signals within the PPG waveforms. Ultimately this can cause the pulse oximeter to generate inaccurate values and false alarms.

Oximeters suffer other problems outside of their measurement accuracy. Probes encapsulating a patient's index finger can be uncomfortable and awkward, especially when worn for extended periods of time. Pulse oximeters that lack body-worn processing units can only provide measurements when a patient is sedentary and attached to a bedside monitor; they are impractical for ambulatory patients moving about the hospital, making it difficult to provide true continuous monitoring. Most body-worn oximeters typically lack systems for continuously measuring all vital signs, and particularly blood pressure, from a patient.

SUMMARY OF THE INVENTION

The invention described herein provides a body-worn monitor that continuously measures pulse oximetry and other vital signs, along with motion, posture, and activity level, from an ambulatory patient. The system features an oximetry probe that comfortably clips to the base of the patient's thumb, thereby freeing up their fingers for conventional activities in a hospital, such as reading and eating. The probe reversibly secures to the thumb with, e.g., an easy-to-use Velcro strap, disposable tape, or similar closure, or may be provided in the form of a closed ring which slips over the thumb. It measures time-dependent waveforms (RED/IR(PPG)) corresponding to LEDs typically operating near 660 nm and 905 nm. Analog versions of these waveforms pass through a low-profile cable to a wrist-worn transceiver enclosing a processing unit. Also within the wrist-worn transceiver is a wireless system (typically based wireless protocols such as 802.11 and 802.15.4) that sends information through a network to a remote receiver, e.g. a computer located in a central nursing station.

Clinically accurate pulse oximetry measurements made at the base of the patient's thumb require a set of coefficients relating r (from Eq. 2) to SpO2 that are typically determined with a set of empirical experiments (e.g. a 'breathe down' study, described below). These coefficients differ from those used in conventional oximetry measurements because of the differences between vasculature in the base of the thumb and the tip of the index finger. Typically the base of the thumb features relatively fewer capillary beds, and thus the coefficients are preferably adjusted accordingly.

Three motion-detecting sensors (e.g. accelerometers) form part of the body-worn monitoring system. They are typically secured to the patient's torso (e.g. chest), upper arm (e.g. bicep), and lower arm (e.g. wrist), and measure time-dependent motion signals

(ACC waveforms). The wrist-worn transceiver receives and processes these motion signals to determine the patient's degree of motion, posture, and activity level. Each sensor typically measures a unique ACC waveform along three axes (x, y, and z), and ultimately yields information that can be processed to determine a separate component of the patient's motion. For example, the sensor worn on the lower arm (which may be within the wrist-worn transceiver) monitors movement of the patient's hand and fingers; such motion typically disrupts the RED/IR(PPG) waveforms. It can therefore be processed and used to exclude certain noise-corrupted artifacts from the SpO2 calculation. Sensors attached to the lower and upper arms each measure signals that are collectively analyzed to estimate the patient's arm height; this can be used to improve accuracy of a continuous blood pressure measurement (cNIBP), as described below. And the sensor attached to the patient's chest measures signals that are analyzed to determine the patient's posture and activity level, which can affect measurements for SpO2, cNIBP, and other vital signs. Algorithms for processing information from the accelerometers for these purposes are described in detail in the following patent applications, the contents of which are fully incorporated herein by reference: BODY-WORN MONITOR FEATURING ALARM SYSTEM THAT PROCESSES A PATIENT'S MOTION AND VITAL SIGNS (U.S.S.N 12/469,182; filed May 20, 2009) and BODY-WORN VITAL SIGN MONITOR WITH SYSTEM FOR DETECTING AND ANALYZING MOTION (U.S.S.N 12/469,094; filed May 20, 2009). As described therein, knowledge of a patient's motion, activity level, and posture can greatly enhance the accuracy of alarms/alerts generated by the body-worn monitor. For example, a walking patient typically yields noisy PPG waveforms, but also has a low probability of being hypoxic due to their activity state. According to the invention, a patient in this condition thus does not typically generate an alarm/alert, regardless of the value of SpO2 that is measured. Similarly, a patient that is convulsing or falling typically yields noisy RED/IR(PPG) waveforms from which it is difficult to extract an SpO2 value. But these activity states, regardless of the patient's SpO2 values, may trigger an alarm/alert because they indicate the patient needs medical assistance.

The body-worn monitor features systems for continuously monitoring patients in a hospital environment, and as the patient ultimately transfers from the hospital to the home. Both SpO2 and cNIBP rely on accurate measurement of PPG and ACC waveforms, along with an electrocardiogram waveform (ECG), from patients that are both moving and at rest. cNIBP is typically measured with the 'Composite Technique',

which is described in detail in the co-pending patent application entitled: VITAL SIGN MONITOR FOR MEASURING BLOOD PRESSURE USING OPTICAL, ELECTRICAL, AND PRESSURE WAVEFORMS (U.S.S.N 12/138, 194; filed June 12, 2008), the contents of which are fully incorporated herein by reference.

