 2009, titled "Pulse Oximetry System for Adjusting Medical Ventilation," the disclosure of which is hereby incorporated by reference in its entirety. The magnitude of the time-domain variations in the oxygen saturation can reflect the degree of recruitment and collapse of alveoli in the respiratory cycle. In the frequency domain, a peak in a magnitude response of the SpO_2 variability within an expected respiratory rate range can be used to determine a respiratory rate measurement.

In certain embodiments, the patient monitor **205** can obtain a respiratory rate measurement from variability detected in a patient's heart rate. The heart rate can be derived from an ECG signal, a bioimpedance signal, an acoustic signal, a plethysmograph signal, and/or combinations of the same.

In one embodiment, an instantaneous heart rate can be derived by determining the interval between successive R waves of the ECG signal and then converting the interval to beats per minute (bpm). For example, the heart rate can be calculated as 60 divided by the R-R interval in seconds. In another embodiment, the instantaneous heart rate can be derived from successive peaks in the plethysmograph signal. For example, the instantaneous heart rate can be calculated as 60 divided by the interval in seconds between the two successive peaks.

Other techniques can be used to derive the heart rate. For instance, the heart rate can be determined by analyzing any successive landmark of an ECG or plethysmograph signal. Further, to improve noise immunity, the patient monitor **205** can use a more robust technique to measure the interval, such as autocorrelation of the ECG or plethysmograph waveform from one beat to the next. More generally, any technique for reliably measuring the period from one beat to the next can be used.

The instantaneous heart rate can be plotted over time to illustrate variability in the patient's heart rate. In certain embodiments, the variability in the patient's heart rate is reflective of the patient's respiratory rate. For example, analysis of the variability in the instantaneous heart rate in the frequency domain (for example, by taking the Fourier transform of the instantaneous heart rate signal in the time domain) can provide an indication of respiratory rate that can be used to assess confidence in a respiratory rate measurement derived from an acoustic sensor or another type of sensor.

In certain embodiments, the patient monitor **205** can also obtain a respiratory rate measurement by measuring arterial pulse wave propagation time from the heart to an extremity. This propagation time is typically used by blood pressure monitoring systems and can be estimated by detecting a time difference between points on an ECG waveform and a photoplethysmograph waveform. This estimated propagation time is sometimes referred to as pulse wave transit time (PWTT) or time difference of arrival (TDOA). Currently available blood pressure monitoring systems trigger an automatic occlusive cuff to take a blood pressure measurement based on detected changes in PWTT.

Variability in the PWTT can be modulated by respiration. Thus, in certain embodiments, the patient monitor **205** can calculate PWTT and determine the variability in PWTT measurements over time. The patient monitor **205** can derive respiratory rate values from the calculated variability. The patient monitor **205** can use these values to improve the accuracy of or calculate confidence in acoustically-derived respiratory values.

As illustrated in FIG. **3**B, in one embodiment, PWTT is determined as a time difference between a peak of an R-wave **335** of a QRS complex of an ECG signal **330** to the foot point **345** of a plethysmograph signal **340**. The R-wave **335** represents the first upward, or positive, deflection of the QRS complex and corresponds to the time of ventricular depolarization. The foot point **345** of the plethysmograph signal **340** can correspond to the time of earliest onset of arrival of the pulse at a location away from the heart (e.g., at a patient's finger). More generally, PWTT can be taken as a time interval from any feature of the ECG waveform to any feature of the pleth waveform. For example, PWTT can be taken as the interval between the Q or S points of the ECG waveform and a point such as the midpoint of the pleth waveform.

The PWTT calculation can be improved by accounting for a patient's pre-ejection period (PEP). The PEP can include the difference in time between initiation of ventricular contraction (e.g., as detected by an ECG) and ejection of blood from the ventricles into the aorta. The PEP can also be considered as an interval between the onset of the QRS complex (of an electrocardiogram) and cardiac ejection. PWTT compensated for PEP can more accurately represent the propagation time of the arterial pulse from the heart to an extremity. In order to determine the PEP, in one embodiment an acoustic sensor is coupled with the patient to detect a patient's heart sound. The time difference between a feature of the ECG signal and a feature of the heart sound (represented as a signal) can be an estimate of PEP. In another embodiment, a bioimpedance sensor can be used to estimate PEP by taking a time difference between features of ECG and bioimpedance sensor signals. The arterial PWTT can then be calculated by subtracting the PEP from the initial PWTT calculation obtained from the ECG and plethysmograph signals. The patient monitor **205** can employ any of the systems or methods for determining PWTT and PEP described in more detail in U.S. Provisional Application No. 61/366,862, titled "System for Triggering A Non-Invasive Blood Pressure Device," filed Jul. 22, 2010, the disclosure of which is hereby incorporated by reference in its entirety.

In yet other embodiments, the PWTT is determined from a landmark of a first plethysmograph signal to a landmark of a second plethysmograph signal. In some embodiments, the first plethysmograph signal is acquired from a sensor applied to a finger of a patient and the second plethysmograph signal is acquired from a sensor applied to a toe of a patient; however other sensor locations can be used as desired and/or required.

The analysis of the heart rate and/or PWTT variability can include correlation in the time, frequency, or other transform domains. In one embodiment of a frequency domain analysis, FIG. **3**C illustrates power spectrums **350**A, **350**B of the PWTT variability and the heart rate variability of a patient being monitored with the patient monitor **205**. The power spectrums **350**A, **350**B plot power amplitude (having an expanded scale) versus frequency. In one embodiment, the respiratory rate measurement is determined from the power spectrums **350**A, **350**B by the highest spectral peak in the frequency range corresponding to the normal range of respiratory rates. The respiratory peak **355** of the power spectrums **350**A, **350**B is approximately 0.3 Hz, which corresponds to a respiratory rate of approximately 18 breaths per minute. This is an example frequency value that can vary for different patients or even for the same patient over time.

The respiratory rate measurement derived from the PWTT variability and the respiratory rate measurement from the heart rate variability can be compared with each other and/or with other respiratory rate measurements to determine an overall respiratory rate measurement or to assess confidence in a respiratory rate measurement derived from another physiological signal, as described in further detail below.

In certain embodiments, the PWTT and/or heart rate variability data can be smoothed or otherwise filtered by various signal processing methods, such as moving average smoothing, sliding average smoothing, box smoothing, binomial (Gaussian) smoothing, polynomial smoothing, and/or the like, to improve the accuracy of, or confidence in, the respiratory rate measurements.

FIG. **4** illustrates an embodiment of a multiparameter patient monitoring system **400** coupled to a patient **401**. The multiparameter patient monitoring system **400** includes a patient monitor **405**, an acoustic sensor **410**, and an optical sensor **415**. The acoustic sensor **410** and the optical sensor **415** can obtain physiological signals from the patient **401** and transmit the signals to the patient monitor **405** through cables **403**A, **403**B.

As shown, the acoustic sensor **410** is attached to the skin of the patient **401** on the neck near the trachea. The acoustic sensor **410** can include adhesive elements (e.g., tape, glue, or the like) to secure the acoustic sensor **410** to the skin. The acoustic sensor **410** can additionally be secured to the patient using an anchor **408**, which can be affixed near a subclavian region of the patient **401** or at other regions. The anchor **408** can reduce stress on the connection between the acoustic sensor **410** and the skin during movement. Other placement locations for the acoustic sensor **410** and the patient anchor **408** are also possible, such as other parts of the neck, the chest, or the like.

