al., 'A physiologically-based early warning score for ward patients: the association between score and outcome', *Anaesthesia* 2005; 60: 547-553). Those with a higher respiratory rate had an even higher mortality rate. In another study, just over half of all patients suffering a serious adverse event on the general wards (e.g. a cardiac arrest or ICU admission) had a respiratory rate greater than 24 breaths/minute. These patients could have been identified as high risk up to 24 hours before the event with a specificity of over 95% (Cretikos et al., 'The Objective Medical Emergency Team Activation Criteria: a case–control study', *Resuscitation* 2007; 73: 62-72). Medical references such as these clearly indicate that an accurate, easy-to-use device for measuring respiratory rate is important for patient monitoring within the hospital.

[0006] Despite its importance and the large number of available monitoring techniques, RR is notoriously difficult to measure, particularly when a patient is moving. During periods of motion, non-invasive techniques based on IP and PPG signals are usually overwhelmed by artifacts and thus completely ineffective. This makes it difficult or impossible to measure RR from an ambulatory patient. Measurements based on et-CO2 are typically less susceptible to motion, but require a plastic tube inserted in the patient's mouth, which is typically impractical for ambulatory patients.

SUMMARY OF THE INVENTION

[0007] This invention provides methods, devices, and systems for use in measuring RR using multiple input signals, including IP, PPG, and ECG waveforms, and a signal processing technique based on adaptive filtering. After being measured with a body-worn system, these waveforms are processed along with those from an accelerometer mounted on the patient's torso (most typically the chest or abdomen). The accelerometer measures small, breathing-induced movements to generate a time-dependent waveform (ACC). With adaptive filtering, an initial RR is preferably estimated from the IP waveform, and

motion, such as that described herein. Other heuristic rules based on analysis of ACC waveforms may also be deployed according to this invention.

[0009] Sensors attached to the wrist and bicep 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, that measures systolic (SYS), diastolic (DIA), and mean (MAP) arterial blood pressures. And the sensor attached to the patient's chest measures signals that are analyzed to determine posture and activity level, which can affect measurements for RR, 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.

[0010] The body-worn monitor features systems for continuously monitoring patients in a hospital environment, and as the patient transfers from different areas in the hospital, and ultimately to the home. Both SpO2 and cNIBP rely on accurate measurement of PPG and ACC waveforms, along with an 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.

[0011] 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 generated with infrared radiation), 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 PPG waveforms. The QRS complex, along with the foot of each pulse in the PPG, can be used to more accurately extract AC signals using a mathematical technique described in detail below. In other embodiments both the red and infrared PPG waveforms are collectively processed to enhance the accuracy of the cNIBP measurement.

[0012] In certain embodiments, the electrical system for measuring RR features a small-scale, low-power circuit mounted on a circuit board that fits within the wrist-worn transceiver. The transceiver additionally includes a touchpanel display, barcode reader, and wireless systems for ancillary applications described, for example, in the above-referenced applications, the contents of which have been previously incorporated herein by reference.

[0013] In one aspect, the invention provides a multi-sensor system that uses an algorithm based on adaptive filtering to monitor a patient's RR. The system features a first sensor selected from the following group: i) an IP sensor featuring at least two electrodes and an IP processing circuit configured to measure an IP signal; ii) an ECG sensor featuring at least two electrodes and an ECG processing circuit configured to

determine the final RR value. In general, according to the invention, any combination of the above-described waveforms can be used in the adaptive filtering process to determine the initial and final RR values.

[0018] In another aspect, the invention provides a system for monitoring a patient's RR that also accounts for their posture, activity level, and degree of motion. Such patient states can result in artifacts that affect the RR measurement, and thus proper interpretation of them can reduce the occurrence of erroneous RR values and ultimately false alarms/alerts in the hospital.

