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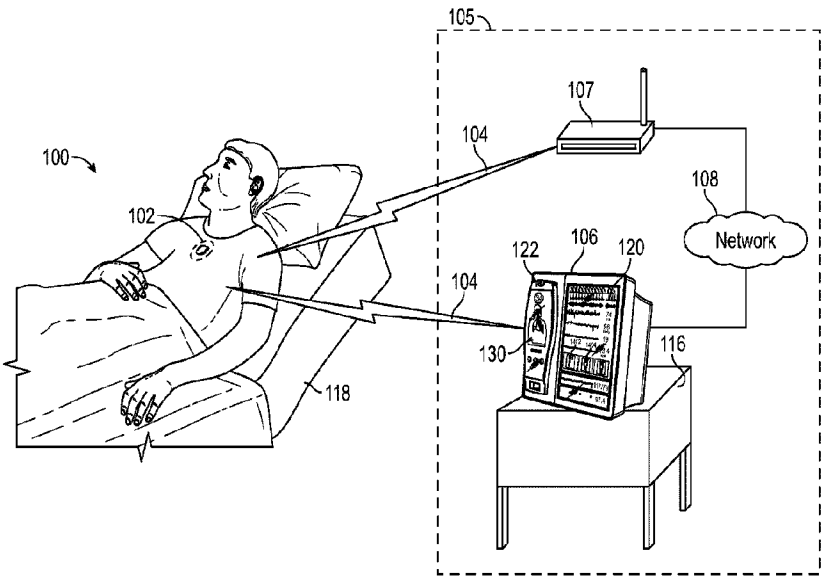
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(57) Abrégé/Abstract:
A patient monitoring system to help manage a patient that is at risk of forming one or more pressure ulcers is disclosed. The system includes a patient-worn wireless sensor that senses the patient's orientation and wirelessly transmits information indicative of the sensed orientation to a patient monitor. The patient monitor receives, stores, and processes the transmitted information. It also displays and transmits information indicative of the patient's orientation to help caregivers manage the patient's risk of formation of one or more pressure ulcers. The system can identify the present orientation of the patient and determine how long the patient has been in the present orientation. If the patient remains in an orientation beyond a predefined duration, the system can notify the patient and/or caretakers that the patient is due to be repositioned.

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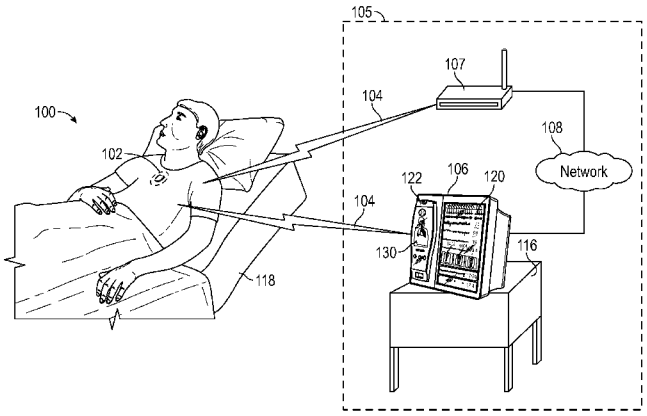


FIG. 1A

(57) Abstract: A patient monitoring system to help manage a patient that is at risk of forming one or more pressure ulcers is disclosed. The system includes a patient-worn wireless sensor that senses the patient's orientation and wirelessly transmits information indicative of the sensed orientation to a patient monitor. The patient monitor receives, stores, and processes the transmitted information. It also displays and transmits information indicative of the patient's orientation to help caregivers manage the patient's risk of formation of one or more pressure ulcers. The system can identify the present orientation of the patient and determine how long the patient has been in the present orientation. If the patient remains in an orientation beyond a predefined duration, the system can notify the patient and/or caretakers that the patient is due to be repositioned.

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WIRELESS PATIENT MONITORING SYSTEMS AND METHODS

[0001] The present application claims benefit to U.S. Provisional Application No. 62/212,467, filed August 31, 2015; U.S. Provisional Application No. 62/212,472, filed August 31, 2015; U.S. Provisional Application No. 62/212,484, filed August 31, 2015; and U.S. Provisional Application No. 62/212,480, filed August 31, 2015.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to the field of patient monitoring. More specifically, the disclosure describes among other things a wearable sensor that measures a patient's position, orientation, and movement and wirelessly communicates the measured information to a patient monitoring system.

BACKGROUND

[0003] In clinical settings, such as hospitals, nursing homes, convalescent homes, skilled nursing facilities, post-surgical recovery centers, and the like, patients are frequently confined to bed for extended periods of time. Sometimes the patients are unconscious or sedated to such an extent that they have limited ability to change or control their position in the bed. These patients can be at risk of forming pressure ulcers, which pose a serious risk to the patient's health and well-being. Pressure ulcers, which may also be referred to as "bed sores," "pressure sores," and "decubitus ulcers," comprise injury to a patient's skin, and often the underlying tissue, which results from prolonged pressure forces applied to a site on the patient's body. Frequently, pressure ulcers develop on skin that covers bony areas of the body which have less muscle and/or fat tissue below the surface to distribute pressure applied thereto resulting from prolonged contact with the surface of a bed or chair. Examples of such body locations include the back or side of the head,

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shoulders, shoulder blades, elbows, spine, hips, lower back, tailbone, heels, ankles, and skin behind the knees.

[0004] Pressure ulcers are caused by application of pressure at an anatomical site that occludes blood flow to the skin and other tissue near the location. Sustained pressure between a structural surface (such as a bed) and a particular point on the patient's body can restrict blood flow when the applied pressure is greater than the blood pressure flowing through the capillaries that deliver oxygen and other nutrients to the skin and other tissue. Deprived of oxygen and nutrients, the skin cells can become damaged, leading to tissue necrosis in as few as 2 to 6 hours. Despite commonly occurring in elderly and mobility-impaired populations, hospital-acquired pressure ulcers are considered to be preventable and have been termed "never events." Insurers have imposed restrictions on the amount they will reimburse a hospital for pressure ulcer treatment, and state and federal legislation now requires hospitals to report the occurrence of pressure ulcers in their facilities.

[0005] Risk factors for pressure ulcers can be categorized as modifiable and non-modifiable. Modifiable risk factors include actions that healthcare providers can take, while non-modifiable risk factors include aspects of patient health and behavior. It is valuable to document such non-modifiable risk factors so that caregivers can identify and attend to patients at risk of developing pressure ulcers. It is recommended that caregivers develop a documented risk assessment policy to predict the risk of a patient developing a pressure ulcer. Such an assessment can encompass all aspects of a patient's health and environment, and may employ commonly used measures in the field, such as the Braden and Norton scales. The risk assessment tool may be used to direct preventative strategies not only when a patient is at rest in his or her bed, but also when undergoing surgery.

[0006] Additional factors that can contribute to the formation of pressure ulcers include friction and shear forces. Friction can occur when skin is dragged across a surface which can happen when patients are moved, especially when the skin is moist. Such frictional forces can damage the skin and make it more vulnerable to injury, including formation of a pressure ulcer. A shear is when two

forces move in opposite directions. For example, when the head portion of a bed is elevated at an incline, the patient's spine, tailbone, and hip regions tend to slide downward due to gravity. As the bony portion of the patient's body moves downward, the skin covering the area can stay in its current position, thereby pulling in the opposite direction of the skeletal structure. Such shear motion can injure the skin and blood vessels at the site, causing the skin and other local tissue to be vulnerable to formation of a pressure ulcer.

[0007] An established practice for patients at risk of forming pressure ulcers is to follow a turning protocol by which the patient is periodically repositioned, or "turned" to redistribute pressure forces placed on various points of the patient's body. Individuals at risk for a pressure ulcer are be repositioned regularly. It is commonly suggested that patients be repositioned every 2 hours at specific inclination angles, and that the method of doing so minimizes the amount of friction and shear on the patient's skin. A repositioning log can be maintained and include key information, such as the time, body orientation, and outcome.

[0008] Pressure ulcer prevention programs have been effective and can reduce long-term costs associated with treatment. A 2002 study employed a comprehensive prevention program in two long-term care facilities, costing $519.73 per resident per month. Results of the program revealed pressure ulcer prevalence to be reduced by 87% and 76% in the two facilities. A later study found that prevention strategies were able to reduce pressure ulcer prevalence from 29.6% to 0% in a medical intensive care unit, and from 9.2% to 6.6% across all units of the hospital. These interventions employed strategies such as manual patient repositioning and logging, tissue visualization and palpation, pressure-reducing mattresses, and use of risk assessment tools.

[0009] Turning protocols, however, do not take into consideration position changes made by the patient between established turn intervals, which are neither observed nor recorded. Thus it is possible that in some circumstances, the act of following a turn protocol can have an unintended negative clinical effect.

SUMMARY

[0010] This disclosure describes, among other things, embodiments of systems, devices, and methods for monitoring the position and orientation of a patient at risk of forming one or more pressure ulcers.

[0011] One aspect of the present disclosure comprises a patient turn and movement monitoring system configured to help manage a patient that is at risk of forming one or more pressure ulcers. Some embodiments of the patient turn and monitoring system include a patient-worn, wireless sensor having one or more sensors configured to obtain information describing the patient's orientation and to wirelessly transmit information indicative of the sensed orientation information. The system also includes a patient monitor configured to receive, store, and process the information transmitted by the wireless sensor and to display and transmit information (or data) indicative of the patient's orientation to help caregivers manage the patient's risk of formation of one or more pressure ulcers. The patient turn and movement monitoring system can identify the present orientation of the patient and determine how long the patient has been in the present orientation. If the patient remains in an orientation beyond a predefined, clinician-prescribed patient orientation duration, the system can notify the patient and/or caretakers that the patient is due to be repositioned. In certain embodiments, a patient orientation duration timer is used to monitor such orientation times. In certain embodiments of the disclosed patient turn and movement monitoring system, a signal repeater, located within reception range of the wireless sensor, is used to receive and forward the information indicative of the sensed orientation information from the wireless sensor to a network-based processing node.