The optical sensor **415** can be removably attached to the finger of the patient **401**. In other embodiments, the optical sensor **415** can be attached to a toe, foot, and/or ear of the patient **401**. The optical sensor **415** can include a reusable clip-type sensor, a disposable adhesive-type sensor, a combination sensor having reusable and disposable components, or the like. Moreover, the optical sensor **415** can also include mechanical structures, adhesive or other tape structures, Velcro™ wraps or combination structures specialized for the type of patient, type of monitoring, type of monitor, or the like.

In certain embodiments, the various sensors and/or monitors can communicate with the patient monitor **405** wirelessly. The wireless communication can employ any of a

variety of wireless technologies, such as Wi-Fi (802.11x), Bluetooth, cellular telephony, infrared, RFID, combinations of the same, and the like.

In certain embodiments, the multiparameter patient monitoring system **200** can include additional physiological parameter measurement devices. FIG. **5** illustrates an example of a multiparameter respiratory monitoring system **500** that includes multiple additional measurement devices. In particular, a patient monitor **505** receives inputs from an acoustic sensor **510**, an optical sensor **515**, an electrocardiograph (ECG) **520**, a capnograph **525**, a bioimpedance monitor **530**, and possibly other physiological monitors or sensors **535**.

In certain embodiments, the multiparameter patient monitor **505** derives respiratory rate measurements from signals received from each of the depicted physiological parameter measurement devices and/or sensors. In certain embodiments, the respiratory rate measurements derived from one or more of the optical sensor **515**, the ECG **520**, the capnograph **525**, and/or the bioimpedance monitor **530** can be compared with the respiratory rate measurement from the acoustic sensor **510**. The monitor **505** can compare one or more of these measurements with the acoustically-derived measurement in order to derive a multiparameter confidence value reflecting a confidence in the acoustic respiratory rate measurement (or confidence in any other of the respiratory rate measurements).

In other embodiments, one or more of the respiratory rate measurements from the ECG **520**, the capnograph **525** and the bioimpedance monitor **530** can be combined with the respiratory rate measurements from the acoustic sensor **510** and/or the optical sensor **515** to generate a combined respiratory rate output. In certain embodiments, the combined respiratory rate output can have greater accuracy than the respiratory rate measurement obtained from any one of the devices shown.

The ECG **520** can monitor electrical signals generated by the cardiac system of a patient. The ECG **520** can include one or more sensors adapted to be attached to the skin of a patient, which can be used to detect electrical heart activity of the patient. The ECG **520** can determine any of a variety of electrical physiological parameters based upon electrical signals received from the one or more sensors, such as heart rate. In certain embodiments, the ECG **520** can generate an electrocardiogram waveform. The patient monitor **505** can compare one or more features of the waveform with an acoustically-derived respiratory rate measurement to determine multiparameter confidence in the acoustically-derived respiratory rate. For instance, the R-R time period of the ECG waveform, or the like can be correlated with respiratory rate in certain individuals. More generally, an envelope of the ECG waveform can include peaks that the patient monitor **505** can correlate in frequency with respiratory rate in certain situations.

The capnograph **525** can determine the carbon dioxide content in inspired and/or expired air from a patient. For example, the capnograph **525** can monitor the inhaled and/or exhaled concentration or partial pressure of carbon dioxide through a breathing mask or nasal cannula. In certain embodiments, the capnograph **525** can generate a capnogram responsive to the patient's breathing. The capnograph **525** can also identify end tidal carbon dioxide ($EtCO_2$) levels and/or other values. From the $EtCO_2$ values, the capnograph **525** can determine a respiratory rate of the patient. The capnograph **525** can provide this respiratory rate measurement to the patient monitor **505**, which can compare the respiratory rate with the acoustically-derived respiratory rate to determine multiparameter confidence.

The bioimpedance monitor **530** can determine electrical impedance or resistance in body tissue of a medical patient. For example, the bioimpedance monitor **530** can include two or more sensors or electrodes positioned on a patient so as to measure the bioelectrical impedance or resistance across the chest region. The measured bioelectrical impedance can vary as a result of the expansion of the chest due to breathing, and from this variance, a respiratory rate measurement can be derived. In certain embodiments, the bioimpedance monitor **530** is a Transthoracic Impedance Monitor or the like, having two or more electrodes that can optionally be combined with ECG electrodes. In other embodiments, the bioimpedance monitor **530** is an impedance tomograph, having many more electrodes that can also be used to form a spatial image of the impedance variation.

The respiratory rate measurement can be derived by the bioimpedance monitor **530**, or alternatively, the bioimpedance monitor **530** can provide impedance values with respect to time to the patient monitor **505**, which can derive the respiratory rate. The patient monitor **505** can also compare the impedance-derived respiratory rate with the acoustically-derived respiratory rate to determine multiparameter confidence.

Additional sensors and/or monitors of different types can also be included. The other patient monitors **135** can include, for example, thermistor-based breathing sensors or pneumatic breathing belt sensors.

In certain embodiments, the electrocardiograph **520**, the capnograph/capnometer **525**, and the bioimpedance monitor **530** are standalone patient monitors that can provide filtered and/or processed signals to the patient monitor **505**. In other embodiments, the electrocardiograph **520**, the capnograph **525**, and the bioimpedance monitor **530** can be replaced with respective sensors, which each provide physiological data directly to the patient monitor **505**. In still other embodiments, the acoustic sensor **510** and the optical sensor **515** can be replaced with an acoustic respiratory monitor and a pulse oximeter, respectively. Thus, any combination of sensors and monitors can provide inputs to the patient monitor **505**, including any subset of the devices shown.

The patient monitor **505** can output for display the respiratory rate value derived from the acoustic sensor **550**. In addition, the patient monitor **505** can output respiratory rate values derived from any of the other devices shown.

In certain embodiments, the respiratory rate measurements derived from one or more of the sensors can be used for sequential hypothesis testing.

FIGS. **6**A through **6**C illustrate embodiments of systems **600**A, **600**B, and **600**C for determining multiparameter confidence of respiratory rate measurements and for outputting respiratory rate values. The systems **600**A, **600**B, and **600**C can be implemented by any of the patient monitors described herein, such as the patient monitors **205**, **405**, and **505**, or by the patient monitors described below. Each of the depicted blocks of the systems **600**A, **600**B, and **600**C can be implemented by hardware and/or software.

Referring to FIG. **6**A, the system **600**A receives signal inputs reflective of physiological parameters from an acoustic sensor and from an optical sensor, such as any of the sensors described above. The signal inputs can be received by respiratory rate determination blocks **640***a*, **640***b*, respectively. Each of the respiratory rate determination blocks **640** can determine a respiratory rate based at least in part on its respective signal input. For example, the respiratory rate

determination block **640***b* can determine respiratory rate of a patient from a time domain or frequency analysis of a photopleth input signal.

In certain embodiments, the respiratory rate determination block **640***b* can be part of any of the patient monitors described above. Thus, for example, an optical sensor could provide the photopleth signal to the respiratory rate determination block **640***b* of a patient monitor, which derives a respiratory rate. The respiratory rate determination block **640***b* could instead be part of a pulse oximetry monitor. The pulse oximetry monitor could determine a respiratory rate measurement based at least in part on the photopleth signal. The pulse oximetry monitor could provide the calculated respiratory rate to the patient monitor (e.g., **205**, **405**, **505**, or the like).