[0019] In another aspect, the invention provides a cable within a body-worn monitor that includes an IP system, a motion sensor (e.g. accelerometer), and a processing system that determines RR from signals generated by these sensors. These components, for example, can be included in a terminal end of the cable, typically worn on the patient's torso, which connects to a series of disposable electrodes that attach to the patient's body. A mechanical housing, typically made of plastic, covers these and other components, such as sensors for measuring signals relating to ECG and skin temperature.

[0020] In embodiments, the cable includes at least one conductor configured to transmit both a first digital data stream representing the digital IP signal or information calculated therefrom, and a second digital data stream representing the digital motion signal or information calculated therefrom. In other embodiments these signals are processed by a microprocessor on the chest to determine an RR value, and this value is then sent in the digital data stream to another processor, such as one within the wrist-worn transceiver, where it is further processed. To transmit the serial data stream, the terminal portion of the cable can include a transceiver component, e.g. a serial transceiver configured to transmit a digital data stream according to the CAN protocol. Other properties, such as heart rate, temperature, alarms relating to ECG signals, and other

information relating to the CAN communication protocol and its timing can be transmitted by the transceiver component.

[0021] While the various sensors are described herein as being operably connected to the wrist-worn transceiver via such a cable, in alternative embodiments the data streams from the various sensors (e.g., the chest-worn sensor(s)) are operably connected to the wrist-worn transceiver in a wireless fashion. By way of example, the wrist-worn transceiver and chest-worn sensor connect through a short-range wireless interface, such as one based on 802.16.4 (e.g. Bluetooth or Zigbee). In this case, both components include a transceiver that operates on the wireless protocol.

[0022] In embodiments, both the IP and ECG systems are contained within a single integrated circuit. The ECG system can be modular and determine multi-lead ECG signals, such as three, five, and twelve-lead ECG signals.

[0023] In another aspect, the invention provides a method for determining RR during periods of motion. The method includes the following steps: (a) measuring a first time-dependent signal by detecting a modulated electrical current passing through the patient's torso; (b) measuring a second time-dependent signal by detecting respiration-induced movements in the patient's torso with at least one motion sensor; (c) determining a motion-related event not related to the patient's respiration rate value by processing signals from the motion sensor; and (d) collectively processing both the first and second time-dependent signals to determine a value for RR corresponding to a period when the patient's motion-related event is below a pre-determined threshold. For example, the motion-related event determined during step (c) can be the patient's posture, activity level, or degree of motion. Typically these parameters are determined from signals measured with an accelerometer mounted on the patient's torso. These signals are processed with an algorithm, described in detail below, that yields a vector indicating

orientation of the patient's chest and their subsequent posture. 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) 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 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.

[0024] In another aspect, the invention provides a method for suppressing alarms related to RR by processing the patient's posture, activity level, and degree of motion as determined by the accelerometer. For example, the alarm can be suppressed if the patient is standing upright, or if their posture changes from lying down to one of sitting and standing upright. Or the alarm can be suppressed if their posture changes from either standing upright or sitting to lying down. In general, a rapid change in posture, which can be determined with the chest-worn accelerometer, may disrupt the signals used to determine RR to the point where a false alarm/alert is generated. In this embodiment, posture is determined from the vector-based analysis, described above.

[0025] In yet another aspect, the invention provides a system for monitoring a patient's RR featuring a sensor unit configured to be mounted on the patient's torso. The sensor unit features IP and motion sensors, as described above, and additionally attaches directly to an electrode that secures the unit to the patient's torso (e.g. chest or abdomen). Here, a housing comprising the IP and motion sensors additionally includes a connector featuring an opening configured to receive a metal snap on the exterior of a conventional disposable electrode. Other electrodes used for IP and ECG measurements connect to the

unit through cables. The unit can additionally send a digital data stream including RR data over a CAN bus to a wrist-worn transceiver, which as described above can further process the RR value to account for alarms/alerts, motion, etc.