As described in these applications, the Composite Technique (or, alternatively, the 'Hybrid Technique' referred to therein) typically uses a single PPG waveform from the SpO2 measurement (typically the IR(PPG) waveform, as this typically has a better signal-to-noise ratio than the RED(PPG) waveform), along with the ECG waveform, to calculate a parameter called 'pulse transit time' (PTT) which strongly correlates to blood pressure. Specifically, the ECG waveform features a sharply peaked QRS complex that indicates depolarization of the heart's left ventricle, and, informally, provides a time-dependent marker of a heart beat. PTT is the time separating the peak of the QRS complex and the onset, or 'foot', of the RED/IR(PPG) waveforms; it is typically a few hundred milliseconds. The QRS complex, along with the foot of each pulse in the RED/IR(PPG), can be used to more accurately extract AC signals using a mathematical technique described in detail below. In other embodiments both the RED/IR(PPG) waveforms are collectively processed to enhance the accuracy of the cNIBP measurement.

The electrical system for measuring SpO2 features a small-scale, low-power circuit mounted on a circuit board that fits within the wrist-worn transceiver. The transceiver can further include a touchpanel display, barcode reader, and wireless systems for ancillary applications described, for example, in the following applications, the contents of which have been previously incorporated by reference: BODY-WORN MONITOR FEATURING ALARM SYSTEM THAT PROCESSES A PATIENT'S MOTION AND VITAL SIGNS (U.S.S.N 12/469,182; filed May 20, 2009) and BODY-WORN VITAL SIGN MONITOR WITH SYSTEM FOR DETECTING AND ANALYZING MOTION (U.S.S.N 12/469,094; filed May 20, 2009).

In one aspect, the invention provides a system and method for monitoring a physiological property of a patient's blood (e.g. a SpO2 value). The invention features a first sensor with two radiation sources that emit optical radiation at first and second wavelengths, and a photodetector configured to detect the radiation after it passes through a portion of the patient. A finger-ring housing that houses the radiation sources and the photodetector features a ring-shaped mounting portion that fits or wraps around a base of the patient's thumb. A processing unit, worn on the patient's wrist and operably connected to the finger-ring sensor, receives signals from the photodetector and includes

both a motion sensor and a processor. The processor is configured to process: i) the first and second signals to determine AC signals; ii) at least one of the AC signals and the motion signal to determine selected AC signals; and iii) the selected AC signals, or signals derived therefrom, to determine the physiological property of the patient's blood.

In certain embodiments, the mounting portion comprises a curved, ring-shaped portion that partially surrounds the base of the patient's thumb, while leaving the tip uncovered. The ring-shaped portion can connect to a flexible strap made of, e.g., nylon or fabric. Typically the first and second radiation sources are proximal to one another (and are often within the same electronic package) and are separated from the photodetector by an angle between 75 – 110 degrees. In these and other embodiments the processing unit includes an input port (e.g. a serial port operating a serial protocol, such a control area network, or CAN protocol) configured to receive an electrical signal (e.g. a digitized ECG signal). The ECG signal, for example, is generated by a series of body-worn electrodes connected to differential amplifier circuit. The cable that supplies the ECG signal can include this circuit, and can plug directly into the serial input port. The ECG signal includes a time-dependent marker (e.g. a QRS complex) that precedes both the first and second PPG waveforms generated by each heartbeat by less than pre-determined time period (e.g. 500 ms). It can be processed to determine heart rate, and can additionally be processed to detect both the AC and DC signals within the PPG waveforms, along with motion that may disrupt them. If motion is detected, the system can be instructed to simply ignore the AC and DC components; this is typically done if motion exceeds a pre-determined level known to corrupt these signals beyond an acceptable level. Alternatively, if motion is present but is less than the pre-determined level, its influence over the AC and DC components may be removed using frequency-domain filtering, deconvolution, or similar techniques.

In other embodiments both cNIBP and SpO2 are simultaneously detected from both the PPG and ECG signals. cNIBP is determined, for example, from a time difference between a peak of a QRS complex in the ECG signal and an onset point in one of the AC signals. The time difference, for example, is PTT, and cNIBP is determined according to the Composite Technique. In this case, cNIBP is most accurately determined when the finger-ring sensor is worn on the base of the patient's thumb. For this configuration, parameters relating ratios of the AC and DC signals to SpO2 need to be determined beforehand using, e.g., conventional breathe down studies.

In another aspect, the invention provides a method for simultaneously measuring both SpO2 and a motion-related event (e.g. a patient's posture, activity level, and degree of motion) from the patient. Typically posture may be measured with a single sensor (e.g. an analog or digital three-axis accelerometer) mounted on the patient's torso. The accelerometer can be mounted alongside the ECG circuit in a terminal portion of the ECG cable. In this embodiment, posture is typically determined from a vector corresponding to orientation of the patient's torso. Specifically, an angle separating the vector from a pre-determined coordinate system ultimately yields posture, as is described in detail below. Activity level (corresponding, e.g., to moving, walking, falling, convulsing) is another motion-related event determined in this embodiment. It can be calculated from a mathematical transform of time-dependent variations of a motion signal that yields a frequency-domain spectrum. Portions of the spectrum (e.g. the power of specific frequency components) are compared to pre-determined frequency-dependent parameters to determine the activity level. Other operations, such as a mathematical derivative of the time-dependent motion signal, or a series of 'decision rules' based on a decision-tree algorithm, can also yield the activity level.