For convenience, the acoustic respiratory rate measurement will be described using the shorthand RR_{AR} and the photopleth respiratory rate measurement will be described using the shorthand RR_{PO}. In the depicted embodiment, the RR_{AR} and the RR_{PO} measurements are provided to a respiratory rate analyzer **645**. The respiratory rate analyzer **645** can analyze the RR_{AR} and the RR_{PO} measurements to determine a multiparameter confidence in the RR_{AR} measurement. For example, the respiratory rate analyzer **645** can compare the two measurements to determine a difference between the two measurements. The respiratory rate analyzer can derive a multiparameter confidence or multiparameter confidence value from this calculated difference. In certain embodiments, the greater the difference between the RR_{AR} and the RR_{PO} measurements, the lower is the multiparameter confidence determined for the RR_{AR} measurement. Conversely, in certain embodiments, the respiratory rate analyzer **645** can use the difference between the two measurements to assign a multiparameter confidence to the RR_{PO} measurement.

The respiratory rate analyzer **645** can output for display a multiparameter confidence indicator **660** responsive to the calculated multiparameter confidence along an output respiratory rate measurement (RR_{OUT}, described below). The multiparameter confidence indicator **660** can include a visual and/or audible indication in various embodiments.

Moreover, in certain embodiments, the respiratory rate analyzer **645** can generate the respiratory rate output RR_{out} based on a combination of the inputs RR_{AR} and RR_{PO}. For example, the respiratory rate analyzer **645** could average the two respiratory rate inputs. This average could be a weighted average or the like (see, e.g., FIG. **6**C).

In another embodiment, the respiratory rate analyzer selects one of the respiratory rate inputs (RR_{AR} and RR_{PO}) to output as the respiratory rate output RR_{OUT}. The respiratory rate analyzer **645** could make this selection based at least partly on single parameter confidence values generated by each respiratory rate determination block **640***a*, **640***b*. These single parameter confidence values can reflect a quality of the signal received by each block **640***a*, **640***b*. Single parameter confidence values can be distinguished from multiparameter confidence values, in certain embodiments, in that single parameter confidence values can reflect confidence that a respiratory rate derived from a single parameter is accurate. In contrast, multiparameter confidence values can reflect respiratory rate accuracy as determined by an analysis of multiple parameters (e.g., photopleth and ECG).

For example, the respiratory rate determination block **640***b* could determine single parameter confidence of the photopleth signal using techniques such as those described in U.S. Pat. No. 6,996,427, titled "Pulse Oximetry Data Confidence Indicator," filed Dec. 18, 2003, (the "'427 patent") the disclosure of which is hereby incorporated by reference in its entirety. Analogous techniques could be used by the respiratory rate determination block **640***a* to determine single parameter confidence in the quality of the acoustic respiratory signal received.

The respiratory rate analyzer **645** could select either the RR_{AR} respiratory rate value or the RR_{PO} respiratory rate value to provide as the respiratory rate output RR_{OUT} based on, for example, which signal has a higher calculated signal quality. In another embodiment, the respiratory rate analyzer **645** could weight a combination of the two respiratory rate values based at least in part on the single parameter confidence values. In various embodiments, the respiratory rate analyzer **645** can also select the respiratory rate value to output based on patient-specific factors, such as age, gender, comorbidity, and the like. For instance, for some patients, one respiratory rate measurement derived from a particular parameter might be more reliable than other respiratory rate measurements derived from other parameters. Many other variations are also possible.

Although the respiratory rate analyzer **645** has been described as being able to average respiratory rate values or select respiratory rate values, the distinction between averaging and selecting can blur. Selecting, for instance, can be considered a subset of weighting where respiratory rate values selected are given a weight of "1" (or substantially 1) and respiratory rate values not selected are given a weight of "0" (or substantially 0).

FIG. **6**B extends the embodiment shown in FIG. **6**A to include additional parameter inputs. In FIG. **6**B, the system **600**B receives an acoustic respiratory signal, a photopleth signal, an ECG signal, a capnograph signal, and a bioimpedance signal. Signal inputs from other types of sensors and/or monitors, or additional sensors of the types listed, can also be received. The respective signal inputs are received by respiratory rate determination blocks **640***a*, **640***b*, **640***c*, **640***d*, and **640***e*. As described above, the respiratory rate determination blocks **640***a*, **640***b* can determine a respiratory rate measurement using any of the techniques described above and optionally a single parameter confidence value based at least in part on its respective signal input. Likewise, the respiratory rate determination blocks **640***c*, **640***d*, and **640***e* can calculate respiratory rate measurements and optionally single parameter confidence values.

Signal inputs can also be used to determine respiratory rate measurements derived from heart rate variability and/or PWTT variability. As shown in FIG. **6**B, the signal inputs (e.g., an acoustic respiratory signal, a photopleth signal, an ECG signal, a bioimpedance signal and/or other signals) are received by a heart rate determination block **670** and a PWTT determination block **675**. In other embodiments, more or fewer signal inputs can be received by the heart rate determination block **670** and/or the PWTT determination block **675**. The heart rate determination block **670** can derive the patient's heart rate from one or more of the signal inputs. The PWTT determination block **675** can determine the patient's PWTT from one or more of the signal inputs using any of the techniques described above with respect to FIG. **3**B.

The respiratory rate determination blocks **640***f* and **640***g* can determine respiratory rate measurements based at least in part on an analysis of the heart rate variability and the PWTT variability, respectively, of the patient, using any of the techniques described above. For example, the respiratory rate determination blocks **640***f* and **640***g* can determine respiratory rate measurements from a frequency analysis of

heart rate and/or PWTT signals over time. The respiratory rate measurements calculated by the respiratory rate determination blocks **640***f* and **640***g* can be provided to the respiratory rate analyzer **650** along with any of the respiratory rate measurements calculated by the respiratory rate determination blocks **640***a*, **640***b*, **640***c*, **640***d* and **640***e*. The respiratory rate determination blocks **640***f* and **640***g* can also calculate single or multiple parameter confidence values.

The respiratory rate determination blocks **640** can be implemented in any of the patient monitors **205**, **405**, **505**, etc. described herein. Thus, for example, a patient monitor can receive sensor inputs from one or more of an acoustic sensor, an optical sensor, an ECG sensor or sensors, a capnometry sensor, and a bioimpedance sensor. Not all of the inputs shown need by received by a patient monitor; rather, a subset can be received by any patient monitor. From the inputs, the patient monitor implementing the respiratory rate determination blocks **640** can calculate individual respiratory rate measurements corresponding to each input, using any of the techniques described above. The patient monitor can further implement the respiratory rate determination blocks **640** by calculating single parameter confidence in each block in an analogous manner to that described in the '427 patent incorporated by reference above. In another embodiment, the respiratory rate calculation for certain of the parameters is performed in a separate monitor. For instance, a capnograph monitor can determine a respiratory rate of a patient and provide this respiratory rate value to a respiratory rate analyzer **650** of the patient monitor.

The respiratory rate determination blocks **640** can provide respiratory rate values and optionally single parameter confidence values to a respiratory rate analyzer **650**. The respiratory rate analyzer **650** can operate in a similar manner to the respiratory rate analyzer **645** described above. For instance, the respiratory rate analyzer **650** can analyze one or more of the respiratory rate measurements to determine a multiparameter confidence in the RR_{ARM} measurement, using any of the techniques described above.