[0026] In all embodiments, the wrist-worn transceiver can include a display configured to display the patient's RR and other vital signs, along with a touchpanel interface. A wireless transceiver within the wrist-worn transceiver can transmit information to a remote computer using conventional protocols such as 802.11, 802.15.4, and cellular. The remote computer, for example, can be connected to a hospital network. It can also be a portable computer, such as a tablet computer, personal digital assistant, or cellular phone.

[0027] Many advantages are associated with this invention. In general, it provides an accurate measurement of RR, along with an independent measurement of a patient's posture, activity level, and motion, to characterize an ambulatory patient in the hospital. These parameters can be collectively analyzed to improve true positive alarms while reducing the occurrence of false positive alarms. Additionally, the measurement of RR is performed with a body-worn monitor that is comfortable, lightweight, and low-profile, making it particularly well suited for patients that are moving about. Such a monitor could continuously monitor a patient as, for example, they transition from the emergency department to the ICU, and ultimately to the home after hospitalization.

[0028] Still other embodiments are found in the following detailed description of the invention and in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Fig. 1A shows a schematic view of a patient wearing accelerometers on their abdomen (position 1) and chest (position 2) to measure ACC waveforms and RR according to the adaptive filtering process of the invention;

room), with each section corresponding to a specific bed, chair, or general location in the area. Typically the display renders graphical icons corresponding to the motion and alarm parameters for each patient in the group. In other embodiments, the body-worn monitor includes a graphical display that renders these parameters directly on the patient.

[0154] Typically the location sensor and the wireless transceiver operate on a common wireless system, e.g. a wireless system based on 802.11, 802.15.4, or cellular protocols. In this case a location is determined by processing the wireless signal with one or more algorithms known in the art. These include, for example, triangulating signals received from at least three different base stations, or simply estimating a location based on signal strength and proximity to a particular base station. In still other embodiments the location sensor includes a conventional global positioning system (GPS).

[0155] The body-worn monitor can include a first voice interface, and the remote computer can include a second voice interface that integrates with the first voice interface. The location sensor, wireless transceiver, and first and second voice interfaces can all operate on a common wireless system, such as one of the above-described systems based on 802.11 or cellular protocols. The remote computer, for example, can be a monitor that is essentially identical to the monitor worn by the patient, and can be carried or worn by a medical professional. In this case the monitor associated with the medical professional features a GUI wherein the user can select to display information (e.g. vital signs, location, and alarms) corresponding to a particular patient. This monitor can also include a voice interface so the medical professional can communicate directly with the patient.

[0156] Figs. 29A, 29B show yet another alternate embodiment of the invention wherein a sensor unit 255 attaches to the abdomen of a patient 10 using an electrode 24 normally attached to the lower left-hand portion of the patient's torso. Specifically, the

What is claimed is:

1. A system for monitoring a patient's respiratory rate, comprising:

a first sensor selected from the group consisting of: i) an impedance pneumography sensor comprising at least two electrodes and an impedance pneumography processing circuit configured to process signals from the two electrodes to measure an impedance pneumography signal from the patient; ii) an ECG sensor comprising at least two electrodes and an ECG processing circuit configured to process signals from the two electrodes to measure an ECG signal from the patient; and iii) a PPG sensor comprising a light source, photodetector, and PPG processing circuit configured to process signals from the photodetector to measure a PPG signal from the patient;

a second sensor comprising a motion sensor configured to attach to the patient's torso and measure a motion signal from the patient;

a processing system configured to be worn on the patient's body and operably connect to the first sensor to receive a first signal representing at least one of the impedance pneumography, ECG, and PPG signals, and connect to the second sensor to receive a second signal representing the motion signal, the processing system configured to: i) process the motion signal to determine an initial respiratory rate; ii) process the first signal with a digital filter determined from the initial respiratory rate to determine a third signal; and iii) process the third signal to determine a value for the patient's respiration rate.