[0012] Another aspect of the present disclosure includes a wireless sensor including one or more sensors configured to obtain position, orientation, and motion information from the patient. The one or more sensors can include an accelerometer, a gyroscope, and a magnetometer, which are configured to determine the patient's position and orientation in three-dimensional space. The wireless sensor is configured to wirelessly transmit the sensor data, and/or information representative of the sensor data, to a patient monitor. The patient

monitor can be configured to process the received information, to display information indicative of, or derived from the received data, and to transmit information – including displays, alarms, alerts, and notifications – to a multi-patient monitoring system which may be located, for example, at a nurse's station.

[0013] Another aspect of the present disclosure is directed to a system and method for associating the wireless sensor with a patient monitor. In some embodiments, the wireless sensor includes an activation tab which, when removed, activates the wireless sensor. Upon activation, a wireless transceiver in the wireless sensor emits a low-power pairing signal having a pairing signal transmission range of up to approximately three inches. In some embodiments, the wireless sensor has a switch or button which, when depressed, places the wireless sensor in a pairing mode of operation, causing the wireless sensor to emit the low-power pairing signal. When the patient monitor is within range of the wireless sensor (e.g., within the about three-inch range), the wireless sensor and the patient monitor associate, thereby configuring the wireless sensor and patient monitor to communicate with each other. Once the pairing between the wireless sensor and the patient monitor is completed, the wireless sensor changes into a patient parameter sensing mode of operation in which the wireless sensor transmits a patient parameter sensing signal. The patient parameter sensing signal has a patient signal transmission range that is substantially greater than the pairing signal transmission range. The wireless sensor is then in condition to be placed on the patient.

[0014] In some aspects of the present disclosure the patient's position and orientation are monitored and recorded. Once the wireless sensor is affixed to the patient's body, such as, for example, the patient's torso, sensor data corresponding to the patient's motion (*e.g.*, acceleration and angular velocity) are obtained, pre-processed, and transmitted to the patient monitor. The patient monitor stores and further processes the received data to determine the patient's orientation. Illustratively, the patient monitor can determine whether the patient is standing, sitting, or lying down in the prone, supine, left side, or right side positions.

[0015] In some embodiments, the patient monitor determines the precise orientation of the patient's body. For example, the patient monitor can determine the

degree to which the patient's body is inclined, vertically and/or horizontally, thereby generating an accurate description of the patient's position relative to the support structure (such as a bed) upon which the patient lies.

[0016] In another aspect of the present disclosure the patient monitor stores the determined position and orientation information and keeps track of how long the patient remains in each determined position, thereby creating a continuous record of the patient's positional history. The patient monitor analyzes and processes the stored data to provide clinically-relevant, actionable information to the patient's care providers. Illustratively, the patient monitor counts the number of in-bed turns performed by the patient and monitors and displays the amount of time that has elapsed since the patient last turned. When the elapsed time exceeds a clinician-defined duration (*e.g.*, two hours), the patient monitor displays an indication that the maximum time between patient turns has been exceeded. The patient monitor can also transmit a notification to one or more clinicians responsible for caring for the patient via, for example, a multi-patient monitoring system, a clinician notification device, or the like. The patient monitor can also determine and display statistical information, such as the average, minimum, and maximum amount of time between turns for a given clinician-defined time period, such as for example, twenty-four hours. The patient monitor can also determine and display the number of turns in the same position and orientation over a clinician-defined period of time. Similarly, the patient monitor can display the total amount of time the patient remained in each specific position within a clinician-defined period. Moreover, the patient monitor can determine the frequency and duration of periods during which the patient remained in clinically-defined acceptable positions.

[0017] In yet another aspect of the present disclosure the patient monitor determines the mobility status of the patient, *e.g.*, whether the patient is ambulatory, standing, sitting, reclining, or falling. In certain aspects, the wireless monitoring system can include an alert system to alert the caregiver that the patient is falling, getting out of bed, or otherwise moving in a prohibited manner or in a manner that requires caregiver attention. The alert can be an audible and/or visual alarm on the monitoring system, or the alert can be transmitted to a caregiver (*e.g.*, nurses'

station, clinician device, pager, cell phone, computer, or otherwise). Illustratively, the patient monitor can display the patient's mobility status and transmit a notification that the patient is active and away from the bed. In some circumstances, the patient monitor can determine whether the patient contravenes a clinician's order, such as, for example, instructions to remain in bed, or to walk to the bathroom only with the assistance of an attendant. In such circumstances, a notification, alert, or alarm can be transmitted to the appropriate caregivers.

[0018] In certain aspects, the information received by the wireless sensor can be used to create a time-sequenced representation of the patient's movement. This representation can be displayed on the patient monitor or transmitted to a nurses' station or other processing nodes to enable the caregiver to monitor the patient. The time-sequenced representation can be viewed in real time and/or be recorded for playback. For example, if an alarm alerts the caregiver that the patient has fallen out of bed, the caregiver can access and review the historical sequence of the patient's movements prior to and during that period of time.

[0019] Another aspect of the present disclosure is directed to predicting a patient's risk of falling based on the patient's gait and other information (such as, for example, the patient's current medication regimen). When the patient monitor determines that the patient's risk of falling is above a predetermined threshold, the patient monitor can issue an alarm or alert to notify care providers of the identified risk in an effort to anticipate and therefore prevent a patient fall. Additionally, the patient monitor can determine when a patient has fallen and issue the appropriate alarms and alerts to summon care provider assistance.

[0020] In an aspect of the present disclosure the patient monitor accesses the patient's health records and clinician input via a network. Illustratively, the patients' positional history data, analyzed in view of the patient's health records, may reveal or suggest a turning protocol (or other treatment protocol) that will likely yield favorable clinical outcomes for the particular patient. Accordingly, the patient monitor analyzes the accessed information in conjunction with the received information from the wireless sensor to determine a recommended patient turn protocol (or other treatment protocol) for the patient.

[0021] In still another aspect of the present disclosure, the patient monitor assesses caregiver and facility compliance with the clinician-defined patient turn protocol established for the patient. For example, the patient monitor can identify the number of times that the patient remains in a position for a period greater than the prescribed duration, indicating a patient turn protocol violation, as well as the length of each such overexposure. The patient monitor can also track the clinician's response time upon issuance of a notification, alert, or alarm.

[0022] According to another aspect of the present disclosure, care provider workflow productivity, efficiency, and effectiveness can be determined, based on aggregated positional history data corresponding to multiple patients wherein each patient is equipped with the disclosed wireless sensor. Additionally, care for patients in a particular location, such as a hospital ward or nursing home floor where the ratio of patients to staff is relatively high, can be prioritized based on the determined risk of formation of pressure ulcers. Thus, patients determined to have the highest risk are designated to receive attention first.

[0023] In yet another aspect of the present disclosure, the wireless sensor includes sensors to obtain additional physiological measurements from the patient. For example, the wireless sensor can include a temperature sensor configured to measure the patient's body core body temperature by insulating the patient's skin surface around the temperature sensor. As a result of the insulation surrounding the temperature sensor, the natural temperature difference between the patient's skin surface and body core reach equilibrium, thereby arriving at the patient's body core temperature (which is typically higher in temperature than the patient's skin surface). The wireless sensor can also include an acoustic respiration sensor configured to sense vibrational motion generated by the patient's chest. The acoustic respiration sensor is configured to mechanically transmit the sensed vibrations through rigid structures of the device to the accelerometer. Processing of the accelerometer signal can provide, among other things, the patient's respiration and heart rates. An electrocardiogram (ECG) sensor, configured to sense electrical signals from two or more electrodes in electrical contact with the patient's chest may also be included in the wireless sensor. The ECG signal can be processed to detect arrhythmias, such

as bradycardia, tachyarrhythmia, ventricular fibrillation and the like. Additionally, the accelerometer signal (containing information indicative of the mechanically-transmitted vibrations from the acoustic respiration sensor) and/or the ECG signal can be processed to identify respiratory distress or dysfunction, including without limitation, snoring, coughing, choking, wheezing, apneic events, and airway obstruction.

[0024] In another aspect of the present disclosure, the patient monitor can determine a score that describes the patient's wellness/sickness state, which may also be referred to as a "Halo Index." Illustratively, the patient monitor accesses and analyzes the patient's health records, clinician input, positional history data provided by the wireless sensor, surface structure pressure data, and other physiological parameter data collected and provided by the wireless sensor (such as, by way of non-limiting example, the patient's temperature, respiration rate, heart rate, ECG signal, and the like) to assess the patient's overall health condition.

[0025] In an aspect of the present disclosure, the patient monitor accesses information provided by the patient's support structure (*e.g.*, bed, mattress, bed sheet, mattress pad, and the like) to determine the extent of pressure forces exerted on particular anatomical sites of the patient's body. Illustratively, the patient's support structure can be configured with an array of pressure sensors that measure the pressure force exerted on the support structure by the patient at specific locations. The patient monitor can analyze the patient's postural history data in conjunction with the information provided by the support structure to determine a likelihood of pressure ulcer formation at a specific anatomical location based on the measured amount of pressure exerted on the anatomical location multiplied by the amount of time the anatomical location has been under such pressure. When the evaluated risk exceeds a predetermined threshold, the patient monitor can issue an alarm and/or an alert to reposition the patient so as to avoid formation of a pressure ulcer in the specified anatomical location. Additionally, the patient monitor can suggest particular positions and/or a patient turn protocol based on the combined analysis of pressure force exerted and length of time under such pressure.