In one embodiment, the respiratory rate analyzer **650** determines multiparameter confidence by comparing the RR_{AR} measurement to one or more of the other respiratory rate measurements. The multiparameter confidence calculated by the respiratory rate analyzer **650** can reflect the differences between the measurements. For example, the respiratory rate analyzer **650** can average the differences to generate a multiparameter confidence value, use a weighted average of the differences to generate a multiparameter confidence value, can select the greatest difference as the multiparameter confidence value, can use any of the above to further derive a multiparameter confidence value (e.g., by looking up the difference value in a look-up table to obtain a corresponding multiparameter confidence value, or by multiplying the difference value by a scalar to obtain a multiparameter confidence value), or by a host of other techniques. Moreover, in certain embodiments, the respiratory rate analyzer **650** can analyze any subset of the respiratory rate measurements received to determine a multiparameter confidence in any given one of the respiratory rate measurements.

The respiratory rate analyzer **650** can output for display a multiparameter confidence indicator **660** responsive to the calculated multiparameter confidence along an output respiratory rate measurement (RR_{OUT}, described below). The multiparameter confidence indicator **660** can include a visual and/or audible indication in various embodiments. The multiparameter confidence indicator **660** can be output to a display **655** along with a respiratory rate output RR_{OUT}.

Moreover, like the respiratory rate analyzer **645** described above, the respiratory rate analyzer **650** can generate the respiratory rate output RR_{OUT} based on a combination or selection of any of the respiratory rate inputs received from the various sensors or monitors. For example, the respiratory rate output RR_{OUT} can be the acoustic respiratory rate (RR_{AR}), or a selected one of the other respiratory rate measurements. Or, the respiratory rate analyzer **650** could average, perform a weighted average (e.g., based on respective single parameter confidences), or otherwise combine the respiratory rate measurements to determine the respiratory rate output RR_{OUT}. In various embodiments, the respiratory rate analyzer **645** can also select and/or combine the respiratory rate values to determine an output based on patient-specific factors, such as age, gender, comorbidity, and the like. For instance, for some patients, one respiratory rate measurement derived from a particular parameter might be more reliable than other respiratory rate measurements derived from other parameters. Many other variations are also possible.

In other embodiments, the combiner/selector module **650** can compare the derived respiratory rate measurements to determine, which, if any, of the respiratory rate determination blocks **640** provided outliers. The combiner/selector module **650** could reject the outliers and combine (e.g., average) the outputs of the remaining respiratory rate determination blocks **640**.

In yet other embodiments, the combiner/selector module **650** could determine which of the outputs from the respiratory rate determination blocks **640** are close to each other (e.g., within a tolerance) and output a combination of those outputs. For example, if three of the five respiratory rate determination blocks **640** produce a similar output and two are outliers, the combiner/selector module **650** could average the three similar outputs or select one of the three outputs as the final RR_{OUT} measurement. Moreover, the combiner/selector module **650** can learn over time and can select the output derived from one of the sensors or monitors based on past performance. Many other configurations and extensions of the combiner/selector module **650** are possible.

In certain embodiments, the respiratory rate output measurements and/or the multiparameter confidence values can be output to an external device over a network, instead of, or in addition to, being output to the display **655**. For example, the output data can be output to a central monitoring station (such as a nurses' monitoring station), a server, a laptop computer, a cell phone, a smart phone, a personal digital assistant, other patient monitors, or other clinician devices, for example. In some embodiments, the patient monitor **505** can transmit data to an external device via a wireless network using a variety of wireless technologies, such as Wi-Fi (802.11x), Bluetooth, cellular telephony, infrared, RFID, combinations of the same, and the like.

FIG. **6**C illustrates yet another embodiment of a system **600**C for calculating multiparameter confidence in respiratory rate measurements. In the system **600**C, acoustic and photopleth signal inputs are provided, as well as optionally any number of other signal inputs (such as any of the inputs described above). As above, respiratory rate determination blocks **640***a*, **640***b*, and so forth down to **640***n* can receive these signal inputs. The respiratory rate determination blocks **640***a*, **640***b*, . . . , **640***n* can calculate respiratory rate values based on the signal inputs, as well as associated internal confidence values. Each of the internal confidence values can reflect an individual respiratory rate block **640** algorithm's confidence in the respiratory rate measurements.

A respiratory rate analyzer **660** receives the respiratory rate and confidence measurements **642** calculated by the respiratory rate determination blocks **640**. The respiratory rate analyzer **660** can have some or all the features of the respiratory rate analyzers described above. In addition, the respiratory rate analyzer **660** can use the internal confidence values calculated by the respiratory rate blocks **640** to weight, select, or otherwise determine appropriate overall respiratory rate and confidence values **652**. The respiratory rate analyzer **660** outputs these values **652** to a display **655** or to some other device.

The respiratory rate analyzer **660** can use any of a variety of techniques to calculate the overall respiratory rate and confidence **652**. Some example techniques are described herein. To illustrate, in one embodiment, the respiratory rate analyzer **660** can perform a weighted average of the respiratory rate values from each respiratory rate determination block **640**. The weights can be derived from, or can be, their respective confidence values.

More complex weighting schemes can also be devised. One example weighting algorithm can implement an adaptive algorithm for dynamically adjusting the weights applied to each respiratory rate value over time. The weights can be adapted based on minimizing some cost function, such as may be applied by a Kalman filter, for instance. More generally, any of a variety of adaptive algorithms may be used to adjust the weights. For example, the respiratory rate analyzer **660** can implement one or more of the following: a least mean squares algorithm (LMS), a least squares algorithm, a recursive least squares (RLS) algorithm, wavelet analysis, a joint process estimator, an adaptive joint process estimator, a least-squares lattice joint process estimator, a least-squares lattice predictor, a correlation canceller, optimized or frequency domain implementations of any of the above, any other linear predictor, combinations of the same, and the like.

In another embodiment, the respiratory rate analyzer **660** can select the top N available sources having the highest confidence level, where N is an integer. For instance, the respiratory rate analyzer **660** can choose the output of N respiratory rate determination blocks **640** having confidence values that exceed a threshold. This threshold may be determined relative to the confidence values provided (e.g., via a ratio or the like) or can be an absolute threshold. The respiratory rate analyzer **660** can then perform a weighted average of the remaining values or select from these values, for example, based on confidence values.

Internal confidence of each respiratory rate determination block **640** can depend on a variety of factors, such as signal to noise ratio, irregularities in the data, probe-off conditions, and the like. A probe off condition, for instance, can result in a zero confidence value, a gradual taper down to zero confidence over time, or the like. Likewise, the confidence values can be derived from the signal to noise ratio for each respiratory rate determination block **640**.

FIG. **7** illustrates an example noninvasive multiparameter physiological monitor **700** that can implement any of the features described herein. An embodiment of the monitor **700** includes a display **701** showing data for multiple physiological parameters. For example, the display **701** can include a CRT or an LCD display including circuitry similar to that available on physiological monitors commercially available from Masimo Corporation of Irvine, Calif. sold under the name Radical™, and disclosed in U.S. Pat. Nos. 7,221,971; 7,215,986; 7,215,984 and 6,850,787, for example, the disclosures of which are hereby incorporated by reference in their entirety. However, many other display components can be used that are capable of displaying respiratory rate and other physiological parameter data along with the ability to display graphical data such as plethysmographs, respiratory waveforms, trend graphs or traces, and the like.

The depicted embodiment of the display **701** includes a measured value of respiratory rate **712** (in breaths per minute (bpm)) and a respiratory rate waveform graph **706**. In addition, other measured blood constituents shown include SpO_2 **702**, a pulse rate **704** in beats per minute (BPM), and a perfusion index **708**. Many other blood constituents or other physiological parameters can be measured and displayed by the multiparameter physiological monitor **700**, such as blood pressure, ECG readings, $EtCO_2$ values, bioimpedance values, and the like. In some embodiments, multiple respiratory rates, corresponding to the multiple input sensors and/or monitors, can be displayed.