2. A system for monitoring a patient's respiratory rate, comprising:

a first sensor selected from the group consisting of: i) an impedance pneumography sensor comprising at least two electrodes and an impedance pneumography processing circuit configured to process signals from the two electrodes to measure an impedance pneumography signal from the patient; ii) an ECG sensor

comprising at least two electrodes and an ECG processing circuit configured to process signals from the two electrodes to measure an ECG signal from the patient; and iii) a PPG sensor comprising a light source, photodetector, and PPG processing circuit configured to process signals from the photodetector to measure a PPG signal from the patient;

a second sensor comprising a motion sensor configured to attach to the patient's torso and measure a motion signal from the patient;

a processing system configured to be worn on the patient's body and operably connect to the first sensor to receive a first signal representing at least one of the impedance pneumography, ECG, and PPG signals, and connect to the second sensor to receive a second signal representing the motion signal, the processing system configured to: i) process the first signal to determine an initial respiratory rate; ii) process the motion signal with a digital filter determined from the initial respiratory rate to determine a third signal; and iii) process the third signal to determine a final value for the patient's respiration rate.

3. A system for determining respiration rate values for a patient, comprising:

a first sensor, configured to worn on the patient's torso, comprising an impedance pneumography sensor;

a second sensor, configured to be worn on the patient's torso, comprising an accelerometer; and

a processing system, configured to be worn on the patient's body and operably connect to the first and second sensors, the processing system configured to determine a respiration rate value by processing a signal from the first sensor with a digital filter determined from a signal from the second sensor.

4. A system for determining respiration rate values for a patient, comprising:

a first sensor, configured to worn on the patient's torso, comprising an impedance pneumography sensor;

a second sensor, configured to be worn on the patient's torso, comprising an accelerometer; and

a processing system, configured to be worn on the patient's body and operably connect to the first and second sensors, the processing system configured to determine a respiration rate value by processing a signal from the second sensor with a digital filter determined from a signal from the first sensor.

5. The system of claim 1, wherein the digital filter is a bandpass filter.

6. The system of claim 1, wherein the digital filter is a low-pass filter.

7. The system of claim 5, wherein the bandpass filter comprises an upper frequency limit determined from a multiple of the initial respiratory rate.

8. The system of claim 1, wherein the processing system is further configured to determine a mathematical derivative of the third signal to determine the final value for the patient's respiratory rate.

9. The system of claim 1, wherein the first sensor is an impedance pneumography sensor that detects a first signal representing an impedance pneumography signal comprising a first series of pulses, and wherein the processing system is configured to count each pulse in the first series of pulses to determine the initial respiratory rate.

10. The system of claim 1, wherein the first sensor is an ECG sensor that detects a first signal representing an ECG signal comprising a first series of pulses with amplitudes characterized by a time-varying envelope, with the frequency of the envelope representing the initial respiratory rate.

11. The system of claim 1, wherein the first sensor is a PPG sensor that detects a first signal representing a PPG signal comprising a first series of pulses with amplitudes characterized by a time-varying envelope, with the frequency of the envelope representing the initial respiratory rate.

12. The system of claim 1, wherein the motion sensor is an accelerometer.

13. A system for determining respiration rate values for a patient, comprising:

a first sensor comprising a motion sensor and configured to be worn on the patient's torso, the first sensor configured to measure a first signal representing the patient's respiratory events, and a second signal representing at least one of the patient's posture and activity level;

a processing system, configured to be worn on the patient's body and operably connect to the first sensor, the processing system configured to process the first signal to determine a parameter related to the patient's respiratory rate, and the second signal to determine one of the patient's posture and activity level, with the parameter related to respiration rate reported by the system modified by at least one of the posture and activity level determined from the second signal.

14. The system of claim 13, wherein the motion sensor is an accelerometer.

15. The system of claim 14, wherein the first sensor comprises an impedance pneumography sensor that generates an impedance pneumography signal.

16. The system of claim 15, wherein the impedance pneumography signal comprises a first series of pulses, with each pulse in the first series representing a respiratory event.

17. The system of claim 14, wherein the second signal comprises data measured along at least one of the x, y, and z axes of the accelerometer.