In another aspect, the invention provides a complete body-worn vital sign monitor for measuring all the patient's vital signs, including SpO2, cNIBP, and oscillometric blood pressure (SYS, DIA, and MAP). Typically in this embodiment the body-worn monitor features a wrist-worn processing unit that includes, for example, multiple input ports to operably connect with stand-alone systems for measuring some of the vital signs (e.g. to receive cables associated with systems for measuring ECG and oscillometric blood pressure). Additional ports may also be used to collect signals from external sensors that measure, e.g., glucose level, respiration rate, and end-tidal CO_2. To simplify data collection, each port typically operates on a common communication protocol, such as the CAN protocol. Input ports corresponding to ECG and oscillometric blood pressure are typically located on a common side of the processing unit that typically faces away from the patient's hand. In this embodiment any cable connecting to an input port may include an accelerometer to characterize the patient's motion.

In certain embodiments the processing unit features a touchpanel display that renders a first user interface that displays information describing oxygen saturation, a second user interface that displays information describing blood pressure, and a third user interface that displays information describing ECG signals. The processing unit can also include a barcode scanner that scans a barcode of a medical professional (located, e.g., on

their badge). In response, the wrist-worn transceiver can render a user interface corresponding to the medical professional. This prevents the patient from viewing medical information that may, for example, cause unnecessary alarm.

In other embodiments the processing unit includes a speaker for voice communications, or for generating audible voice messages intended for the patient. The processing unit can also include a wireless transmitter that communicates through, e.g., a hospital network.

In another aspect, the invention provides a method for measuring SpO2 and cNIBP by processing ECG, PPG, and motion signals with filters that analyze both PTT and AC signals of the PPG waveforms with a mathematical filter. The filter, for example, can be a 'matched filter', described in detail below. Typically only signals that are generated when motion is relatively low are considered in this embodiment. For example, signals are typically not processed further when the motion sensors indicate that motion is greater than an acceptable level. Filtering PTT values includes, for example, determining values that lie outside a pre-determined range using statistical filters (e.g. a simple average and standard deviation). More sophisticated techniques, such as calculating a power value from a frequency-domain spectrum corresponding to the time-dependent motion signal, and then comparing this to a pre-determined value, can be used to estimate if either the PTT values or PPG signals are affected by motion. SpO2 values are typically calculated from ratios describing the AC and DC signals measured from individual pulses using optical systems operating in the red and infrared optical spectral regions. One or more ratios can be calculated for the pulse.

In another aspect, the invention provides a method for suppressing an alarm/alert based on the SpO2 value by processing the patient's posture and activity state. For example, the alarm can be suppressed if the patient's posture is upright (e.g. standing up), as patients having this posture are typically not in immediate need of medical assistance. Similarly, the alarm can be suppressed if the patient's posture changes from lying down to sitting or standing up (or, alternatively, the other way around). In this case the change in posture, which can be determined with the chest-worn accelerometer, may disrupt the PPG waveforms to the point where an alarm/alert would be falsely generated in the absence of such alarm suppression.

Still other embodiments are found in the following detailed description of the invention, and in the claims.

even if the values for SYS, DIA, and SpO2 fall within the pre-determined alarm thresholds. Specific methodologies for alarms/alerts that consider both vital signs and patient motion are found in the above-referenced patent applications, the contents of which have been previously incorporated by reference.

As shown in Fig. 8, SpO2 data collected with the pulse oximeter probe shown in Fig. 2 and processed with the algorithm shown in Fig. 7 correlate well with that analyzed with a blood gas analyzer, which in this case represents a 'gold standard'. Data shown in the figure were collected during a conventional breathe down study, wherein SpO2 values of 15 healthy volunteers were systematically lowered from a normal value near 100 %O2 to an abnormal value near about 70 %O2 by carefully controlling the subjects' oxygen intake. In total, about 20 data points were measured for each subject over this range. Blood samples for the blood gas analyzer were extracted using an in-dwelling catheter, similar to a conventional arterial line, inserted in the subjects' radial artery. Data in the graph measured according to the invention described herein (shown along the y-axis) correlate well with the gold standard (x-axis), yielding an r^2 value of 0.9. The BIAS for this correlation is -0.3 %O2, and the standard deviation is 2.56 %O2. Data were collected and analyzed with a prototype system, and indicate the efficacy of the invention described herein. They are expected to further improve with a production-quality system. As is clear from the graph, correlation for relatively low SpO2 values (e.g. those near 70 %O2) is worse than that for relatively high SpO2 values (e.g. those near 95%); such a measurement response is typical for commercially available pulse oximeters, and is primarily due to a decreasing signal-to-noise ration in the RED(PPG), which decreases with SpO2.

Figs. 9A,B – 11A,B indicate how different degrees of motion from a patient's fingers can influence both ECG and PPG signals, thereby affecting the accuracy of both SpO2 and cNIBP measurements. In these figures the IR(PPG) is shown, as this signal typically has a better signal-to-noise ratio than that of the RED(PPG). The ACC waveform is typically measured along the vertical axis of the accelerometer embedded in the wrist-worn transceiver. The magnitude of the axes for ECG, PPG, and ACC waveforms are the same for all figures.