FIGS. **8**A through **8**C illustrate example multiparameter physiological monitor displays **801**A-**801**C that output multiparameter confidence indicators **814**. The multiparameter confidence indicators **814** can be generated using any of the techniques described above.

Referring to FIG. **8**A, an example display **801**A is shown that includes parameter data for respiratory rate, including a measured respiratory rate value **812** in breaths per minute (bpm) and a respiratory waveform graph **806**. The display **801**A also includes parameter data for SpO_2 **802** and pulse rate **804** in beats per minute (BPM). A respiratory rate multiparameter confidence indicator **814**A is also depicted. In the depicted embodiment, the multiparameter confidence indicator **814**A includes text that indicates that the current respiratory rate has a low multiparameter confidence level. The multiparameter confidence indicator **814**A can function as a visual multiparameter confidence-based alarm by flashing, changing color, or the like when the multiparameter confidence is below a threshold level. The multiparameter confidence indicator can include symbols other than (or in addition to) text in certain embodiments. An audible multiparameter confidence-based alarm can alternatively, or additionally, be output through a speaker or other audio output device. A multiparameter confidence-based alarm can be generated as described in the '427 patent described above.

In certain embodiments, an alarm can be output when the monitored respiratory rate of the patient deviates beyond a patient-specific and/or patient-independent threshold. The utility and effectiveness of an alarm based on a respiratory rate measurement determined solely from an acoustic signal can be improved by joint processing of ancillary signals from multiple monitored physiological parameters, such as those described herein (e.g., electrical signals, photoplethysmographic signals, bioimpedance signals, and/or the like).

For example, respiratory rate measurements determined from the ancillary signals can be used to continuously or periodically refine or assess confidence in the respiratory rate measurements derived from the acoustic signal. If the multiparameter confidence in the acoustic respiratory rate measurement is low, the alarm can be suppressed, at least pending further consideration; however, if the multiparameter confidence in the acoustic respiratory rate measurement is sufficiently high, the alarm can be output without further consideration.

In other embodiments, the ancillary signals can be used to estimate the initial respiratory rate or timing information to assist an acoustic signal processing algorithm in capturing a respiratory component of the acoustic signal. The use of the ancillary signals from multiple parameters to assist in the capturing of the respiratory component of the acoustic signal

can lead to increased confidence in the accuracy of the respiratory rate measurement, thereby increasing the accuracy, reliability, and effectiveness of the alarm based on the respiratory rate measurement from the acoustic signal.

The display **801**B of FIG. **8**B includes the same parameter data as the display **801**A. However, the display **801**B includes a multiparameter confidence indicator **814**B that indicates the current multiparameter confidence level numerically, rather than textually (displayed as a percentage in the depicted embodiment). A present multiparameter confidence of 90% is shown by the multiparameter confidence indicator **814**B.

The display **800**C of FIG. **8**C includes a respiratory rate trend graph **816**, which depicts respiratory rate measurements over a period of time. The display **801**C also depicts a multiparameter confidence indicator **814**C in the form of a bar graph below the trend graph **816**. The multiparameter confidence indicator **814**C includes bars that can correspond to occurrences of breaths of a patient. The bars can have a height that corresponds to a degree of multiparameter confidence in the respiratory rate measurements for any given breath. As the breaths change over time, the multiparameter confidence can also change over time, resulting in a changing multiparameter confidence indicator **814**C. The multiparameter confidence indicator **814**C can be generated using analogous techniques to those described in the '427 patent described above.

In certain embodiments, the bars can all be depicted with the same color and/or pattern or with varying colors and/or patterns depending on the multiparameter confidence level. For example, bars within a desired multiparameter confidence range can be displayed with a first color and/or pattern, bars within a tolerable multiparameter confidence range can be displayed with a second color and/or pattern, and bars within a low multiparameter confidence range can be displayed with a third color and/or pattern. In certain embodiments, the bars can be replaced with pulses, lines, or other shapes.

FIG. **8**D illustrates another example multiparameter physiological monitor **800** having a display **801**D. As shown, the physiological monitor **800** can be configured with a vertical display instead of a horizontal display. The display **801**D can include similar parameter data as shown in displays **801**A-**801**C. The multiparameter physiological monitor **800** includes a multiparameter confidence indicator **814**D that is positioned off the display **801**D. The multiparameter confidence indicator **814**D can include one or more light emitting diodes (LEDs) positioned adjacent to text, such as "LOW RR CONF" or "LOW SQ" or "LOW SIQ™," where SQ and SIQ stand for signal quality and signal intelligence quotient, respectively. The multiparameter confidence indicator **810**D can be activated to inform a caregiver that a measured value of the multiparameter confidence of the incoming signal is below a certain threshold, for instance. In certain embodiments, different colored LEDs can be used to represent different multiparameter confidence range levels, such as in the manner described above.

The example displays **801**A-**801**D in FIGS. **8**A-**8**D are merely illustrative examples. Many other variations and combinations of multiparameter confidence indicators **814** are also possible in other implementations without departing from the spirit and/or scope of the disclosure.

Moreover, in certain embodiments, the features described in U.S. Pat. No. 6,129,675, filed Sep. 11, 1998 and issued Oct. 10, 2000 and in U.S. patent application Ser. No. 11/899,512, filed Sep. 6, 2007, titled "Devices and Methods for Measuring Pulsus Paradoxus," each of which is hereby incorporated by reference in its entirety, can be used in combination with the features described in the embodiments herein.

FIG. **9** illustrates an embodiment of a patient monitoring process **900** in which a user (e.g., a clinician) has the ability to specify a delay time for an alarm to be triggered. In one implementation, the patient monitoring process **900** is performed by any of the patient monitoring systems (e.g., systems **10**, **200**, **400**, **500**, **600***a*, **600***b*) and/or the patient monitors (e.g., monitors **205**, **405**, **505**, **700**, **800**) described above. More generally, the patient monitoring process **900** can be implemented by a machine having one or more processors. Advantageously, in certain embodiments, the patient monitoring process **900** provides a user-customizable alarm delay that can reduce nuisance alarms.

Currently available patient monitoring devices often generate alarms prematurely or generate alarms that may not correspond to a clinically significant event. For example, a monitoring device can generate an alarm even though the patient's physiological state or condition does not warrant attention. Instead of providing useful, actionable information, these "nuisance" alarms can result in unnecessary worry or stress of the patient and/or clinician and wasted time on the part of the clinician in responding to the nuisance alarms. The patient monitoring process **900** can advantageously reduce or suppress the number of nuisance alarms by providing an alarm delay period. The alarm delay period can advantageously be adjusted by a user.

The patient monitoring process **900** begins by receiving user input of an alarm delay time at block **902**. For example, a user such as a clinician can select a desired alarm delay by inputting the desired delay time into a physiological monitor via a user interface, a numerical keypad, or the like. The alarm delay time can correspond to a particular physiological parameter to be monitored. The physiological parameter can include, for example, blood pressure, respiratory rate, oxygen saturation (SpO_2) level, other blood constitutions and combinations of constitutions, and pulse, among others. The input from the clinician can adjust a default alarm delay. For example, the default alarm delay time might be 15 seconds, and the clinician input can change the alarm delay time to 30 seconds.