[0026] In some aspects, a method to reduce a risk that a monitored patient will develop one or more pressure ulcers by pairing a wireless physiological sensor with a patient monitoring device in a caregiver environment where other wireless sensors may be paired with and communicating with other patient monitoring devices, the physiological sensor including a movement sensor, a first processor, and a first wireless transceiver, the physiological sensor configured to eventually be positioned with respect to a surface of said monitored patient to transmit information responsive to one or more of the patient's movement, lack of movement, or both, the patient monitoring device including a second processor, a memory device, a storage device, a display, and a second wireless transceiver, the patient monitoring device responsive to the transmitted information from the physiological sensor to present to a caregiver patient information indicative of said risk of said pressure ulcers, comprises in said physiological sensor, initiating a pairing mode of operation; wirelessly transmitting from said physiological sensor a pairing signal configured to be effective for a pairing signal transmission range, said pairing signal including information identifying said physiological sensor; in said physiological sensor, receiving a confirmation signal from said patient monitoring device confirming that said physiological sensor has been paired with said patient monitoring device; in said physiological sensor, initiating a patient parameter sensing mode of operation; and wirelessly transmitting to said patient monitoring device, a patient parameter sensing signal configured to be effective for a patient parameter sensing signal transmission range, said patient parameter sensing signal including information indicative of said risk of said pressure ulcers, wherein said pairing signal transmission range is configured to be substantially less than said patient parameter sensing transmission range.

[0027] In some aspects, the pairing signal comprises wirelessly transmitting said pairing signal configured to be effective approximately zero (0) to approximately (36) thirty six inches. In some aspects, the wirelessly transmitting said pairing signal comprises wirelessly transmitting said pairing signal configured to be effective approximately zero (0) to approximately twelve (12) inches. In some aspects, the wirelessly transmitting said pairing signal comprises wirelessly

transmitting said pairing signal configured to be effective approximately zero (0) to approximately six (6) inches. In some aspects, the pairing signal comprises wirelessly transmitting said pairing signal configured to be effective approximately zero (0) to approximately three (3) inches.

[0028] In some aspects, the patient parameter sensing signal comprises wirelessly transmitting said patient parameter sensing signal configured to be effective approximately ten (10) feet to approximately thirty (30) feet. In some aspects, the patient parameter sensing signal comprises wirelessly transmitting said patient parameter sensing signal configured to be effective approximately ten (10) feet. In some aspects, the wirelessly transmitting said patient parameter sensing signal comprises wirelessly transmitting said patient parameter sensing signal configured to be effective approximately three (3) meters. In some aspects, the pairing signal and said patient parameter sensing signal comprises wirelessly transmitting said patient parameter sensing signal configured to be effective an order of magnitude greater than said wirelessly transmitting said pairing signal.

[0029] In some aspects, the method includes wherein said transmitting said pairing signal and said patient parameter sensing signal further comprises transmitting to an extender/repeater, and wherein said receiving said confirmation signal further comprises receiving from said extender/repeater. In some aspects, the method includes sensing acceleration using an accelerometer of said patient movement sensor and angular velocity using a gyroscope of said patient movement sensor; with said first processor, processing signals responsive to said sensed acceleration and angular velocity; and with said first wireless transceiver, transmitting said patient parameter sensing signal responsive to said processing.

[0030] In some aspects, the pairing signal further comprises transmitting a message indicating that said wireless physiological sensor has been previously activated. In some aspects, the pairing signal further comprises transmitting a notification indicating that a quality standard associated with said physiological sensor is compromised. In some aspects, the patient parameter sensing signal further comprises transmitting a message indicating that said physiological sensor is nearing an end of service life.

[0031] In some aspects, said initiating said pairing mode of operation further comprises activating said wireless physiological sensor. In some aspects, activating said wireless physiological sensor comprises removing a battery isolator from said wireless physiological sensor. In some aspects, activating said wireless physiological sensor comprises depressing for a predetermined duration a button on said wireless physiological sensor.

[0032] According to some aspects, a method to reduce a risk that a monitored patient will develop one or more pressure ulcers by pairing a wireless physiological sensor with a patient monitoring device in a caregiver environment where other wireless sensors may be paired with and communicating with other patient monitoring devices, the physiological sensor including a movement sensor, a first processor, and a first wireless transceiver, the physiological sensor configured to eventually be positioned with respect to a surface of said monitored patient to transmit information responsive to one or more of the patient's movement, lack of movement, or both, the patient monitoring device including a second processor, a memory device, a storage device, a display, and a second wireless transceiver, the patient monitoring device responsive to the transmitted information from the physiological sensor to present to a caregiver patient information indicative of said risk of said pressure ulcers, comprises in said patient monitoring device, receiving a pairing signal transmitted from said wireless physiological sensor, wherein said transmitted pairing signal is configured to be effective for a pairing signal transmission range, said pairing signal including information identifying said physiological sensor; in said patient monitoring device, associating said wireless physiological sensor with said patient monitoring device; wirelessly transmitting to said wireless physiological sensor, a confirmation signal confirming that said wireless physiological sensor is associated with said patient monitoring device; and in said patient monitoring device, receiving a patient parameter sensing signal transmitted from said physiological sensor, wherein said transmitted patient parameter sensing signal is configured to be effective for a patient parameter sensing signal transmission range, said patient parameter sensing signal including information indicative of said risk of said pressure ulcers, wherein said pairing signal

transmission range is substantially less than said patient parameter sensing transmission range.

[0033] In some aspects, the said patient parameter sensing signal is responsive to an orientation of said patient at a first time period and at a second time period; the method further comprises processing said patient parameter sensing signal to determine whether there is a sufficient difference in said patient parameter sensing signal between said first time period and said second time period to indicate a patient turn. In some aspects, the patient parameter sensing signal is responsive to a sensor data vector comprising data elements; the method comprises electronically: processing said data elements to determine a plurality of features indicative of a patient fall to form a feature vector; applying a weight vector to said feature vector to derive an activation value; analyzing said activation value to determine whether the patient has fallen; and reporting a patient fall in response to a determination that a patient fall has occurred.

[0034] According to some aspects, a system for reducing a risk that a monitored patient will develop one or more pressure ulcers by pairing a wireless sensor with a portable computing device in a caregiver environment where other wireless sensors may be paired with and communicating with other computing devices, comprises a wireless sensor comprising an accelerometer, a gyroscope, a first processor, and a first wireless transceiver, said wireless sensor configured to operate in an association mode to transmit an association signal a desired association transmission range, the wireless sensor also configured to operate in a patient parameter measurement mode to transmit a measurement signal a desired measurement transmission range, wherein said association transmission range is substantially less than said measurement signal transmission range; and a portable computing device comprising a second processor, a memory device, a storage device, a display, and a second wireless transceiver, said computing device configured to receive said association signal, said patient monitor also configured to transmit an association confirmation signal, and said patient monitor also configured to receive said measurement signal; wherein said computing device, in response to receiving said association signal, associates said wireless sensor with said

computing device and transmits said association confirmation signal; and wherein said wireless sensor, in response to receiving said association confirmation signal, discontinues operating in said association mode and begins to operate in said patient parameter measurement mode and to transmit said measurement signal.

[0035] According to some aspects, a system for monitoring an orientation of a patient to reduce a risk of the patient developing a pressure ulcer, comprises a sensor including an accelerometer, a processor, and a first wireless transceiver, said sensor configured to output a signal responsive to acceleration, said acceleration indicative of a possible change in an orientation of said patient when said sensor is worn by said patient; and a patient monitor comprising a signal processor, a memory device, a storage device, and a second wireless transceiver, said second wireless transceiver is configured to receive said signal, and said signal processor is configured to process said signal to determine whether said possible change corresponds to an actual change in said orientation, when said actual change has occurred, configured to record a patient turn event, to compare said patient turn event with a patient turn protocol, and when said possible change is not said actual change and no patient turn event occurs according to the patient turn protocol, said patient monitor is configured to notify a caregiver of a patient turn protocol violation, wherein said signal processor configured to determine whether said possible change corresponds to said actual change includes being configured to determine a difference between said orientation at a previous time and at a current time based at least on said signal, and when said difference is above a threshold, recording said patient turn event.

[0036] In some aspects, said signal processor of said patient monitor is further configured to reset a patient orientation duration timer when said processor records said patient turn event. In some aspects, the system comprises a third wireless transceiver, said third wireless transceiver configured to receive said signal from said sensor and to transmit said signal to said patient monitor.

[0037] In some aspects, the system comprises a power supply for said third wireless transceiver different from a power supply for said sensor or said patient monitor. In some aspects, said sensor comprises a gyroscope. In some

aspects, said sensor comprises an acoustic sensor. In some aspects, said sensor comprises a temperature sensor. In some aspects, said sensor comprises an ECG sensor. In some aspects, said sensor comprises one or more of an acoustic sensor, a temperature sensor and an ECG sensor. In some aspects, said patient monitor is configured to determine measurements of one or more of the following parameters: an acceleration, an angular velocity, a magnetic field, a respiration rate, a temperature, an impedance value, a moisture value, an oximetry value and an electrocardiogram.

[0038] According to some aspects a method to determine a patient's change in orientation by monitoring patient movement with a patient-worn sensor, communicating a signal indicative of said monitoring to a processing device, receiving said signal at said processing device, and processing using a signal processor said signal to determine whether said change in orientation has occurred, said patient-worn sensor including an accelerometer, a processor, and a first wireless transceiver, said processing device including said signal processor, a memory device, a storage device, and a second wireless transceiver, comprises: receiving, from said patient-worn sensor, information indicative of a patient's orientation at a first time period; receiving, from said patient-worn sensor, information indicative of the patient's orientation at a second time period, wherein said first time period is prior to, and in close temporal proximity to said second time period; and with said signal processor, processing said information including: combining said received information to form a time window of patient orientation information, wherein said time window spans said first and second time periods; dividing said time window into segments, wherein each segment has a segment value indicative of said patient's orientation; determining a difference between said segment values; when said determined difference exceeds a predetermined threshold, determining a patient turn event has occurred; classifying said patient turn event; reporting said classified patient turn event to a caregiver; and resetting a timer associated with a patient turn protocol.

[0039] In some aspects, the method comprises determining whether the patient has remained in an orientation for a period of time that exceeds a

predetermined maximum duration and transmitting an alert in response to said determination. In some aspects, said receiving information indicative of said patient's orientation at said first and second time periods comprises receiving acceleration data at said first and second time periods. In some aspects, said acceleration data includes a roll axis value and a pitch axis value. In some aspects, the method comprises determining a change in a longitudinal axis of said patient responsive to said roll axis value and determining a change relative to an axis aligned with hips of the patient responsive to said pitch axis value.