In Fig. 9B, for example, the ACC waveform is relatively flat and lacking any significant time-dependent features, indicating that the patient is not moving and is relatively still. Consequently the IR(PPG) in Fig. 9A, which is strongly affected by motion, features well-defined values for IR(foot), indicated by marker 53, and IR(peak),

What is claimed is:

1. A system for monitoring at least one physiological property of a patient's blood, comprising:

a first sensor comprising: a first radiation source configured to emit optical radiation at a first wavelength; a second radiation source configured to emit optical radiation at a second wavelength; a photodetector configured to detect radiation emitted by the first radiation source after it passes through a portion of the patient to generate a first signal, and radiation emitted by the second radiation source after it passes through a portion of the patient to generate a second signal; and a finger-ring housing comprising a mounting portion that comprises the first and second radiation sources and the photodetector, the mounting portion configured to wrap around a base of the patient's thumb while leaving a tip of the thumb uncovered; and

a processing unit configured to be worn on the patient's wrist and connected to the first sensor to receive the first and second signals, the processing unit comprising a motion sensor configured to detect a motion signal, and a processor configured to process: i) the first and second signals to determine AC signals; ii) at least one of the AC signals and the motion signal to determine selected AC signals; and iii) the selected AC signals, or signals derived therefrom, to determine the physiological property of the patient's blood.

2. A method for determining an oxygen saturation value from a patient, comprising the following steps:

(a) measuring a first time-dependent signal by detecting radiation emitted by a first radiation source after it passes through a portion of the patient;

(b) measuring a second time-dependent signal by detecting radiation emitted by a second radiation source after it passes through a portion of the patient;

(c) measuring a time-dependent motion signal with at least one motion sensor;

(d) measuring a time-dependent electrical signal with an electrical sensor comprising at least two electrodes;

(e) processing the time-dependent electrical signal to determine at least one reference point;

(f) processing the time-dependent motion signal to determine a motion-related event that affects at least one of the first and second time-dependent signals;

(g) processing both the first and second time-dependent signals from the reference point and outside of the motion-related event to determine time-dependent signals; and

(h) processing the time-dependent signals to determine a value of oxygen saturation.

3. A method for determining both oxygen saturation and blood pressure values for a patient, comprising:

(a) measuring at least one optical signal with a first sensor;

(b) measuring an electrical signal comprising a time-dependent marker with a second sensor;

(c) measuring a motion signal with a motion sensor;

(d) processing both the motion and optical signals from the time-dependent marker to a later point in time to determine AC signals and a transit time; and

(e) determining a blood pressure value from the transit time, and an oxygen saturation value from the AC signals.

4. The method of claim 2, wherein the method further comprises processing the time-dependent motion signal to determine a motion-related event selected from the patient's posture, activity level, and degree of motion.

5. The method of claim 4, wherein the motion-related event is posture, and the method further comprises determining a parameter corresponding to orientation of the patient's torso.

6. The method of claim 5, wherein the parameter corresponding to orientation of the patient's torso is a vector.

7. The method of claim 6, wherein the method further comprises processing signals corresponding to three axes of a motion sensor to determine the vector.

8. The method of claim 7, wherein the motion sensor is an accelerometer.

9. The method of claim 7, wherein the method further comprises comparing the vector to a pre-determined coordinate system to determine an angle.

10. The method of claim 9, wherein the method further comprises comparing the angle to a set of pre-determined values, each corresponding to a different posture, to determine the patient's posture.

11. The method of claim 2, wherein the motion-related event is activity level, and the method further comprises processing time-dependent variations in the motion signal to determine the activity level.

12. A system for monitoring both blood pressure and oxygen saturation values from a patient, comprising:

a first sensor comprising: a first radiation source configured to emit optical radiation at a first wavelength; a second radiation source configured to emit optical radiation at a second wavelength; a photodetector configured to detect radiation emitted by the first radiation source after it passes through a portion of the patient to generate a first time-dependent signal, and radiation emitted by the second radiation source after it passes through a portion of the patient to generate a second time-dependent signal; and a housing comprising the first and second radiation sources and the photodetector, the housing configured to attach to one of the patient's fingers;

a second sensor comprising: at least two electrodes, each configured to attach to the patient and measure electrical signals and an electrical circuit configured to receive and process the electrical signals to determine a time-dependent electrical signal; and

a processing unit configured to be worn on the patient's arm and connected to the first sensor to receive the first and second time-dependent signals, and to the second sensor to receive the time-dependent electrical signal, the processing unit comprising a processor configured to process: i) the first and second time-dependent signals to determine AC signals, or signals derived therefrom, to determine the oxygen saturation value; and ii) at least one of the AC signals and the electrical signal, or signals derived therefrom, to determine the blood pressure value.

13. A system for determining both oxygen saturation and blood pressure values for a patient, comprising:

a first sensor, configured to worn around the base of the patient's thumb, comprising at least one optical sensor for measuring an optical signal; and

a processing unit, configured to be worn on the patient's arm and operably connected to the first sensor, the processing unit comprising a motion sensor for detecting a motion signal and an input port for receiving an electrical signal and configured to determine both oxygen saturation and blood pressure values by collectively processing the optical, electrical, and motion signals.