At block **904**, the user-specified alarm delay time is stored in a memory device. At block **906**, the physiological parameter corresponding to the user-specified alarm delay time is monitored by a patient monitor of a patient monitoring system. At decision block **908**, it is determined whether a value of the monitored physiological parameter has remained past a threshold (e.g., above or below a threshold or thresholds) for the user-specified alarm delay time. If it is determined that the value of the monitored physiological parameter has passed a threshold for the time period of the user-specified alarm delay, an alarm is output at block **910**. If, however, it is determined that the value of the monitored physiological parameter has not remained past the threshold for the time period of the user-specified alarm delay, the patient monitoring process **900** loops back to block **906** to continue monitoring. In various implementations, the threshold can be set or adjusted by a user (e.g., a clinician) depending on patient-specific factors (e.g., age, gender, comorbidity, or the like).

The alarm can be provided as a visual and/or audible alarm. In one embodiment, the alarm is output by a patient monitor. In another embodiment, the patient monitor transmits the alarm to another device, such as a computer at a central nurses' station, a clinician's end user device (e.g., a pod, a pager), or the like, which can be located in a hospital

or at a remote location. The patient monitor can transmit the alarm over a network, such as a LAN, a WAN, or the Internet.

As one example, a user can set an alarm delay time for a respiratory rate to be sixty seconds. In certain situations, a respiratory rate that is outside a threshold range of values for less than sixty seconds can be considered an apnea event. Accordingly, an alarm generated before the respiratory rate has remained outside the threshold range of values for a time period of more than sixty seconds may not be desirable or provide useful information for a clinician to act on. In one embodiment, the patient monitor can monitor the respiratory rate by receiving signals from an acoustic sensor, such as any of the acoustic sensors described herein. When the patient monitor determines that the respiratory rate has been outside a threshold range of values for at least sixty seconds, then an alarm can be output by the patient monitor.

In certain embodiments, an indication can be provided to a user (e.g., a clinician) regarding a current status of the alarm delay period. The indication can be audible and/or visual. In one embodiment, a confidence indicator can be altered or modified based on the alarm delay period. For example, the confidence indicator can be modified to reflect a "countdown" to the time of triggering of the alarm. If the confidence indicator is represented by an LED, for example, the LED can blink once the alarm delay has been initiated and can blink faster as the trigger time of the alarm grows closer. If the confidence indicator is represented by a bar graph, for example, the bars can be modified during the period from initiation of the alarm delay until the time of triggering of the alarm. A separate countdown timer that is not coupled with the confidence indicator could also be provided, which counts down seconds remaining in the alarm delay period.

FIG. **10** illustrates an embodiment of a multiparameter patient monitoring process **1000**. In the multiparameter patient monitoring process **1000**, an alarm delay time for a first physiological parameter can be modified dynamically based on a measurement of a second physiological parameter. In one implementation, the patient monitoring process **1000** is performed by any of the patient monitoring systems (e.g., systems **10**, **200**, **400**, **500**, **600***a*, **600***b*) and/or the patient monitors (e.g., monitors **205**, **405**, **505**, **700**, **800**) described above. More generally, the patient monitoring process **1000** can be implemented by a machine having one or more processors.

At block **1006**, first and second physiological parameters are monitored by a multiparameter patient monitor. In one embodiment, respiratory rate and SpO_2 are the two monitored physiological parameters. In other embodiments, the first and second monitored physiological parameters can include, for example, blood pressure, respiratory rate, oxygen saturation (SpO_2) level, other blood constitutions and combinations of constitutions, and pulse, among others.

At decision block **1008**, it is determined whether the current monitored value of the first physiological parameter has passed a threshold. If so, then at decision block **1010**, it is determined whether an alarm delay time corresponding to the first parameter has been reached. The alarm delay time can be a default alarm delay time or a user-selected delay time, such as the user-selected delay time described above with respect to FIG. **9**. If the first physiological parameter has not passed the threshold, the multiparameter patient monitoring process **1000** loops back to block **1006** to continue monitoring.

If it is determined at decision block **1010** that the user-specified alarm delay time has been reached, then an alarm is output at block **1012**. If, however, it is determined that the alarm delay time has not been reached, then the multiparameter patient monitoring process **1000** proceeds to decision block **1014**. The alarm can have similar features as described above and can be provided by, on, or to any of the devices described above.

At decision block **1014**, it is determined whether a value of the second monitored physiological parameter has deviated from a previous value. If so, then the alarm delay time is dynamically modified at block **1016**, and the process **1000** loops back to block **1006** to continue monitoring. If not, the process **1000** loops back to decision block **1006** to continue monitoring without changing the delay time.

In certain embodiments, a deviation from a previous value for the second monitored physiological parameter includes a reduction or increase in value. In other embodiments, a deviation from a previous value includes a deviation beyond a threshold or threshold range of acceptable values. The threshold or threshold range for the second monitored physiological parameter can be set or adjusted by a user (e.g., a clinician) depending on patient-specific factors (e.g., age, gender, comorbidity, or the like). The threshold range of values can be set to include any range of values.

In one embodiment, the degree of modification of the alarm delay can depend on the degree of deviation of the second monitored physiological parameter. In another embodiment, the degree of modification of the alarm delay can also depend on the value of the user-specified or default alarm delay time and/or the identity of the first physiological parameter being monitored.

The dynamic modification can be performed in a linear, step-wise, logarithmic, proportional, or any other fashion. For example, the change in the alarm delay corresponding to the first monitored physiological parameter can be proportional to the change or deviation in the second monitored physiological parameter. In another embodiment, a series of successive threshold ranges of values of the second physiological parameter can be provided, wherein each threshold range corresponds to a different amount of delay adjustment.

For example and not by way of limitation, the first physiological parameter can be respiratory rate and the second physiological parameter can be SpO_2. In one embodiment, a user-specified or default alarm delay time can be sixty seconds. If the respiratory rate is less than a given threshold for less than the alarm delay time, it can be determined whether the current SpO_2 level has deviated. Based at least partly on this deviation, the alarm delay time can be adjusted. For example, if the SpO_2 level has dropped, the alarm delay time can be reduced, for example, to 30 seconds, or to 15 seconds, or to another value. If the second monitored physiological parameter deviates too far beyond a threshold range, an alarm corresponding to the second monitored physiological parameter can also be triggered.

FIGS. **11** through **17** illustrate additional example embodiments of physiological parameter displays **1100-1700**. These displays **1100-1700** can be implemented by any physiological monitor, including any of the monitors described herein. The displays **1100-1700** shown illustrate example techniques for depicting parameter values and associated confidence. The displays **1100-1700** can be used to depict single parameter (e.g., internal) confidence, multiparameter confidence, or both. The displays **1100-1700** can be implemented for respiratory rate or for any other physiological parameter, including, but not limited to, SpO_2, hemoglobin species (including total hemoglobin), pulse rate, glucose, or any of the other parameters described herein.

Referring initially to FIG. **11**, the display **1100** includes an example parameter value scale **1102** and a plot area **1106**. An indicator **1110** displayed in the plot area **1106** plots a parameter value **1108** together with associated confidence. In the depicted embodiment, the indicator **1110** is a normal or Gaussian density function (e.g., bell curve) that includes a peak **1112**. The indicator **1110** can represent a current (or most recent) parameter value at the peak **1112** and the confidence associated with that parameter value.

The value of the parameter at the peak **1112** matches the parameter value scale **1102**. Thus, for instance, the normal density function is centered at 8.0, and a superimposed value **1108** of "8.0" is superimposed on the indicator **1110**, indicating a value of 8.0 for the measured parameter. If the parameter is respiratory rate, the 8.0 can correspond to breaths per minute. If the parameter were hemoglobin (SpHb), the value can be reported as a concentration in g/dL (grams per deciliter) or the like. Other parameters, such as glucose or SpO_2, can have different parameter value scales. The parameter value scale **1102** and/or the superimposed value **1108** are optional and may be omitted in certain embodiments. Likewise, vertical grid lines **1104** are shown but can be optional, and horizontal grid lines can also be provided.