[0040] In some aspects, said classifying said patient turn event comprises comparing said segment values with a table of profiles of patient orientation change actions. In some aspects, each of said segment values comprises a roll axis median and a pitch axis median, and wherein said roll axis median and said pitch axis median are in units of degrees ranging from -180 degrees to +180 degrees. In some aspects, said predetermined threshold of said difference between said segment values is 45 degrees.

[0041] According to some aspects, a method to determine a patient's change in orientation by monitoring patient movement with a patient-worn sensor, communicating a signal indicative of said monitoring to a processing device, receiving said signal at said processing device, and processing using a signal processor said signal to determine whether said change in orientation has occurred, said patient-worn sensor including an accelerometer, a processor, and a first wireless transceiver, said processing device including said signal processor, a memory device, a storage device, and a second wireless transceiver, comprises: receiving, from said patient-worn sensor, information indicative of a patient's orientation at a current time period, said information including acceleration data having a roll axis value and a pitch axis value; with said signal processor, electronically processing said information including: extracting, from said storage device, information indicative of the patient's orientation at a previous time period, said previous time period is prior to, and in close temporal proximity to said current time period; combining said current and previous orientation information to form a time window of patient orientation information, said time window spanning said

previous and current time periods ;segmenting said time window into at least two segments; determining, for each segment, a segment value, each segment value comprising a roll component and a pitch component; comparing, pairwise, said determined segment values; determining, for each pairwise comparison whether a patient turn event has occurred; in response to a determined patient turn event occurrence classifying said determined turn event; identifying a most frequently classified turn event; reporting, as said patient's new orientation, said most frequently classified turn event; and resetting an orientation duration timer.

[0042] In some aspects, said received information comprises a plurality of samples, sampled at a sampling rate. In some aspects, said sampling rate is configured to be between approximately 10 Hz and approximately 100Hz. In some aspects, said sampling rate is configured to be between approximately 5 Hz and approximately 40Hz. In some aspects, processing said information further comprises: determining a roll axis orientation indicative of said patient's orientation relative to a longitudinal axis of the patient; and determining a pitch axis orientation indicative of said patient's orientation relative to an axis aligned with hips of the patient.

[0043] In some aspects, said received information comprises a plurality of samples, sampled at a sampling rate, and wherein processing said information further comprises determining, for each of said plurality of samples, a roll axis value indicative of said patient's orientation relative to a longitudinal axis of the patient and a pitch axis value indicative of said patient's orientation relative to an axis aligned with hips of the patient. In some aspects, determining said roll and pitch axis values includes determining said values in units of degrees ranging from -180 degrees to +180 degrees. In some aspects, determining said segment values comprises determining a roll axis median and a pitch axis median said roll and pitch axis medians in units of degrees ranging from -180 degrees to +180 degrees. In some aspects, comparing said segment values comprises determining a difference between roll axis medians and a difference between pitch axis medians. In some aspects, determining whether a patient turn event is indicated comprises determining whether said difference between roll axis medians or said difference

between pitch axis medians exceeds a predetermined threshold, when said predetermined threshold is exceeded, a patient turn event is determined to have occurred. In some aspects, the method further comprises determining that said patient has remained in an orientation for a period of time that exceeds a predetermined duration; and transmitting an alert that said patient has remained in the orientation for a period of time that exceeds said predetermined duration.

[0044] According to some aspects, a method of detecting at least one of whether a monitored patient has fallen or is about to fall by processing signals indicative of movement by the patient, the signals output from a wireless sensor and communicated to a processing device, the sensor including an accelerometer, a gyroscope, a first processor, and a first wireless transceiver, the sensor being configured to be worn by the patient, the processing device having a signal processor, a memory device, a storage device, a display, and a second wireless transceiver, the processing device configured to process the signals to determine at least one of whether the patient has fallen or is about to fall comprises receiving, by said processing device from said wireless sensor, signals responsive to a linear acceleration and an angular velocity of said patient; and processing said signals with said signal processor of said processing device, including electronically: forming a sensor data vector comprising data elements responsive to said linear acceleration and said angular velocity; normalizing said data elements to form a normalized sensor data vector; determining from said normalized sensor data vector, a plurality of features indicative of a patient fall, to form a feature vector; applying an *a priori* weight vector to said feature vector to derive an activation value; analyzing said derived activation value to determine at least one of whether a patient fall has occurred or is about to occur; and when said determination is that the at least one of said patient fall has occurred or is about to occur, alerting a caregiver.

[0045] In some aspects, said receiving said signals includes receiving said signals indicative of said linear acceleration responsive to an output of an accelerometer and receiving said signals indicative of said angular velocity responsive to an output of a gyroscope. In some aspects, the method further

comprises wherein said receiving said signals indicative of said linear acceleration includes receiving said signals indicative of said linear acceleration in three dimensions, wherein said receiving said signals indicative of said angular velocity includes receiving said signals indicative of said angular velocity in three dimensions, and wherein said sensor vector comprises six data elements. In some aspects, said normalizing said data elements comprises: normalizing each of said data elements to have zero-mean and unit-variance; and forming said normalized sensor data vector comprising normalized data elements, wherein certain of said normalized data elements correspond to said linear acceleration and certain of said normalized data elements correspond to said angular velocity.

[0046] In some aspects, determining said plurality of features to form a feature vector further comprises: determining an acceleration magnitude; determining an angular velocity magnitude; determining a jerk magnitude; determining a fall duration; determining a pitch change; and determining vertical velocities. In some aspects, said applying said weight vector to said feature vector to derive said activation value comprises computing an inner product of said feature vector with said weight vector. In some aspects, said applying said weight vector to said feature vector to derive said activation value comprises: presenting, to a supervised learning algorithm, training data that include example inputs and known outputs; and mapping, by said supervised learning algorithm, said example inputs to said known outputs to derive said weight vector.

[0047] In some aspects, said mapping said example inputs to said known outputs to derive said weight vector is performed by Fishers' linear discriminant. In some aspects, said analyzing said derived activation value to determine at least one of whether a patient fall has occurred or is about to occur comprises identifying a sign attribute of said derived activation value, wherein a positive sign attribute of said derived activation value indicates that said patient has fallen or is about to fall.

[0048] According to some aspects, a system configured to determine at least one of whether a patient has fallen or is about to fall comprises: a wireless physiological sensor including an accelerometer, a gyroscope, a processor, and a first wireless transceiver, said sensor configured to sense a linear acceleration and

an angular velocity of said patient, said sensor also configured to transmit information indicative of said sensed linear acceleration and angular velocity of said patient; a patient monitor comprising a signal processor, a memory device, a storage device, a communications interface, a display, and a second wireless transceiver, said patient monitor configured to receive said transmitted information, to analyze said received information, and to determine at least one of whether said patient has fallen or is about to fall, said patient monitor further configured to transmit, in response to determining said patient has fallen or is about to fall, a notification that said patient has fallen or is about to fall.

[0049] In some aspects, said patient monitor is further configured to determine from said received information one or more of an acceleration magnitude, an angular velocity magnitude, a jerk magnitude, a fall duration, and a pitch change, and to form a feature vector comprising said determined acceleration magnitude, angular velocity magnitude, jerk magnitude, fall duration, and pitch change. In some aspects, said patient monitor is further configured to apply a weight vector to said feature vector. In some aspects, said patient monitor is further configured to determine an inner product of said weight vector and said feature vector. In some aspects, said accelerometer comprises a three-axis accelerometer and said gyroscope comprises a three-axis gyroscope. In some aspects, said weight vector is derived using a supervised learning algorithm comprising executable instructions stored on a computer-readable medium. In some aspects, said supervised learning algorithm is configured to execute on a processing device, to receive a set of training data having example inputs and known outputs, and to map said example inputs to said known outputs to derive said weight vector. In some aspects, said supervised learning algorithm is Fisher's linear discriminant.

[0050] According to some aspects, a wireless physiological sensor for measuring acceleration of a patient, the physiological sensor comprising: a base including a bottom surface and a top surface, said base also including a first aperture, a second aperture, and a third aperture, wherein each of said first, second, and third apertures extends between said bottom surface and said top surface of said base; a substrate layer including conductive tracks and connection pads, a top

side, and a bottom side, said bottom side of said substrate layer being disposed above said top surface of said base, said substrate layer also including a first through-hole via and a second through-hole via, wherein each of said first and second through-hole vias extends through said substrate layer between said top and bottom sides of said substrate layer; a temperature sensor responsive to thermal energy of said patient, said temperature sensor mounted on said top side of said substrate layer, said temperature sensor including a thermal contact in thermal communication with said top side of said substrate layer, wherein said first through-hole via is aligned with said thermal contact of said temperature sensor on said top side of said substrate layer and with said first aperture of said base on said bottom side of said substrate layer, and wherein said first aperture of said base and said first through-hole via of said substrate layer are filled with at least a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said bottom surface of said base corresponding to said first aperture; an ECG sensor mounted on said top side of said substrate layer, said ECG sensor responsive to electrical signals generated by said patient's heart, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG sensor also including an electrical contact in electrical communication with said top side of said substrate layer, wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said top side of said substrate layer and with said second aperture of said base on said bottom side of said substrate layer, and wherein said second aperture of said base and said second through-hole via of said substrate layer are filled with at least an electrically conductive material to cause said ECG sensor to be in electrical communication with a portion of said bottom surface of said base corresponding to said second aperture; an accelerometer, mounted on said substrate layer, said accelerometer responsive to a linear acceleration of said patient; and an acoustic respiration sensor responsive to vibrational motion generated by said patient, said acoustic respiration sensor being disposed on said bottom side of said substrate layer and extending through said third aperture in said base and beyond said bottom surface of said base, said acoustic respiration sensor being in structural

communication with said substrate layer so as to mechanically transmit vibrational motion to said accelerometer.