14. The system of claim 12, wherein the processing unit further comprises a motion sensor.

15. The system of claim 14, wherein the motion sensor is an accelerometer.

16. The system of claim 12, wherein the processing unit further comprises an input port for receiving a cable.

17. The system of claim 16, wherein the cable further comprises an accelerometer.

18. The system of claim 17, wherein the cable further comprises an ECG circuit.

19. The system of claim 18, wherein the ECG circuit is comprised by the second sensor.

20. The system of claim 19, wherein the second sensor further comprises an analog-to-digital converter.

21. The system of claim 20, wherein the input port is configured to receive a digital signal.

22. The system of claim 21, wherein the input port is a serial port.

23. The system of claim 22, wherein the input port is a serial port operating a CAN communication protocol.

24. A method for monitoring a patient, comprising:

(a) measuring a first time-dependent signal by detecting radiation emitted by a first radiation source after it passes through a portion of the patient;

(b) measuring a second time-dependent signal by detecting radiation emitted by a second radiation source after it passes through a portion of the patient;

(c) measuring a time-dependent motion signal with at least one motion sensor;

(d) processing the time-dependent motion signal to determine at least one of the patient's posture and activity state;

(e) processing both the first and second time-dependent signals to determine an oxygen saturation value for the patient; and,

(f) suppressing an alarm based on the oxygen saturation value due to at least one of the patient's posture and activity state.

25. A method for determining an oxygen saturation value for a patient, comprising:

(a) measuring at least one optical signal with a first sensor;

(b) measuring a motion signal with a motion sensor;

(c) processing the optical signal to determine an oxygen saturation value;

(d) processing the motion signal to determine at least of one of the patient's posture and activity state; and

(e) suppressing an alarm based on the oxygen saturation value due to at least one of the patient's posture and activity state.

signals within the PPG waveforms. Ultimately this can cause the pulse oximeter to generate inaccurate values and false alarms.

Oximeters suffer other problems outside of their measurement accuracy. Probes encapsulating a patient's index finger can be uncomfortable and awkward, especially when worn for extended periods of time. Pulse oximeters that lack body-worn processing units can only provide measurements when a patient is sedentary and attached to a bedside monitor; they are impractical for ambulatory patients moving about the hospital, making it difficult to provide true continuous monitoring. Most body-worn oximeters typically lack systems for continuously measuring all vital signs, and particularly blood pressure, from a patient.

SUMMARY OF THE INVENTION

The invention is defined in the independent claims. Some optional features of the invention are also defined in the dependent claims.

Implementation of the techniques disclosed herein provides a body-worn monitor that continuously measures pulse oximetry and other vital signs, along with motion, posture, and activity level, from an ambulatory patient. The system features an oximetry probe that comfortably clips to the base of the patient's thumb, thereby freeing up their fingers for conventional activities in a hospital, such as reading and eating. The probe reversibly secures to the thumb with, e.g., an easy-to-use Velcro strap, disposable tape, or similar closure, or may be provided in the form of a closed ring which slips over the thumb. It measures time-dependent waveforms (RED/IR(PPG)) corresponding to LEDs typically operating near 660 nm and 905 nm. Analog versions of these waveforms pass through a low-profile cable to a wrist-worn transceiver enclosing a processing unit. Also within the wrist-worn transceiver is a wireless system (typically based wireless protocols such as 802.11 and 802.15.4) that sends information through a network to a remote receiver, e.g. a computer located in a central nursing station.

Clinically accurate pulse oximetry measurements made at the base of the patient's thumb require a set of coefficients relating r (from Eq. 2) to SpO2 that are typically determined with a set of empirical experiments (e.g. a 'breathe down' study, described below). These coefficients differ from those used in conventional oximetry measurements because of the differences between vasculature in the base of the thumb and the tip of the index finger. Typically the base of the thumb features relatively fewer capillary beds, and thus the coefficients are preferably adjusted accordingly.

Three motion-detecting sensors (e.g. accelerometers) form part of the body-worn monitoring system. They are typically secured to the patient's torso (e.g. chest), upper arm (e.g. bicep), and lower arm (e.g. wrist), and measure time-dependent motion signals

(ACC waveforms). The wrist-worn transceiver receives and processes these motion signals to determine the patient's degree of motion, posture, and activity level. Each sensor typically measures a unique ACC waveform along three axes (x, y, and z), and ultimately yields information that can be processed to determine a separate component of the patient's motion. For example, the sensor worn on the lower arm (which may be within the wrist-worn transceiver) monitors movement of the patient's hand and fingers; such motion typically disrupts the RED/IR(PPG) waveforms. It can therefore be processed and used to exclude certain noise-corrupted artifacts from the SpO2 calculation. Sensors attached to the lower and upper arms each measure signals that are collectively analyzed to estimate the patient's arm height; this can be used to improve accuracy of a continuous blood pressure measurement (cNIBP), as described below. And the sensor attached to the patient's chest measures signals that are analyzed to determine the patient's posture and activity level, which can affect measurements for SpO2, cNIBP, and other vital signs. Algorithms for processing information from the accelerometers for these purposes are described in detail in the following patent applications, the contents of which are fully incorporated herein by reference: BODY-WORN MONITOR FEATURING ALARM SYSTEM THAT PROCESSES A PATIENT'S MOTION AND VITAL SIGNS (U.S.S.N 12/469,182; filed May 20, 2009) and BODY-WORN VITAL SIGN MONITOR WITH SYSTEM FOR DETECTING AND ANALYZING MOTION (U.S.S.N 12/469,094; filed May 20, 2009). As described therein, knowledge of a patient's motion, activity level, and posture can greatly enhance the accuracy of alarms/alerts generated by the body-worn monitor. For example, a walking patient typically yields noisy PPG waveforms, but also has a low probability of being hypoxic due to their activity state. According to the techniques disclosed herein, a patient in this condition thus does not typically generate an alarm/alert, regardless of the value of SpO2 that is measured. Similarly, a patient that is convulsing or falling typically yields noisy RED/IR(PPG) waveforms from which it is difficult to extract an SpO2 value. But these activity states, regardless of the patient's SpO2 values, may trigger an alarm/alert because they indicate the patient needs medical assistance.