The confidence is represented in certain embodiments by the characteristics of the indicator **1110** as a normal density function (or a variation thereof). The normal density function can be plotted using the Gaussian function or bell curve:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

where parameters μ and σ^2 are the mean and variance, respectively. Other related formulas can also be used. In one embodiment, the indicator **1110** can be plotted by assigning μ to be the parameter value and σ^2 (or σ, the standard deviation) to be the computed confidence value (internal, multiparameter, or a combination of the same). Then, the location on the parameter scale **1102** of the indicator **1110** can depend on the value of the parameter (μ), and the width or dispersion of the indicator **1110** can depend on the confidence (σ^2 or σ). Thus, with higher confidence, the variance (σ^2) can be lower, and the curve of the indicator **1110** can be narrower. With lower confidence, the variance can be higher, and the curve of the indicator **1110** can be wider or more dispersed.

The parameter value and/or confidence can have values that are some linear combination of μ and σ^2. For instance, the parameter value can be represented as $\alpha\mu$, where α is a real number. Likewise, the confidence value can be represented as $\beta\sigma^2$, where β is a real number.

Advantageously, in certain embodiments, the indicator **1110** provides an at-a-glance view of a parameter value and associated confidence. Because the confidence can be represented as the width of the indicator **1110**, the indicator **1110** can rapidly convey qualitative as well as quantitative information about confidence to a clinician. Most clinicians may be familiar with the normal density function or its associated distribution and may therefore readily associate the shape of the indicator **1110** with qualitative meaning regarding confidence.

Other features of the display **1100** include a phantom indicator **1120**, shown as dashed lines, that represents the previous-calculated parameter and confidence values. The phantom indicator **1120** can be used for the immediately previous values, or multiple phantom indicators **1120** can be used for multiple sets of previous values. A safety zone bar **1130** is also displayed. The safety zone bar **1130** includes three areas—a red zone **1132**, a yellow zone **1134**, and a green zone **1136**, representing unsafe, marginally safe, and safe parameter values, respectively. If the peak **1112** of the indicator **1110** is in the green zone **1132**, the value is represented as being safe, and so forth. The colors, including any colors discussed herein, may be outlines instead of solid colors. Further, the colors can be replaced with hatch marks, lines, dots, or any of a variety of other indications to represent different zones of safety.

Some example safety zone ranges for respiratory rate for an adult are as follows. The red, or danger zone **1132** can include about 5 breaths per minute (BPM) or less. A second red zone (see, e.g., FIG. **12**) might include about 30 BPM or more. The yellow, or marginally safe zone **1134**, can include about 6 BPM to about 10 BPM. A second yellow zone (see, e.g., FIG. **12**) can include about 24 BPM to about 30 BPM. The green zone **1336** can include about 11 BPM to about 23 BPM. These ranges are merely examples, however, and can vary considerably depending on, for instance, patient age, gender, comorbidity, medications, current activities (e.g., exercising or sitting), combinations of the same, and the like.

Although the normal density function has been used to illustrate confidence, other indicators in other embodiments can be illustrated using different probability density functions (such as binomial or Poisson functions). Further, the indicator need not be illustrated using a probability density function but can instead be illustrated using one or more boxes, circles, triangles, or other geometric shapes whose width, length, height, or other property changes with changing confidence (see, e.g., FIG. **16**). Further, the characteristics of the density function can depend on other factors in addition to or instead of confidence, such as patient comorbidities (other diseases can affect the confidence of the measurement), drugs taken by the patient (which can also affect the confidence), age, gender, combinations of the same, and the like. Further, the parameter value scale **1102** can change depending on the range of the parameter being considered, and a clinician can optionally zoom in or zoom out to a smaller or larger range.

Moreover, the safety ranges on the safety zone bar **1130** can depend on or otherwise be adjusted by a clinician based on patient comorbidity (e.g., hemoglobinopathy or thalacemia can affect the safe zones for hemoglobin), medications, age, gender, current activities or patient condition (such as donating blood, which can result in a higher start point of the green safety zone for hemoglobin), combinations of the same, and the like. The alternative implementations described with respect to FIG. **11**, as well as any of the other features of the display **1100**, can be used for any of the displays **1200-1700** described below as well.

A variant of the display **1100** is shown as the display **1200** in FIG. **12**. The display **1200** also shows an indicator **1210**, which can represent a normal density function as described above with respect to FIG. **11**. As such, the indicator **1210** can represent a parameter value at a peak of the indicator **1210** and a confidence value associated with the shape of the indicator. In this indicator **1210**, however, the indicator **1210** itself is colored to show vertical safety zones **1240**, **1242**, and **1244**. These safety zones can be similar to the safety zones described above with respect to the safety zone bar **1130** of FIG. **11**.

The safety zone **1240** can represent a green or safe zone, the safety zone **1242** can represent a yellow or marginal zone, and the zone **1244** can represent a red or danger zone.

Although the indicator **1210** is centered on these zones, different values of the parameter represented by the indicator **1210** can shift the indicator **1210** closer toward one or more of the zones. Thus, the color of the indicator **1210** can change, for example, be entirely yellow, or entirely red, or entirely green, or some different combination of the same. Further, the display **1200** can be modified in some embodiments to add a safety zone bar like the safety zone bar **1130** of FIG. **11**. The colors of the safety zone bar can vertically match the colors above the bar shown in the indicator **1210** (see, e.g., FIG. **14**).

FIG. **13** depicts another embodiment of a display **1300**. Similar to the displays **1100**, **1200**, the display **1300** includes an indicator **1310** that uses normal density function features to represent a parameter value and confidence. However, the indicator **1310** includes horizontal safety zones **1340**, **1342**, **1344**. The horizontal zones can be similar to the safety zones described above and can include, for example, red, green, and yellow (or other) colors. In another embodiment (not shown), the indicator **1310** can be a single solid color corresponding to the safety zone of the peak of the indicator **1310**. The indicator **1310** can also include gradual instead of abrupt transitions between colors.

Referring to FIG. **14**, a display **1400** includes an indicator **1410** having the density function characteristics described above. In addition, the indicator **1410** is colored vertically with safety zones **1442** and **1444**, similar to the indicator **1210** above. In addition, a safety zone bar **1430** is also shown, which has colors that correspond vertically to the colors of the indicator **1410**. Thus, a zone **1440** can be green, the zones **1442** and **1452** (of the bar **1430**) can be yellow, and the zones **1444** and **1454** (of the bar) can be red, or the like.

FIG. **15** illustrates a display **1500** having an indicator **1510** without color. Instead, the indicator **1510**, which can include the features of the indicators described above, includes markings **1520** to reflect percentages of standard deviations of the normal density function. These standard deviations can correspond to confidence intervals. These markings **1520** include horizontal arrows, vertical lines, and associated percentage numbers to mark a first standard deviation (e.g., 68% confidence that the parameter lies within the interval marked by the arrow), a second standard deviation (e.g., 95% confidence that the parameter lies within the interval marked by the arrow), and the third standard deviation (e.g., 99% confidence interval). Color or safety zones can be added to the indicator **1510** as in any of the other example indicators described herein.