[0051] In some aspects, the sensor further comprises an information element configured to store information indicative of whether said physiological sensor has been previously activated. In some aspects, the sensor further comprises a gyroscope, mounted on said substrate layer, said gyroscope responsive to an angular velocity of said patient. In some aspects, said base insulates a portion of said patient's body surrounding said portion of said bottom surface of said base corresponding to said first aperture. In some aspects, the sensor further comprises a wireless transceiver configured to wirelessly transmit information representative of said thermal energy, said electrical signals, said linear acceleration, and said vibrational motion. In some aspects said wireless transceiver is configured to transmit a pairing signal. . In some aspects said wireless transceiver is configured to transmit a message indicating that said physiological sensor has been previously activated. . In some aspects said wireless transceiver is configured to transmit a notification that a quality standard associated with said physiological sensor is compromised. . In some aspects said wireless transceiver is configured to transmit a message indicating that said physiological sensor is nearing an end of service life.

[0052] In some aspects, the sensor further comprises a battery, mounted on said bottom side of said substrate layer and between said bottom side of said substrate layer and said top surface of said base, said battery being in electrical contact with said substrate layer, wherein said battery forms a recess between a portion of said bottom side of said substrate layer and said top surface of said base; and a mounting frame, disposed to fill said formed recess, said mounting frame configured to provide rigid structural support between said base and said substrate layer. In some aspects, said mounting frame further comprises: a first mounting frame aperture aligned with said first through-hole via and with said first aperture of said base, wherein said first mounting aperture is at least filled with said thermally conductive material to cause said temperature sensor to be in thermal communication with said portion of said bottom surface of said base corresponding

to said first aperture; and a second mounting frame aperture aligned with said second through-hole via and with said second aperture of said base, wherein said second mounting aperture is at least filled with said electrically conductive material to cause said ECG sensor to be in electrical communication with said portion of said bottom surface of said base corresponding to said second aperture. .

[0053] In some aspects the sensor further comprises a gyroscope, mounted on said substrate layer, said gyroscope responsive to an angular velocity of said patient; a magnetometer, mounted on said substrate layer, said magnetometer responsive to a magnetic field; a processor, mounted on said substrate layer and in communication with said temperature sensor, ECG sensor, accelerometer, gyroscope, and magnetometer, said processor configured to generate signals representative of said thermal energy, electrical signals, linear acceleration, vibratory motion, angular velocity, and magnetic field; and a wireless transceiver, mounted on said substrate layer and in communication with said processor, said wireless transceiver configured to transmit said generated signals representative of said thermal energy, electrical signals, linear acceleration, vibrational motion, angular velocity and magnetic field.

[0054] In some aspects the sensor further comprises an impedance sensor, mounted on said substrate layer and in electrical communication with said portion of said bottom surface of said base corresponding to said second aperture. In some aspects, said accelerometer is a three-dimensional accelerometer and said gyroscope is a three-dimensional gyroscope.

[0055] According to some aspects, a wearable wireless sensor for monitoring at least one of pressure ulcer risk, fall detection, or fall risk, comprises : a base including a first aperture; a circuit layer including a first through-hole via extending through said circuit layer; and a temperature sensor responsive to a thermal energy of a patient, said temperature sensor mounted on said circuit layer, said temperature sensor including a thermal contact in thermal communication with said circuit layer, wherein said first through-hole via is aligned with said thermal contact of said temperature sensor and with said first aperture of said base, and wherein said first aperture and said first through-hole via include a thermally

conductive material to cause said temperature sensor to be in thermal communication with a portion of said base corresponding to said first aperture.

[0056] In some aspects, said base insulates a portion of said patient's body surrounding said portion of said base corresponding to said first aperture. In some aspects, the sensor further comprises a second aperture in said base; a second through-hole via extending through said circuit layer between said top side and bottom side of said circuit layer; an ECG sensor mounted on said circuit layer, said ECG sensor responsive to electrical signals, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG lead also including an electrical contact in electrical communication with said circuit layer, wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said circuit layer and with said second aperture of said base, and wherein said second aperture of said base and said second through-hole via of said circuit layer include an electrically conductive material, said ECG sensor in electrical communication with a portion of said base corresponding to said second aperture through said conductive material.

[0057] In some aspects, the sensor further comprises an accelerometer, mounted on said circuit layer, said accelerometer responsive to a linear acceleration of said patient; a third aperture in said base; and an acoustic respiration sensor responsive to vibrational motion of said patient, said acoustic respiration sensor being disposed on said circuit layer and extending through said third aperture in said base, wherein said acoustic respiration sensor is in rigid structural communication with said circuit layer so as to mechanically transmit sensed vibrational motion to said accelerometer.

[0058] In some aspects, the sensor further comprises a gyroscope mounted on said circuit layer, said gyroscope responsive to an angular velocity of said patient. In some aspects, said accelerometer comprises a three-dimensional accelerometer and said gyroscope comprises a three-dimensional gyroscope. In some aspects, the sensor further comprises an information element configured to store information indicative of whether said physiological sensor has been previously activated.

[0058a] According to an aspect of the invention is a method to reduce a risk that a monitored patient will develop one or more pressure ulcers by pairing a wireless physiological sensor with a patient monitoring device in a caregiver environment where other wireless sensors may be paired with and communicating with other patient monitoring devices,

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[0058a] According to an aspect of the invention is a wireless physiological sensor for measuring acceleration of a patient, the physiological sensor comprising:

a base including a bottom surface and a top surface, said base also including a first aperture, a second aperture, and a third aperture, wherein each of said first, second, and third apertures extends between said bottom surface and said top surface of said base;

a substrate layer including conductive tracks and connection pads, a top side, and a bottom side, said bottom side of said substrate layer being disposed above said top surface of said base, said substrate layer also including a first through-hole via and a second through-hole via, wherein each of said first and second through-hole vias extends through said substrate layer between said top and bottom sides of said substrate layer;

a temperature sensor responsive to thermal energy of said patient, said temperature sensor mounted on said top side of said substrate layer, said temperature sensor including a thermal contact in thermal communication with said top side of said substrate layer, wherein said first through-hole via is aligned with said thermal contact of said temperature sensor on said top side of said substrate layer and with said first aperture of said base on said bottom side of said substrate layer, and wherein said first aperture of said base and said first through-hole via of said substrate layer are filled with at least a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said bottom surface of said base corresponding to said first aperture;

an electrocardiogram (ECG) sensor mounted on said top side of said substrate layer, said ECG sensor responsive to electrical signals generated by said patient's heart, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG sensor also including an electrical contact in electrical communication with said top side of said substrate layer, wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said top side of said substrate layer and with said second aperture of said base on said bottom side of said substrate layer, and wherein said second aperture of said base and said second through-hole via of said substrate layer are filled with at least an electrically conductive material to cause said ECG sensor to be in electrical communication with a portion of said bottom surface of said base corresponding to said second aperture;

an accelerometer, mounted on said substrate layer, said accelerometer responsive to a linear acceleration of said patient; and

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an acoustic respiration sensor responsive to vibrational motion generated by said patient, said acoustic respiration sensor being disposed on said bottom side of said substrate layer and extending through said third aperture in said base and beyond said bottom surface of said base, said acoustic respiration sensor being in structural communication with said substrate layer so as to mechanically transmit vibrational motion to said accelerometer.

[0058b] According to an aspect of the invention is a wearable wireless sensor for monitoring at least one of pressure ulcer risk, fall detection, or fall risk, said wearable wireless sensor comprising:

a base including a first aperture;

a circuit layer including a first through-hole via extending through said circuit layer; and

a temperature sensor responsive to a thermal energy of a patient, said temperature sensor mounted on said circuit layer, said temperature sensor including a thermal contact in thermal communication with said circuit layer,

wherein said first through-hole via is aligned with said thermal contact of said temperature sensor and with said first aperture of said base, and

wherein said first aperture and said first through-hole via include a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said base corresponding to said first aperture.

[0058c] According to an aspect of the invention is a wearable wireless sensor for monitoring a thermal energy of a patient and at least one of pressure ulcer risk, fall detection, or fall risk, said wearable wireless sensor comprising:

a housing including a predetermined position for at least a first sensor and a second sensor,

one or more accelerometers responsive to an acceleration of said patient and configured to output one or more signals indicative of at least one of said pressure ulcer risk, said fall detection, or said fall risk;

a base including a first aperture;

a circuit layer including a first through-hole via extending through said circuit layer; and

a temperature sensor responsive to said thermal energy of said patient, said temperature sensor mounted on said circuit layer, said temperature sensor including a

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thermal contact in thermal communication with said circuit layer, wherein said temperature sensor is at least one of the first sensor or the second sensor,

wherein said first through-hole via is aligned with said thermal contact of said temperature sensor and with said first aperture of said base, said first through-hole via is configured to provide a structure to transmit said thermal energy across a length of the first through-hole via from said patient to said temperature sensor,

wherein said first aperture and said first through-hole via include a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said base corresponding to said first aperture, and

wherein the housing is configured to operably position the base and the circuit layer.

[0058d] According to an aspect of the invention is a wireless physiological sensor for measuring one or more physiological parameters of a patient, the wireless physiological sensor comprising:

a base including a bottom surface and a top surface, said base also including a first aperture and a second aperture, wherein each of said first and second apertures extends between said bottom surface and said top surface of said base;

a substrate layer including conductive tracks and connection pads, a top side, and a bottom side, said bottom side of said substrate layer being disposed above said top surface of said base, said substrate layer also including a first through-hole via and a second through-hole via, wherein each of said first and second through-hole vias extends through said substrate layer between said top and bottom sides of said substrate layer;

a temperature sensor responsive to thermal energy of said patient, said temperature sensor mounted on said top side of said substrate layer, said temperature sensor including a thermal contact in thermal communication with said top side of said substrate layer, wherein said first through-hole via is aligned with said thermal contact of said temperature sensor on said top side of said substrate layer and with said first aperture of said base on said bottom side of said substrate layer, and wherein said first aperture of said base and said first through-hole via of said substrate layer are filled with at least a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said bottom surface of said base corresponding to said first aperture;

an electrocardiogram (ECG) sensor mounted on said top side of said substrate layer, said ECG sensor responsive to electrical signals generated by said patient's heart,

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said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG sensor also including an electrical contact in electrical communication with said top side of said substrate layer, wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said top side of said substrate layer and with said second aperture of said base on said bottom side of said substrate layer, and wherein said second aperture of said base and said second through-hole via of said substrate layer are filled with at least an electrically conductive material to cause said ECG sensor to be in electrical communication with a portion of said bottom surface of said base corresponding to said second aperture; and

an accelerometer, mounted on said substrate layer, said accelerometer responsive to a linear acceleration of said patient.