The body-worn monitor features systems for continuously monitoring patients in a hospital environment, and as the patient ultimately transfers from the hospital to the home. Both SpO2 and cNIBP rely on accurate measurement of PPG and ACC waveforms, along with an electrocardiogram waveform (ECG), from patients that are both moving and at rest. cNIBP is typically measured with the 'Composite Technique',

which is described in detail in the co-pending patent application entitled: VITAL SIGN MONITOR FOR MEASURING BLOOD PRESSURE USING OPTICAL, ELECTRICAL, AND PRESSURE WAVEFORMS (U.S.S.N 12/138, 194; filed June 12, 2008), the contents of which are fully incorporated herein by reference.

As described in these applications, the Composite Technique (or, alternatively, the 'Hybrid Technique' referred to therein) typically uses a single PPG waveform from the SpO2 measurement (typically the IR(PPG) waveform, as this typically has a better signal-to-noise ratio than the RED(PPG) waveform), along with the ECG waveform, to calculate a parameter called 'pulse transit time' (PTT) which strongly correlates to blood pressure. Specifically, the ECG waveform features a sharply peaked QRS complex that indicates depolarization of the heart's left ventricle, and, informally, provides a time-dependent marker of a heart beat. PTT is the time separating the peak of the QRS complex and the onset, or 'foot', of the RED/IR(PPG) waveforms; it is typically a few hundred milliseconds. The QRS complex, along with the foot of each pulse in the RED/IR(PPG), can be used to more accurately extract AC signals using a mathematical technique described in detail below. In other exemplary techniques, both the RED/IR(PPG) waveforms are collectively processed to enhance the accuracy of the cNIBP measurement.

The electrical system for measuring SpO2 features a small-scale, low-power circuit mounted on a circuit board that fits within the wrist-worn transceiver. The transceiver can further include a touchpanel display, barcode reader, and wireless systems for ancillary applications described, for example, in the following applications, the contents of which have been previously incorporated by reference: BODY-WORN MONITOR FEATURING ALARM SYSTEM THAT PROCESSES A PATIENT'S MOTION AND VITAL SIGNS (U.S.S.N 12/469,182; filed May 20, 2009) and BODY-WORN VITAL SIGN MONITOR WITH SYSTEM FOR DETECTING AND ANALYZING MOTION (U.S.S.N 12/469,094; filed May 20, 2009).

In an exemplary technique, there is provided a system and method for monitoring a physiological property of a patient's blood (e.g. a SpO2 value). The exemplary technique features a first sensor with two radiation sources that emit optical radiation at first and second wavelengths, and a photodetector configured to detect the radiation after it passes through a portion of the patient. A finger-ring housing that houses the radiation sources and the photodetector features a ring-shaped mounting portion that fits or wraps around a base of the patient's thumb. A processing unit, worn on the patient's wrist and operably connected to the finger-ring sensor, receives signals from the photodetector and includes

both a motion sensor and a processor. The processor is configured to process: i) the first and second signals to determine AC signals; ii) at least one of the AC signals and the motion signal to determine selected AC signals; and iii) the selected AC signals, or signals derived therefrom, to determine the physiological property of the patient's blood.

In certain exemplary techniques, the mounting portion comprises a curved, ring-shaped portion that partially surrounds the base of the patient's thumb, while leaving the tip uncovered. The ring-shaped portion can connect to a flexible strap made of, e.g., nylon or fabric. Typically the first and second radiation sources are proximal to one another (and are often within the same electronic package) and are separated from the photodetector by an angle between 75 – 110 degrees. In these and other exemplary techniques the processing unit includes an input port (e.g. a serial port operating a serial protocol, such a control area network, or CAN protocol) configured to receive an electrical signal (e.g. a digitized ECG signal). The ECG signal, for example, is generated by a series of body-worn electrodes connected to differential amplifier circuit. The cable that supplies the ECG signal can include this circuit, and can plug directly into the serial input port. The ECG signal includes a time-dependent marker (e.g. a QRS complex) that precedes both the first and second PPG waveforms generated by each heartbeat by less than pre-determined time period (e.g. 500 ms). It can be processed to determine heart rate, and can additionally be processed to detect both the AC and DC signals within the PPG waveforms, along with motion that may disrupt them. If motion is detected, the system can be instructed to simply ignore the AC and DC components; this is typically done if motion exceeds a pre-determined level known to corrupt these signals beyond an acceptable level. Alternatively, if motion is present but is less than the pre-determined level, its influence over the AC and DC components may be removed using frequency-domain filtering, deconvolution, or similar techniques.