18. The system of claim 17, wherein data measured along each of the x, y, and z axes of the accelerometer are processed with a mathematical model to determine the patient's posture.

19. The system of claim 18, wherein the mathematical model comprises determining an angle between a variable normal vector and a constant vector, the angle indicating the patient's posture.

20. The system of claim 19, wherein the parameter related to respiration rate is an alarm.

21. The system of claim 20, wherein the alarm is deactivated if the patient's posture is standing upright.

22. The system of claim 17, wherein the data measured along at least one of the x, y, and z axes of the accelerometer are processed with a mathematical model to determine the patient's activity level.

23. The system of claim 22, wherein the mathematical model comprises determining a variation in the data measured along at least one of the x, y, and z axes of the accelerometer, the variation indicating the patient's activity level.

24. The system of claim 23, wherein the parameter related to respiration rate is an alarm.

25. The system of claim 24, wherein the alarm is deactivated if the patient's activity level indicates they are in motion.

26. A system for monitoring respiratory rate from a patient, comprising:

a cable comprising:

an impedance pneumography system comprising: i) a connecting portion configured to connect to a plurality of electrodes configured to be worn on the patient; ii) a differential amplifier configured to receive electrical signals from each of the plurality of electrodes and process them to generate an analog impedance pneumography signal; and iii) an analog-to-digital converter configured to convert the analog impedance pneumography signal into a digital impedance pneumography signal;

an accelerometer system comprising: i) an accelerometer configured to generate an analog motion signal; and ii) analog-to-digital converter configured to convert the analog motion signal into a digital motion signal; and

a processing system comprising a processor in electrical communication with the cable and configured to receive a digital data stream comprising the digital impedance pneumography and motion signals and process these signals to determine the patient's respiratory rate.

27. A system for monitoring respiratory rate from a patient, comprising:

a processing system configured to be worn on a patient's body comprising a processor configured to receive a digital data stream from a cable comprising a motion sensor and an impedance pneumography sensor, and collectively process motion signals and respiratory signals in the digital data stream to determine respiratory rate; and,

a cable comprising the motion sensor and the impedance pneumography sensor, each sensor comprising an analog-to-digital converter configured to generate a digital

signal, and a transceiver component configured to transmit the digital signals in the digital data stream through the cable and to the processing system.

28. The system of claim 26, wherein the impedance pneumography system is comprised by a terminal end of the cable.

29. The system of claim 28, wherein the cable comprises a housing at its terminal end that comprises the impedance pneumography system.

30. The system of claim 29, wherein the housing further comprises the accelerometer system.

31. The system of claim 26, wherein the cable comprises at least one conductor configured to transmit both a first digital data stream representing the digital impedance pneumography signal or information calculated therefrom, and a second digital data stream representing the digital motion signal or information calculated therefrom.

32. The system of claim 31, wherein the first digital data stream comprises a first header portion and a first data portion, the first header portion indicating that the first data portion comprises impedance pneumography information or information calculated therefrom.

33. The system of claim 31, wherein the second digital data stream comprises a first header portion and a first data portion, the first header portion indicating that the first data portion comprises motion information or information calculated therefrom.

al., 'A physiologically-based early warning score for ward patients: the association between score and outcome', *Anaesthesia* 2005; 60: 547-553). Those with a higher respiratory rate had an even higher mortality rate. In another study, just over half of all patients suffering a serious adverse event on the general wards (e.g. a cardiac arrest or ICU admission) had a respiratory rate greater than 24 breaths/minute. These patients could have been identified as high risk up to 24 hours before the event with a specificity of over 95% (Cretikos et al., 'The Objective Medical Emergency Team Activation Criteria: a case–control study', *Resuscitation* 2007; 73: 62-72). Medical references such as these clearly indicate that an accurate, easy-to-use device for measuring respiratory rate is important for patient monitoring within the hospital.