[0058e] According to an aspect of the invention is a wearable wireless sensor for monitoring at least one physiological parameter, said wearable wireless sensor comprising:

a base including a first aperture, the base configured to be positioned proximate skin of a patient when the wearable wireless sensor is in use;

a housing secured to the base;

a circuit layer enclosed by at least a portion of the housing and including a first side, a second side opposite the first side, and at least one through-hole via extending through said circuit layer;

a temperature sensor responsive to a thermal energy of the patient, said temperature sensor mounted on said first side of said circuit layer, said temperature sensor configured to be in thermal communication with a portion of the skin of the patient proximate the first aperture of the base when the wearable wireless sensor is in use, wherein said at least one through-hole via is positioned between said temperature sensor and said first aperture of said base, said at least one through-hole via configured to allow said thermal energy to pass through the circuit layer to the temperature sensor; and

a thermally conductive material configured to be positioned between said portion of the skin of the patient and said at least one through-hole via when the wearable wireless sensor is in use, said thermally conductive material configured to transmit said thermal energy from the portion of the skin of said patient to the at least one through-hole via of the circuit layer.

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[0058f] According to an aspect of the invention is a wearable physiological sensor for measuring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

a housing;

a base secured to the housing and including a first opening and a second opening spaced from the first opening, the base configured to be positioned proximate skin of the patient when the wearable physiological sensor is in use;

a circuit layer;

a first electrocardiogram (ECG) electrode located at least partially within the first opening of the base and in electrical communication with the circuit layer, the first ECG electrode

configured to transmit one or more electrical signals to said circuit layer responsive to electrical activity of the patient's heart;

a second ECG electrode positioned outside the housing and electrically connected to said circuit layer via an ECG lead, the second ECG electrode configured to transmit one or more electrical signals to said circuit layer responsive to electrical activity of the patient's heart;

a temperature sensor responsive to a thermal energy of the patient, said temperature sensor configured to be in thermal communication with a portion of skin of the patient proximate the second opening of the base when the wearable physiological sensor is in use; and

a thermally conductive material configured to be positioned between said portion of the skin of the patient and said temperature sensor when the wearable physiological sensor is in use.

[0058g] According to an aspect of the invention is a wearable physiological sensor for monitoring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

a housing;

a base configured to secure the housing to skin of the patient;

a circuit board positioned within the housing, the circuit board comprising a first surface and a second surface opposite the first surface, the second surface configured to be positioned closer to the patient's skin than the first surface when the base and housing are secured to the patient's skin, the circuit board including at least one

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opening spaced from a perimeter of the circuit board and extending through the circuit board;

a temperature sensor positioned within the housing above the first surface of the circuit board and said at least one opening extending through the circuit board; and

thermally conductive material positioned below the second surface of the circuit board and said at least one opening extending through the circuit board, said thermally conductive material configured to transmit thermal energy of the patient toward said at least one opening, said at least one opening configured to allow said thermal energy to pass through the circuit board toward said temperature sensor.

[0058h] According to an aspect of the invention is a wearable physiological sensor for monitoring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

a substrate having a top surface and a bottom surface opposite the top surface, the bottom surface comprising an adhesive configured to secure the substrate to skin of the patient, the substrate further comprising an opening spaced inward from a perimeter of the substrate;

a housing configured to cover at least a portion of the substrate, the housing configured to be secured to the patient via the substrate;

a circuit board positioned within the housing, the circuit board comprising a first surface and a second surface, the second surface positioned closer to the substrate than the first surface, the circuit board including a plurality of openings spaced inward from a perimeter of the circuit board and extending through the circuit board; and

a temperature sensor responsive to thermal energy of the patient and positioned within the housing, said temperature sensor positioned above the first surface of the circuit board and the plurality of openings in the circuit board;

thermally conductive material positioned below the second surface of the circuit board and said plurality of openings in the circuit board, wherein, when the wearable physiological sensor is in use, said temperature sensor is in thermal contact with a portion of the skin of the patient located proximate the opening of the substrate via said plurality of openings, said thermally conductive material, and the opening of the substrate.

[0058i] According to an aspect of the invention is a wearable physiological sensor for monitoring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

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a housing;

a base configured to secure the housing to skin of the patient;

a circuit board positioned within the housing, the circuit board comprising a first surface and a second surface opposite the first surface, the second surface configured to be positioned closer to the patient's skin than the first surface when the base and housing are secured to the patient's skin, the circuit board including a plurality of openings spaced from a perimeter of the circuit board and extending through the circuit board;

a temperature sensor positioned within the housing above the first surface of the circuit board and said plurality of openings extending through the circuit board;

thermally conductive material positioned below the second surface of the circuit board and said plurality of openings, said thermally conductive material configured to transmit thermal energy of the patient toward said plurality of openings, said plurality of openings configured to allow said thermal energy to pass through the circuit board toward said temperature sensor;

a first electrode positioned within at least one of the housing and the base and in electrical communication with the circuit board, the first electrode configured to transmit one or more electrical signals responsive to electrical activity of a heart of the patient;

a second electrode positioned away from the housing and the base and configured for electrical communication with the circuit board via a lead, the second electrode configured to transmit one or more electrical signals responsive to electrical activity of the patient's heart; and

a processor in communication with the temperature sensor and the first and second electrodes, the processor configured to generate one or more signals responsive to said thermal energy and said one or more electrical signals.

[0058j] According to an aspect of the invention is a system comprising:

a wearable device comprising:

a housing comprising an interior;

a base configured to secure the housing to a chest of the subject, the base comprising a foam material and an adhesive material configured to adhere to skin of the subject's chest, the base configured to insulate a portion of the subject's skin when the base is secured to the subject's chest;

a circuit board positioned within the interior of the housing;

a battery positioned within the interior of the housing adjacent said circuit board;

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an inertial measurement unit positioned within the interior of the housing and coupled to the circuit board, the inertial measurement unit configured to generate a first set of signals responsive to acceleration of the subject and a second set of signals responsive to angular velocity of the subject;

a temperature sensor positioned within the interior of the housing and coupled to the circuit board, the temperature sensor configured to generate one or more signals responsive to thermal energy radiating from the portion of the subject's skin insulated by the base; and

a thermally conductive material positioned below the circuit board and said temperature sensor, said thermally conductive material configured to transmit said thermal energy toward said temperature sensor; and

one or more processors configured to receive and process said first and second sets of signals generated by said inertial measurement unit to determine orientation of the subject relative to a bed when the subject is laying in said bed, said one or more processors further configured to determine body temperature of the subject based on said one or more signals generated by said temperature sensor responsive to said thermal energy.

[0058k] According to an aspect of the invention is a system comprising:

a wearable device comprising:

a housing comprising an interior;

a base configured to secure the housing to a chest of the subject, the base comprising a foam material and an adhesive material configured to adhere to skin of the subject's chest, wherein the base is configured to insulate a portion of the subject's skin when the base is secured to the subject's chest;

a circuit board positioned within the interior of the housing;

a battery positioned within the interior of the housing adjacent said circuit board;

a temperature sensor positioned within the interior of the housing and coupled to the circuit board, the temperature sensor configured to generate one or more signals responsive to thermal energy radiating from the portion of the subject's skin insulated by the base;

a thermally conductive material positioned below the circuit board and said temperature sensor, said thermally conductive material configured to transmit said thermal energy toward said temperature sensor; and

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a sensor for determining at least one of heart rate and respiration rate of the subject based on vibrations emanating from the subject's chest; and

one or more processors configured to receive one or more signals generated based upon said vibrations emanating from the subject's chest and said one or more signals generated by said temperature sensor responsive to said thermal energy, said one or more processors further configured to determine a score indicative of a wellness state of the subject based upon said one or more signals generated based upon said vibrations and said one or more signals generated by said temperature sensor.

[0058l] According to an aspect of the invention is a system comprising:

a wearable device comprising:

a housing comprising an interior;

a base configured to secure the housing to skin of the subject;

a circuit board positioned within the interior of the housing;

an inertial measurement unit positioned within the interior of the housing and coupled to the circuit board, the inertial measurement unit configured to generate one or more signals responsive to at least one of acceleration and angular velocity of the subject; a temperature sensor positioned within the interior of the housing and coupled to the circuit board, the temperature sensor configured to generate one or more signals responsive to thermal energy radiating from a portion of the subject's skin underneath the base;

a thermally conductive material positioned below the circuit board and said temperature sensor, said thermally conductive material configured to transmit said thermal energy toward said temperature sensor; and

one or more processors configured to receive and process said one or more signals generated by said inertial measurement unit to determine at least one of orientation and movement of the subject, said one or more processors further configured to determine body temperature of the subject based on said one or more signals generated by said temperature sensor responsive to said thermal energy.