In other exemplary techniques both cNIBP and SpO2 are simultaneously detected from both the PPG and ECG signals. cNIBP is determined, for example, from a time difference between a peak of a QRS complex in the ECG signal and an onset point in one of the AC signals. The time difference, for example, is PTT, and cNIBP is determined according to the Composite Technique. In this case, cNIBP is most accurately determined when the finger-ring sensor is worn on the base of the patient's thumb. For this configuration, parameters relating ratios of the AC and DC signals to SpO2 need to be determined beforehand using, e.g., conventional breathe down studies.

In another exemplary technique, there is provided a method for simultaneously measuring both SpO2 and a motion-related event (e.g. a patient's posture, activity level, and degree of motion) from the patient. Typically posture may be measured with a single sensor (e.g. an analog or digital three-axis accelerometer) mounted on the patient's torso. The accelerometer can be mounted alongside the ECG circuit in a terminal portion of the ECG cable. In this exemplary technique, posture is typically determined from a vector corresponding to orientation of the patient's torso. Specifically, an angle separating the vector from a pre-determined coordinate system ultimately yields posture, as is described in detail below. Activity level (corresponding, e.g., to moving, walking, falling, convulsing) is another motion-related event determined in this exemplary technique. It can be calculated from a mathematical transform of time-dependent variations of a motion signal that yields a frequency-domain spectrum. Portions of the spectrum (e.g. the power of specific frequency components) are compared to pre-determined frequency-dependent parameters to determine the activity level. Other operations, such as a mathematical derivative of the time-dependent motion signal, or a series of 'decision rules' based on a decision-tree algorithm, can also yield the activity level.

In another exemplary technique, there is provided a complete body-worn vital sign monitor for measuring all the patient's vital signs, including SpO2, cNIBP, and oscillometric blood pressure (SYS, DIA, and MAP). Typically in this exemplary technique the body-worn monitor features a wrist-worn processing unit that includes, for example, multiple input ports to operably connect with stand-alone systems for measuring some of the vital signs (e.g. to receive cables associated with systems for measuring ECG and oscillometric blood pressure). Additional ports may also be used to collect signals from external sensors that measure, e.g., glucose level, respiration rate, and end-tidal CO_2. To simplify data collection, each port typically operates on a common communication protocol, such as the CAN protocol. Input ports corresponding to ECG and oscillometric blood pressure are typically located on a common side of the processing unit that typically faces away from the patient's hand. In this exemplary technique any cable connecting to an input port may include an accelerometer to characterize the patient's motion.

In certain exemplary techniques the processing unit features a touchpanel display that renders a first user interface that displays information describing oxygen saturation, a second user interface that displays information describing blood pressure, and a third user interface that displays information describing ECG signals. The processing unit can also include a barcode scanner that scans a barcode of a medical professional (located, e.g., on

their badge). In response, the wrist-worn transceiver can render a user interface corresponding to the medical professional. This prevents the patient from viewing medical information that may, for example, cause unnecessary alarm.

In other exemplary techniques the processing unit includes a speaker for voice communications, or for generating audible voice messages intended for the patient. The processing unit can also include a wireless transmitter that communicates through, e.g., a hospital network.

In another exemplary technique, there is provided a method for measuring SpO2 and cNIBP by processing ECG, PPG, and motion signals with filters that analyze both PTT and AC signals of the PPG waveforms with a mathematical filter. The filter, for example, can be a 'matched filter', described in detail below. Typically only signals that are generated when motion is relatively low are considered in this exemplary technique. For example, signals are typically not processed further when the motion sensors indicate that motion is greater than an acceptable level. Filtering PTT values includes, for example, determining values that lie outside a pre-determined range using statistical filters (e.g. a simple average and standard deviation). More sophisticated techniques, such as calculating a power value from a frequency-domain spectrum corresponding to the time-dependent motion signal, and then comparing this to a pre-determined value, can be used to estimate if either the PTT values or PPG signals are affected by motion. SpO2 values are typically calculated from ratios describing the AC and DC signals measured from individual pulses using optical systems operating in the red and infrared optical spectral regions. One or more ratios can be calculated for the pulse.

In another exemplary technique, there is provided a method for suppressing an alarm/alert based on the SpO2 value by processing the patient's posture and activity state. For example, the alarm can be suppressed if the patient's posture is upright (e.g. standing up), as patients having this posture are typically not in immediate need of medical assistance. Similarly, the alarm can be suppressed if the patient's posture changes from lying down to sitting or standing up (or, alternatively, the other way around). In this case the change in posture, which can be determined with the chest-worn accelerometer, may disrupt the PPG waveforms to the point where an alarm/alert would be falsely generated in the absence of such alarm suppression.

Still other embodiments are found in the following detailed description, and in the claims.

even if the values for SYS, DIA, and SpO2 fall within the pre-determined alarm thresholds. Specific methodologies for alarms/alerts that consider both vital signs and patient motion are found in the above-referenced patent applications, the contents of which have been previously incorporated by reference.