[0006] Despite its importance and the large number of available monitoring techniques, RR is notoriously difficult to measure, particularly when a patient is moving. During periods of motion, non-invasive techniques based on IP and PPG signals are usually overwhelmed by artifacts and thus completely ineffective. This makes it difficult or impossible to measure RR from an ambulatory patient. Measurements based on et-CO2 are typically less susceptible to motion, but require a plastic tube inserted in the patient's mouth, which is typically impractical for ambulatory patients.

SUMMARY OF THE INVENTION

[0006a] The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

[0007] Implementation of the techniques disclosed herein provides methods, devices, and systems for use in measuring RR using multiple input signals, including IP, PPG, and ECG waveforms, and a signal processing technique based on adaptive filtering. After being measured with a body-worn system, these waveforms are processed along with those from an accelerometer mounted on the patient's torso (most typically the chest or abdomen). The accelerometer measures small, breathing-induced movements to generate a time-dependent waveform (ACC). With adaptive filtering, an initial RR is preferably estimated from the IP waveform, and

motion, such as that described herein. Other heuristic rules based on analysis of ACC waveforms may also be deployed according to the techniques disclosed herein.

[0009] Sensors attached to the wrist and bicep 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, that measures systolic (SYS), diastolic (DIA), and mean (MAP) arterial blood pressures. And the sensor attached to the patient's chest measures signals that are analyzed to determine posture and activity level, which can affect measurements for RR, 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.

[0010] The body-worn monitor features systems for continuously monitoring patients in a hospital environment, and as the patient transfers from different areas in the hospital, and ultimately to the home. Both SpO2 and cNIBP rely on accurate measurement of PPG and ACC waveforms, along with an 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.

[0011] 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 generated with infrared radiation), 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 PPG waveforms. The QRS complex, along with the foot of each pulse in the PPG, can be used to more accurately extract AC signals using a mathematical technique described in detail below. In other embodiments both the red and infrared PPG waveforms are collectively processed to enhance the accuracy of the cNIBP measurement.

[0012] In certain embodiments, the electrical system for measuring RR features a small-scale, low-power circuit mounted on a circuit board that fits within the wrist-worn transceiver. The transceiver additionally includes a touchpanel display, barcode reader, and wireless systems for ancillary applications described, for example, in the above-referenced applications, the contents of which have been previously incorporated herein by reference.

[0013] In one exemplary technique, there is provided a multi-sensor system that uses an algorithm based on adaptive filtering to monitor a patient's RR. The system features a first sensor selected from the following group: i) an IP sensor featuring at least two electrodes and an IP processing circuit configured to measure an IP signal; ii) an ECG sensor featuring at least two electrodes and an ECG processing circuit configured to

determine the final RR value. In general, according to the techniques disclosed herein, any combination of the above-described waveforms can be used in the adaptive filtering process to determine the initial and final RR values.

[0018] In another exemplary technique, there is provided a system for monitoring a patient's RR that also accounts for their posture, activity level, and degree of motion. Such patient states can result in artifacts that affect the RR measurement, and thus proper interpretation of them can reduce the occurrence of erroneous RR values and ultimately false alarms/alerts in the hospital.

[0019] In another exemplary technique, there is provided a cable within a body-worn monitor that includes an IP system, a motion sensor (e.g. accelerometer), and a processing system that determines RR from signals generated by these sensors. These components, for example, can be included in a terminal end of the cable, typically worn on the patient's torso, which connects to a series of disposable electrodes that attach to the patient's body. A mechanical housing, typically made of plastic, covers these and other components, such as sensors for measuring signals relating to ECG and skin temperature.