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upon activation of initial power in said physiological sensor, automatically electronically entering a default mode of operation in said physiological sensor, wherein the default mode of operation initiates a pairing mode of operation in said physiological sensor, wherein the default mode is a low-power mode;

wirelessly transmitting from said physiological sensor a low-power pairing signal based on a first transmission protocol comprising a frequency of transmission configured to be effective for a limited pairing signal transmission range, thereby preventing unintended or incidental association of said physiological sensor with said other patient monitoring devices that may be nearby but which are not intended to be paired with said physiological sensor, said low-power pairing signal including information identifying said physiological sensor;

in said physiological sensor, electronically receiving a confirmation signal from said patient monitoring device confirming that said physiological sensor has been paired with said patient monitoring device responsive to a user physically moving the physiological sensor in proximity with the patient monitoring device that is stationary during the default mode of operation;

upon said receipt of said confirmation signal in said physiological sensor, automatically electronically exiting said pairing mode of operation with said physiological sensor and subsequently initiating a patient parameter sensing mode of operation using said physiological sensor; and

wirelessly transmitting to said patient monitoring device from said physiological sensor, a patient parameter sensing signal based on said first transmission protocol and said frequency of transmission, said patient parameter sensing signal configured to be effective for a patient parameter sensing signal transmission range, and using said physiological sensor, increasing power to said patient parameter sensing signal transmission range, said patient parameter sensing signal including information indicative of said risk of said pressure ulcers,

wherein said pairing signal transmission range is predetermined to be effective up to one (1) foot and said patient parameter sensing transmission range is predetermined to be effective up to thirty (30) feet.

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[0058l] According to an aspect of the invention is a method to reduce a risk that a monitored patient will develop one or more pressure ulcers by pairing a wireless physiological sensor with a patient monitoring device in a caregiver environment where other wireless sensors may be paired with and communicating with other patient monitoring devices,

the physiological sensor including a movement sensor, a first processor, and a first wireless transceiver, the physiological sensor configured to eventually be positioned with respect to a surface of said monitored patient to transmit information responsive to one or more of a movement of the patient, a lack of movement of the patient, or both, said physiological sensor being disposable and configured for power activation from an inactive powered-down state and further configured to enter a default mode of operation which initiates a pairing mode of operation in said physiological sensor, wherein the default mode is a low-power mode,

the patient monitoring device including a second processor, a memory device, a storage device, a display, and a second wireless transceiver, the patient monitoring device responsive to the transmitted information from the physiological sensor to present to a caregiver patient information indicative of said risk of said pressure ulcers,

the method comprising:

in said patient monitoring device, automatically electronically receiving a low-power pairing signal transmitted from said wireless physiological sensor upon activation of initial power in said physiological sensor, wherein said transmitted low-power pairing signal is based on a first transmission protocol comprising a frequency of transmission and is configured to be effective for a limited pairing signal transmission range, thereby preventing unintended or incidental association of said physiological sensor with said other patient monitoring devices that may be nearby but which are not intended to be paired with said physiological sensor, said low-power pairing signal including information identifying said physiological sensor;

in said patient monitoring device, automatically electronically associating said wireless physiological sensor with said patient monitoring device, said patient monitoring device responsive to a user physically moving the wireless physiological sensor in proximity to the patient monitoring device that is stationary during the default mode of operation;

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wirelessly transmitting to said wireless physiological sensor, a confirmation signal confirming that said wireless physiological sensor is associated with said patient monitoring device; and

upon receipt of the confirmation signal in said physiological sensor, in said patient monitoring device, receiving a patient parameter sensing signal transmitted from said physiological sensor, wherein said transmitted patient parameter sensing signal is based on said first transmission protocol and said frequency of transmission and is configured to be effective for a patient parameter sensing signal transmission range, and using said physiological sensor, increasing power to the patient parameter sensing signal transmission range, said patient parameter sensing signal including information indicative of said risk of said pressure ulcers,

wherein said pairing signal transmission range is predetermined to be effective up to one (1) foot and said patient parameter sensing transmission range is predetermined to be effective up to thirty (30) feet.

[0058m] According to an aspect of the invention is a system for reducing a risk that a monitored patient will develop one or more pressure ulcers by pairing a wireless sensor with a portable computing device in a caregiver environment where other wireless sensors may be paired with and communicating with other computing devices, the system comprising:

a wireless sensor comprising an accelerometer, a gyroscope, a first processor, and a first wireless transceiver, said wireless sensor being disposable and configured for power activation from an inactive powered-down state, said wireless sensor configured to, upon activation of initial power in said wireless sensor, automatically electronically enter a default mode of operation, the default mode of operation being a low-power mode, wherein the default mode of operation initiates an association mode to transmit a low-power association signal a limited desired association transmission range, thereby preventing unintended or incidental association of said wireless sensor with said other computing devices that may be nearby but which are not intended to be paired with said wireless sensor, said low-power association signal based on a first transmission protocol comprising a frequency of transmission, the wireless sensor also configured to operate in a patient parameter measurement mode to transmit a

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measurement signal a desired measurement signal transmission range, said measurement signal based on said first transmission protocol and said frequency of transmission, wherein said association transmission range is predetermined to be effective up to one (1) foot and said measurement signal transmission range is predetermined to be effective up to thirty (30) feet; and

a portable computing device comprising a second processor, a memory device, a storage device, a display, and a second wireless transceiver, said computing device configured to automatically electronically receive said association signal, said computing device also configured to transmit an association confirmation signal, and said computing device also configured to receive said measurement signal;

wherein said computing device, in response to receiving said association signal, automatically electronically associates said wireless sensor with said computing device and automatically electronically transmits said association confirmation signal, said portable computing device responsive to a user physically moving the wireless sensor in proximity to the portable computing device that is configured to be stationary during the default mode of operation; and

wherein said wireless sensor, upon receipt of said association confirmation signal, discontinues operating in said association mode, begins to operate in said patient parameter measurement mode and to transmit said measurement signal, and increases power to said measurement signal transmission range.

[0058n] According to an aspect of the invention is a system for monitoring an orientation of a patient to reduce a risk of the patient developing a pressure ulcer, the system comprising:

a sensor configured to attach to the patient, the sensor including an accelerometer, a processor, and a first wireless transceiver, said accelerometer configured to measure an acceleration of the patient with respect to a roll axis and a pitch axis, said roll axis corresponding to a longitudinal axis extending along a length of the patient's body and said pitch axis corresponding to an axis aligned with the patient's hips, said sensor configured to output a signal responsive to the acceleration measured by the accelerometer, said acceleration indicative of a possible change in the orientation of said patient when said sensor is worn by said patient; and

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a patient monitor comprising a signal processor, a memory device, a storage device, and a second wireless transceiver, said second wireless transceiver configured to receive said signal from said first wireless transceiver of said sensor and said signal processor configured to process said received signal to determine whether said possible change corresponds to an actual change in said orientation and, when said actual change has occurred, said signal processor further configured to record a patient turn event, to compare said patient turn event with a patient turn protocol, and when said possible change is not said actual change and no patient turn event occurs according to the patient turn protocol, said patient monitor is configured to notify a caregiver of a patient turn protocol violation;

wherein said signal processor is configured to determine whether said possible change corresponds to said actual change by:

receiving a first set of information responsive to the acceleration of the patient with respect to the roll axis over a first time period;

receiving a second set of information responsive to the acceleration of the patient with respect to the pitch axis over the first time period;

processing said first and second sets of information responsive to the acceleration of the patient with respect to the roll axis and the pitch axis to form a time window of patient orientation history over the first time period, said time window comprising a first plurality of orientation values corresponding to the roll axis and a second plurality of orientation values corresponding to the pitch axis;

dividing said time window of patient orientation history into a plurality of segments, each of the plurality of segments comprising a portion of the first plurality of orientation values and a portion of the second plurality of orientation values;

determining, for each of the plurality of segments, a segment value indicative of said patient's orientation during the segment to reduce an impact of noise in the time window associated with false indications of patient turn events, wherein the segment value is a vector including a first component representative of the portion of the first plurality of orientation values that are within the segment and a second component representative of the portion of the second plurality of orientation values that are within the segment; and

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determining a difference between each one of said plurality of segment values and another one of said plurality of segment values and comparing said difference to a threshold, wherein said signal processor is configured to record said patient turn event based at least on said comparison;

wherein said first component comprises a median of the portion of the first plurality of orientation values that are within the segment and wherein said second component comprises a median of the portion of the second plurality of orientation values that are within the segment, and wherein said medians are in units of degrees ranging from -180 degrees to +180 degrees.

[0058o] According to an aspect of the invention is a method of determining a patient turn event based on a patient's recent orientation history with a patient-worn sensor, the patient-worn sensor comprising an accelerometer, a processor, and a first wireless transceiver, said method comprising:

receiving, with a patient monitor, a first set of acceleration data from the patient-worn sensor over a first time period, said first set of acceleration data responsive to a roll axis corresponding to a longitudinal axis extending along a length of the patient's body;

receiving, with the patient monitor, a second set of acceleration data from the patient-worn sensor over the first time period, said second set of acceleration data responsive to a pitch axis corresponding to an axis aligned with the patient's hips;

processing said first and second sets of acceleration data responsive to the acceleration of the patient with respect to the roll axis and the pitch axis over the first time period to form a time window of patient orientation history, said time window comprising a first plurality of orientation values corresponding to the roll axis and a second plurality of orientation values corresponding to the pitch axis;

dividing said time window into a plurality of segments to reduce an impact of noise in the time window associated with false indications of patient turn events, each of the plurality of segments comprising a portion of the first plurality of orientation values and a portion of the second plurality of orientation values;

determining, for each of the plurality of segments within said time window:

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a segment vector, the segment vector comprising a first component and a second component, the first component being a median of the portion of the first plurality of orientation values within the segment, the second component being a median of the portion of the second plurality of orientation values within the segment;

determining differences between each one of the segment vectors of the plurality of segments and each of the other segment vectors of the plurality of segments; and

identifying the patient turn event based on comparisons of said differences with one or more thresholds.