As shown in Fig. 8, SpO2 data collected with the pulse oximeter probe shown in Fig. 2 and processed with the algorithm shown in Fig. 7 correlate well with that analyzed with a blood gas analyzer, which in this case represents a 'gold standard'. Data shown in the figure were collected during a conventional breathe down study, wherein SpO2 values of 15 healthy volunteers were systematically lowered from a normal value near 100 %O2 to an abnormal value near about 70 %O2 by carefully controlling the subjects' oxygen intake. In total, about 20 data points were measured for each subject over this range. Blood samples for the blood gas analyzer were extracted using an in-dwelling catheter, similar to a conventional arterial line, inserted in the subjects' radial artery. Data in the graph measured described herein (shown along the y-axis) correlate well with the gold standard (x-axis), yielding an r^2 value of 0.9. The BIAS for this correlation is -0.3 %O2, and the standard deviation is 2.56 %O2. Data were collected and analyzed with a prototype system, and indicate the efficacy of the invention described herein. They are expected to further improve with a production-quality system. As is clear from the graph, correlation for relatively low SpO2 values (e.g. those near 70 %O2) is worse than that for relatively high SpO2 values (e.g. those near 95%); such a measurement response is typical for commercially available pulse oximeters, and is primarily due to a decreasing signal-to-noise ration in the RED(PPG), which decreases with SpO2.

Figs. 9A,B – 11A,B indicate how different degrees of motion from a patient's fingers can influence both ECG and PPG signals, thereby affecting the accuracy of both SpO2 and cNIBP measurements. In these figures the IR(PPG) is shown, as this signal typically has a better signal-to-noise ratio than that of the RED(PPG). The ACC waveform is typically measured along the vertical axis of the accelerometer embedded in the wrist-worn transceiver. The magnitude of the axes for ECG, PPG, and ACC waveforms are the same for all figures.

In Fig. 9B, for example, the ACC waveform is relatively flat and lacking any significant time-dependent features, indicating that the patient is not moving and is relatively still. Consequently the IR(PPG) in Fig. 9A, which is strongly affected by motion, features well-defined values for IR(foot), indicated by marker 53, and IR(peak),

What is claimed is:

1. A method for monitoring a patient, comprising:

(a) positioning a pulse oximetry sensor on a base of the patient's thumb, the pulse oximetry sensor comprising a first radiation source configured to emit a first optical radiation at a first wavelength; a second radiation source configured to emit a second optical radiation at a second wavelength; a photodetector configured to detect the first optical radiation emitted by the first radiation source after the first optical radiation passes through a portion of the patient to generate a first signal, and the second optical radiation emitted by the second radiation source after the second optical radiation passes through a portion of the patient to generate a second signal; and a finger-ring housing comprising the first and second radiation sources and the photodetector, wherein the pulse oximetry sensor is positioned such that the first optical radiation emitted by the first radiation source and the second optical radiation emitted by the second radiation source pass through the thumb tissue and are received by the princeps pollicis artery before reaching the photodetector;

(b) causing the first radiation source to emit the first optical radiation and measuring a first time-dependent signal by detecting the first optical radiation with the photodetector;

(c) causing the second radiation source to emit the second optical radiation and measuring a second time-dependent signal by detecting the second optical radiation with the photodetector;

(d) measuring a time-dependent motion signal with at least one motion sensor;

(e) transmitting the first time-dependent signal, the second time-dependent signal, and the time-dependent motion signal at a processing component;

(f) processing the time-dependent motion signal with the processing component to determine the patient's posture and activity state;

(g) processing both the first and second time-dependent signals with the processing component to determine an oxygen saturation value for the patient; and,

(h) suppressing generation of an alarm based on the oxygen saturation value when the patient's posture and activity state meet a predetermined criteria.

2. The method of claim 1, wherein step (h) further comprises suppressing generation of the alarm if the patient's posture and activity state indicate that the patient is standing upright.

3. The method of claim 1, wherein step (h) further comprises suppressing generation of the alarm if the patient's posture and activity state indicate a change from lying down to one of sitting and standing upright.

4. The method of claim 1, wherein step (h) further comprises suppressing generation of the alarm if the patient's posture and activity state indicate a change from one of standing upright and

sitting to lying down.

5. The method of claim 1, wherein step (f) further comprises analyzing three time-dependent motion signals, each corresponding to a unique axis, to determine the patient's posture and activity state, the three time-dependent motion signals having been generated by the at least one motion sensor, the at least one motion sensor being worn on a torso of the patient.

6. The method of claim 5, wherein step (f) further comprises determining a vector corresponding to orientation of the torso of the patient from the three time-dependent motion signals.

7. The method of claim 6, wherein step (f) further comprises comparing the vector to a coordinate space defined by three positional vectors, each indicating an orientation of the motion sensor on the patient wherein a first positional vector corresponds to a vertical axis in the coordinate space, a second positional vector corresponds to a horizontal axis in the coordinate space, and a third positional vector corresponds to a normal axis extending normal to the patient's chest, and wherein the three positional vectors are defined relative to a chest accelerometer coordinate space.

8. The method of claim 1, wherein step (c) further comprises detecting a set of time-dependent motion signals with at least one motion-detecting sensor positioned on the patient's chest.

9. The method of claim 1, where the at least one motion sensor is an accelerometer.