[0020] In embodiments, the cable includes at least one conductor configured to transmit both a first digital data stream representing the digital IP signal or information calculated therefrom, and a second digital data stream representing the digital motion signal or information calculated therefrom. In other embodiments these signals are processed by a microprocessor on the chest to determine an RR value, and this value is then sent in the digital data stream to another processor, such as one within the wrist-worn transceiver, where it is further processed. To transmit the serial data stream, the terminal portion of the cable can include a transceiver component, e.g. a serial transceiver configured to transmit a digital data stream according to the CAN protocol. Other properties, such as heart rate, temperature, alarms relating to ECG signals, and other

information relating to the CAN communication protocol and its timing can be transmitted by the transceiver component.

[0021] While the various sensors are described herein as being operably connected to the wrist-worn transceiver via such a cable, in alternative embodiments the data streams from the various sensors (e.g., the chest-worn sensor(s)) are operably connected to the wrist-worn transceiver in a wireless fashion. By way of example, the wrist-worn transceiver and chest-worn sensor connect through a short-range wireless interface, such as one based on 802.16.4 (e.g. Bluetooth or Zigbee). In this case, both components include a transceiver that operates on the wireless protocol.

[0022] In embodiments, both the IP and ECG systems are contained within a single integrated circuit. The ECG system can be modular and determine multi-lead ECG signals, such as three, five, and twelve-lead ECG signals.

[0023] In another exemplary technique, there is provided a method for determining RR during periods of motion. The method includes the following steps: (a) measuring a first time-dependent signal by detecting a modulated electrical current passing through the patient's torso; (b) measuring a second time-dependent signal by detecting respiration-induced movements in the patient's torso with at least one motion sensor; (c) determining a motion-related event not related to the patient's respiration rate value by processing signals from the motion sensor; and (d) collectively processing both the first and second time-dependent signals to determine a value for RR corresponding to a period when the patient's motion-related event is below a pre-determined threshold. For example, the motion-related event determined during step (c) can be the patient's posture, activity level, or degree of motion. Typically these parameters are determined from signals measured with an accelerometer mounted on the patient's torso. These signals are processed with an algorithm, described in detail below, that yields a vector indicating

orientation of the patient's chest and their subsequent posture. 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) 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 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.

[0024] In another exemplary technique, there is provided a method for suppressing alarms related to RR by processing the patient's posture, activity level, and degree of motion as determined by the accelerometer. For example, the alarm can be suppressed if the patient is standing upright, or if their posture changes from lying down to one of sitting and standing upright. Or the alarm can be suppressed if their posture changes from either standing upright or sitting to lying down. In general, a rapid change in posture, which can be determined with the chest-worn accelerometer, may disrupt the signals used to determine RR to the point where a false alarm/alert is generated. In this embodiment, posture is determined from the vector-based analysis, described above.

[0025] In yet another exemplary technique, there is provided a system for monitoring a patient's RR featuring a sensor unit configured to be mounted on the patient's torso. The sensor unit features IP and motion sensors, as described above, and additionally attaches directly to an electrode that secures the unit to the patient's torso (e.g. chest or abdomen). Here, a housing comprising the IP and motion sensors additionally includes a connector featuring an opening configured to receive a metal snap on the exterior of a conventional disposable electrode. Other electrodes used for IP and ECG measurements connect to the

unit through cables. The unit can additionally send a digital data stream including RR data over a CAN bus to a wrist-worn transceiver, which as described above can further process the RR value to account for alarms/alerts, motion, etc.

[0026] In all embodiments, the wrist-worn transceiver can include a display configured to display the patient's RR and other vital signs, along with a touchpanel interface. A wireless transceiver within the wrist-worn transceiver can transmit information to a remote computer using conventional protocols such as 802.11, 802.15.4, and cellular. The remote computer, for example, can be connected to a hospital network. It can also be a portable computer, such as a tablet computer, personal digital assistant, or cellular phone.

[0027] Many advantages are associated with the implementation of the exemplary techniques disclosed herein. In general, it provides an accurate measurement of RR, along with an independent measurement of a patient's posture, activity level, and motion, to characterize an ambulatory patient in the hospital. These parameters can be collectively analyzed to improve true positive alarms while reducing the occurrence of false positive alarms. Additionally, the measurement of RR is performed with a body-worn monitor that is comfortable, lightweight, and low-profile, making it particularly well suited for patients that are moving about. Such a monitor could continuously monitor a patient as, for example, they transition from the emergency department to the ICU, and ultimately to the home after hospitalization.