FIG. **16** illustrates yet another display **1600** with an indicator **1600**. Unlike the indicators described above, the indicator **1610** is not a bell curve but instead a geometric arrangement of vertical bars **1612**. The vertical bars **1612** can approximate a bell curve, however. Horizontal bars may also be used similarly. The width of the vertical bars **1612** and/or the width of the indicator **1600** as a whole can represent the confidence of a parameter. Further, the parameter value can be represented by the center bar **1612** on a parameter value scale (not shown; see FIG. **11**). The narrower the indicator **1610**, the more confidence is represented, and the wider the indicator **1610**, the less confidence is represented, in one embodiment.

Referring to FIG. **17**, another embodiment of a display **1700** is shown. The display **1700** illustrates additional features that can be combined with any of the embodiments described above. The display **1700** includes two indicators **1710***a*, **1710***b*. Each of the indicators **1710** is asymmetrical instead of bell-curve shaped. On one side of the peak **1712***a*, **1712***b* for each indicator **1710***a*, **1710***b*, a portion **1714***a*, **1714***b* of the curve is wider or more dispersed than the other side, leading to the asymmetry.

In one embodiment, the indicator **1710** can be asymmetrical if the confidence measure indicates higher confidence on one side of the parameter value as opposed to the other. Asymmetric confidence can occur for some parameters due to bias. For instance, with hemoglobin, a bias for more positive values at lower values of hemoglobin may occur based on the levels of other blood constituents such as oxygen saturation (SpO_2) or carboxyhemoglobin (SpCO). Similarly, hemoglobin can have a bias for more negative values at higher values of hemoglobin based on levels of other blood constituents. Thus, for lower values of hemoglobin, the curve may be wider in the positive direction, and vice versa.

Positive asymmetry for lower parameter values is illustrated by the indicator **1710***a*, while negative asymmetry for higher parameter values is illustrated by the indicator **1710***b*. To illustrate both positive and negative asymmetry, two indicators **1710***a*, **1710***b* are depicted on the display **1700**. However, in one implementation, only one indicator **1710** is displayed. Multiple indicators are also possible, such as for multiple parameters on a single display. Moreover, the features described herein with respect to FIG. **17** can be extended to arbitrary geometric shapes. A triangle, for instance, can have one half that is wider than another half based on positive or negative bias in confidence levels.

Any of the displays **1100**-**1700** can be used to indicate the occurrence and/or severity of an alarm. For instance, the indicators described above can pulsate or flash when an alarm occurs, optionally in conjunction with an audible alarm. The seriousness of the alarm can depend at least partially on the measured confidence. Higher confidence (e.g., a narrow indicator) can result in a more urgent alarm, whereas less urgent alarms can result for less confident parameter values. This urgency can be displayed in a variety of ways, for example, by increasing the rate that the indicator flashes, increasing the frequency and/or pitch of an audible alarm, combinations of the same, and the like.

Conditional language used herein, such as, among others, "can," "could," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

Depending on the embodiment, certain acts, events, or functions of any of the methods described herein can be performed in a different sequence, can be added, merged, or left out all together (e.g., not all described acts or events are necessary for the practice of the method). Moreover, in certain embodiments, acts or events can be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors or processor cores, rather than sequentially.

The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein can be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware

and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. The described functionality can be implemented in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the disclosure.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein can be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor can be a microprocessor, but in the alternative, the processor can be any conventional processor, controller, microcontroller, or state machine. A processor can also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The blocks of the methods and algorithms described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other form of computer-readable storage medium known in the art. An exemplary storage medium is coupled to a processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor. The processor and the storage medium can reside in an ASIC. The ASIC can reside in a user terminal. In the alternative, the processor and the storage medium can reside as discrete components in a user terminal.

While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the devices or algorithms illustrated can be made without departing from the spirit of the disclosure. As will be recognized, certain embodiments of the inventions described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others. The scope of certain inventions disclosed herein is indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. A system for monitoring parameters of a medical patient using signals received from physiological sensors associated with the medical patient, the system comprising:

a memory device configured to store an alarm delay time and an alarm threshold;

a hardware processor in communication with the memory device, the hardware processor configured to:

monitor a physiological parameter reflecting physiological information obtained from a physiological sensor coupled to a medical patient, and

determine whether the physiological parameter satisfies the alarm threshold for an amount of time corresponding to the alarm delay time;

a visible alarm or an audible alarm configured to be triggered in response to determining that the physiological parameter satisfies the alarm threshold for the amount of time corresponding to the alarm delay time; and

a display configured to output an indicator responsive to an amount of time that the physiological parameter satisfies the alarm threshold,

wherein the indicator is a visible indicator that is responsive to a comparison of (i) the amount of time that the physiological parameter satisfies the alarm threshold and (ii) the alarm delay time, and

wherein the visible indicator comprises (i) a count that depends on the comparison, (ii) a first alert having a display frequency that depends on the comparison, or (iii) a second alert having a display size that depends on the comparison.

2. The system of claim **1**, comprising the visible alarm.

3. The system of claim **1**, comprising the audible alarm.

4. The system of claim **1**, wherein the visible indicator comprises the count.

5. The system of claim **4**, wherein the count comprises a countdown.

6. The system of claim **1**, wherein the visible indicator comprises the first alert.

7. The system of claim **1**, wherein the visible indicator comprises the second alert.

8. The system of claim **1**, wherein the physiological parameter is a respiratory rate.

9. The system of claim **1**, wherein the physiological parameter is an oxygen saturation level.

10. A method for monitoring parameters of a medical patient using signals received from physiological sensors associated with the medical patient, the method comprising:

monitoring, using a hardware processor, a physiological parameter reflecting physiological information obtained from a physiological sensor coupled to a medical patient;

determining, using the hardware processor, that the physiological parameter satisfies an alarm threshold for an amount of time corresponding to an alarm delay time;

triggering, using the hardware processor, a visible alarm or an audible alarm in response to determining that the physiological parameter satisfies the alarm threshold for the amount of time corresponding to the alarm delay time; and

outputting, using a display, an indicator responsive to an amount of time that the physiological parameter satisfies the alarm threshold,

wherein the indicator is a visible indicator that is responsive to a comparison of (i) the amount of time that the physiological parameter satisfies the alarm threshold and (ii) the alarm delay time,

wherein the visible indicator comprises (i) a count that depends on the comparison, (ii) a first alert having a display frequency that depends on the comparison, or (iii) a second alert having a display size that depends on the comparison.

11. The method of claim **10**, wherein said triggering comprises triggering the visible alarm in response to determining that the physiological parameter satisfies the alarm threshold for the amount of time corresponding to the alarm delay time.

12. The method of claim 10, wherein said triggering comprises triggering the audible alarm in response to determining that the physiological parameter satisfies the alarm threshold for the amount of time corresponding to the alarm delay time.

13. The method of claim 10, wherein the visible indicator comprises the count.

14. The method of claim 13, wherein the count comprises a countdown.

15. The method of claim 10, wherein the visible indicator comprises the first alert.

16. The method of claim 10, wherein the visible indicator comprises the second alert.

17. The method of claim 10, wherein the physiological parameter is a respiratory rate.

18. The method of claim 10, wherein the physiological parameter is an oxygen saturation level.

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摘要(译)

除了其他特征之外，本公开还描述了用于使用多个生理参数输入来确定呼吸速率测量中的多参数置信度的系统和方法。例如，患者监测系统可以至少部分地基于从其他非声学传感器或监测器获得的输入，以编程方式确定从声学传感器获得的呼吸速率测量的多参数置信度。患者监测系统可以输出反映编程确定的多参数置信度的多参数置信度指示。多参数置信度指示可以帮助临床医生基于患者的呼吸率确定是否或如何治疗患者。