[0028] Still other embodiments are found in the following detailed description of the invention and in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Fig. 1A shows a schematic view of a patient wearing accelerometers on their abdomen (position 1) and chest (position 2) to measure ACC waveforms and RR according to the adaptive filtering process of the invention;

room), with each section corresponding to a specific bed, chair, or general location in the area. Typically the display renders graphical icons corresponding to the motion and alarm parameters for each patient in the group. In other embodiments, the body-worn monitor includes a graphical display that renders these parameters directly on the patient.

[0154] Typically the location sensor and the wireless transceiver operate on a common wireless system, e.g. a wireless system based on 802.11, 802.15.4, or cellular protocols. In this case a location is determined by processing the wireless signal with one or more algorithms known in the art. These include, for example, triangulating signals received from at least three different base stations, or simply estimating a location based on signal strength and proximity to a particular base station. In still other embodiments the location sensor includes a conventional global positioning system (GPS).

[0155] The body-worn monitor can include a first voice interface, and the remote computer can include a second voice interface that integrates with the first voice interface. The location sensor, wireless transceiver, and first and second voice interfaces can all operate on a common wireless system, such as one of the above-described systems based on 802.11 or cellular protocols. The remote computer, for example, can be a monitor that is essentially identical to the monitor worn by the patient, and can be carried or worn by a medical professional. In this case the monitor associated with the medical professional features a GUI wherein the user can select to display information (e.g. vital signs, location, and alarms) corresponding to a particular patient. This monitor can also include a voice interface so the medical professional can communicate directly with the patient.

[0156] Figs. 29A, 29B show yet another alternate embodiment wherein a sensor unit 255 attaches to the abdomen of a patient 10 using an electrode 24 normally attached to the lower left-hand portion of the patient's torso. Specifically, the

What is claimed is:

1. A system for monitoring a patient's respiratory rate, comprising:

an impedance pneumography sensor comprising at least two electrodes configured to measure thoracic electrical impedance indicative of respiration and processing circuitry configured to process signals from the two electrodes and to generate therefrom an impedance pneumography waveform from the patient;

a motion sensor configured to attach to the patient' s torso and to measure breathing-induced movements of the torso, and to generate therefrom a motion waveform from the patient;

a processing system configured to be worn on the patient's body and to receive the impedance pneumography waveform, and the motion waveform,

the processing system further configured to:

i) process the impedance pneumography waveform to determine therefrom an initial respiratory rate estimate by filtering the impedance pneumography waveform with a 0.01-12 Hz finite impulse response bandpass filter, derivatizing the filtered impedance pneumography waveform, and identifying zero point crossing features in the derivatized impedance pneumography waveform corresponding to respiration events, so that peaks corresponding to the initial respiratory rate can be counted;

ii) process the motion waveform by filtering the motion waveform with an adaptive digital filter determined from the initial respiratory rate estimate, derivatizing the filtered motion waveform, and identifying zero point crossing features in the derivatized motion waveform corresponding to respiration events to count peaks in the derivatized motion waveform to determine a final value for the patient's respiration rate.

2. The system of claim 1, wherein the adaptive digital filter is a bandpass filter comprising an upper frequency limit determined from a multiple of the initial respiratory rate.

3. The system of claim 1, further comprising an ECG sensor, the ECG sensor comprising at least two electrodes and an ECG processing circuit configured to process signals from the at least two electrodes to measure an ECG signal from the patient.

4. The system of claim 1, further comprising a PPG sensor, the PPG sensor comprising a light source, photodetector, and PPG processing circuit configured to process signals from the photodetector to measure a PPG signal from the patient.

5. The system of claim 1, wherein the motion sensor is an accelerometer.