[0058p] According to an aspect of the invention is a method of detecting whether a monitored patient has fallen by processing signals indicative of movement by the patient, the method comprising:

receiving, with a processing device from a wireless sensor, signals responsive to a linear acceleration of said patient with respect to a roll axis, a pitch axis, and a yaw axis, said roll axis corresponding to a longitudinal axis extending along a length of said patient's body, said pitch axis corresponding to said patient's hips, and said yaw axis corresponding to a horizontal plane in which said patient is located, wherein said wireless sensor is configured to be worn by said patient and comprises an accelerometer, a gyroscope, and a first wireless transceiver, and wherein said processing device comprises a processor, a memory device, a storage device, a display, and a second wireless transceiver configured to communicate with the first wireless transceiver;

receiving, with said processing device from said wireless sensor, signals responsive to an angular velocity of said patient with respect to said roll axis, said pitch axis, and said yaw axis; and

processing said received signals responsive to said linear acceleration and said angular velocity of said patient with said processor of said processing device, including electronically:

forming a sensor data vector comprising a plurality of data elements, each of the plurality of data elements responsive to one of said linear

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acceleration or said angular velocity with respect to one of said roll axis, said pitch axis, and said yaw axis;

normalizing said plurality of data elements to form a normalized sensor data vector;

generating a feature vector from said normalized sensor data vector, the feature vector comprising a plurality of features indicative of a patient fall, wherein each of the plurality of features are generated based on one or more of the data elements from said normalized sensor data vector;

deriving an activation value based on an application of a weight vector to said feature vector, wherein said weight vector comprises a plurality of weights, each of the plurality of weights corresponding to one of the plurality of features of said feature vector;

determining whether a patient fall has occurred based on the derived activation value; and

alerting a caregiver based on said determination, said alert indicating that said patient fall has occurred.

[0058q] According to an aspect of the invention is a method of detecting a patient fall, the method comprising:

receiving, with a processing device, a first set of signals responsive to an acceleration of a patient from a wireless sensor, wherein said wireless sensor is configured to be worn by said patient and comprises a accelerometer, a gyroscope, and a first wireless transceiver, and wherein said processing device comprises a processor, a memory device, a storage device, and a second wireless transceiver configured to communicate with the first wireless transceiver of the wireless sensor;

receiving, with said processing device, a second set of signals responsive to an angular velocity of said patient from said wireless sensor; and

generating a sensor data vector comprising a plurality of data elements, each of the plurality of data elements responsive to one of the first set of signals or one of the second set of signals;

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generating a feature vector from said sensor data vector, the feature vector comprising a plurality of features indicative of a patient fall, wherein each of the plurality of features are generated based on one or more of the data elements from said sensor data vector;

deriving an activation value based on an application of a weight vector to said feature vector, wherein said weight vector comprises a plurality of weights, each of the plurality of weights corresponding to one of the plurality of features of said feature vector;

determining whether the patient fall has occurred based on the derived activation value; and

alerting a caregiver based on said determination.

[0058r] According to an aspect of the invention is a method of determining whether a user has fallen by processing signals indicative of movement by the user, the method comprising:

receiving, with a processing device from a sensor, signals responsive to a linear acceleration of said user with respect to a roll axis, a pitch axis, and a yaw axis, said roll axis corresponding to a longitudinal axis extending along a length of said user's body, said pitch axis corresponding to said user's hips, and said yaw axis corresponding to a horizontal plane in which said user is located, wherein said sensor is configured to be worn by said user and comprises an accelerometer, a gyroscope, and a first wireless transceiver, and wherein said processing device comprises a processor and a second wireless transceiver configured to communicate with the first wireless transceiver of said sensor;

receiving, with said processing device from said sensor, signals responsive to an angular velocity of said user with respect to said roll axis, said pitch axis, and said yaw axis; and

processing said received signals responsive to said linear acceleration and said angular velocity of said user with said processor of said processing device by:

forming a sensor data vector comprising a plurality of data elements, each of the plurality of data elements responsive to one of said linear acceleration or said angular velocity with respect to one of said roll axis, said pitch axis, and said yaw axis;

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normalizing said plurality of data elements to form a normalized sensor data vector;

generating a feature vector from said normalized sensor data vector, said feature vector comprising a plurality of features indicative of a fall, wherein each of the plurality of features are generated based on one or more of the plurality of data elements from said normalized sensor data vector;

deriving an activation value based on an application of a weight vector to said feature vector, wherein said weight vector comprises a plurality of weights, each of the plurality of weights associated with one of the plurality of features of said feature vector; and

determining whether the fall has occurred based on the derived activation value.

[0058s] According to an aspect of the invention is a method of determining whether a user has fallen, the method comprising:

receiving, with a processing device, a first set of signals responsive to an acceleration of the user from a sensor configured to be worn by said user, said sensor comprising an accelerometer and a gyroscope, said processing device comprising a processor;

receiving, with said processing device, a second set of signals responsive to an angular velocity of said user from said sensor; and

generating a feature vector comprising a plurality of features indicative of a fall, wherein each of the plurality of features are generated based on at least one of:

one or more of the first set of signals; and

one or more of the second set of signals;

deriving an activation value based on an application of a weight vector to said feature vector, said weight vector comprising a plurality of weights, each of the plurality of weights associated with one of the plurality of features of said feature vector; and

determining whether the fall has occurred based on the derived activation value.

[0058t] According to an aspect of the invention is a system configured to determine whether a user has fallen, the system comprising:

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a sensor including an accelerometer and a gyroscope, said sensor configured to transmit a first set of signals responsive to an acceleration of the user and a second set of signals responsive to an angular velocity of said user;

a processing device comprising a processor, said processing device configured to:

receive said first and second sets of signals from said sensor;

generate a feature vector comprising a plurality of features indicative of a fall, wherein each of the plurality of features are generated based on at least one of:

one or more of the first set of signals; and

one or more of the second set of signals;

derive an activation value based on an application of a weight vector to said feature vector, said weight vector comprising a plurality of weights, each of the plurality of weights associated with one of the plurality of features of said feature vector; and

determine whether the fall has occurred based on the derived activation value.

[0058u] According to an aspect of the invention is a method comprising:

obtaining, from a motion sensor of a wearable wireless device, motion data indicative of motion of a user over a time period when the wearable wireless device is worn by the user, wherein said motion sensor comprises an accelerometer and a gyroscope, and wherein said motion data comprises movement data and orientation data of the user;

normalizing the motion data with training data comprising a plurality of fall and non-fall scenarios;

determining, with the wearable wireless device and based on the motion data, an impact experienced by the user during the time period;

determining, with the wearable wireless device and based on the motion data, one or more first activity scenarios representative of the user's motion during the time period and prior to the impact experienced by the user;

determining, with the wearable wireless device and based on the motion data, an amount of rotation of the user during the time period and comparing said amount of rotation to a first threshold;

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determining, with the wearable wireless device and based on the motion data, one or more second activity scenarios representative of the user's motion during the time period and after the impact experienced by the user;

determining, with the wearable wireless device, that the user has fallen based on the impact experienced by the user, the one or more first activity scenarios representative of the user's motion during the time period and prior to the impact, said amount of rotation exceeding said first threshold, and the one or more second activity scenarios representative of the user's motion during the time period and after the impact; and

responsive to determining that the user has fallen, generating, with the wearable wireless device, a notification indicating that the user has fallen.

[0058v] According to an aspect of the invention is a method comprising:

obtaining, from a motion sensor of a wearable device, motion data indicative of motion of a user over a time period when the wearable device is worn by the user;

normalizing the motion data with training data comprising a plurality of fall and non-fall scenarios;

determining, with the wearable device and based on the motion data, an impact experienced by the user during the time period;

determining, with the wearable device and based on the motion data, one or more first activity characteristics associated with the user's motion during the time period and prior to the impact experienced by the user;

determining, with the wearable device and based on the motion data, an amount of rotation of the user during the time period and comparing said amount of rotation to a first threshold;

determining, with the wearable device and based on the motion data, one or more second activity characteristics associated with the user's motion during the time period and after the impact experienced by the user;

determining, with the wearable device, that the user has fallen based on the impact experienced by the user, the one or more first activity characteristics associated with the user's motion during the time period and prior to the impact, said amount of rotation exceeding said

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first threshold, and the one or more second activity characteristics associated with the user's motion during the time period and after the impact; and

responsive to determining that the user has fallen, generating, with the wearable device, a notification indicating that the user has fallen.

[0058w] According to an aspect of the invention is a wearable device comprising:

one or more processors;

a non-transitory computer readable medium storing instructions that, when executed by the one or more processors, cause the one or more processors to perform operations comprising:

obtaining, from a motion sensor of the wearable device, motion data indicative of motion of a user;

normalizing the motion data with training data comprising a plurality of fall and non-fall scenarios;

determining, based on the motion data, an impact experienced by the user;

determining, based on the motion data, one or more first activity characteristics associated with the user's motion prior to the impact experienced by the user;

determining, based on the motion data, an amount of rotation of the user and comparing said amount of rotation to a first threshold;

determining, based on the motion data, one or more second activity characteristics associated with the user's motion after the impact experienced by the user;

determining that the user has fallen based on the impact experienced by the user, the one or more first activity characteristics, said amount of rotation exceeding said first threshold, and the one or more second activity characteristics; and

responsive to determining that the user has fallen, generating a notification indicating that the user has fallen.

[0058x] According to an aspect of the invention is a method comprising:

obtaining, with an accelerometer and a gyroscope of a wearable wireless device, motion data indicative of motion of a subject over a time period when the wearable wireless device is worn by the subject, wherein said motion data is indicative of movement and orientation of the subject;

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correlating, with one or more processors of the wearable wireless device, at least a portion of said motion data with training data comprising a plurality of fall and non-fall scenarios;

determining, with said one or more processors of the wearable wireless device and based on at least a portion of said motion data, an impact experienced by the subject during a first portion of the time period;

determining, with said one or more processors of the wearable wireless device and based on at least a portion of said motion data, one or more first activity characteristics representative of the subject's motion during a second portion of the time period that is prior to said impact;

determining, with said one or more processors of the wearable wireless device and based on at least a portion of said motion data, rotation of the subject during at least a portion of the time period and comparing said rotation to a first threshold;

determining, with said one or more processors of the wearable wireless device and based on at least a portion of said motion data, one or more second activity characteristics representative of the subject's motion during a third portion of the time period that is after said impact;

determining, with said one or more processors of the wearable wireless device, that the subject experienced a fall based on at least said impact, said one or more first activity characteristics representative of the subject's motion during the second portion of the time period that is prior to said impact, said rotation exceeding said first threshold, and said one or more second activity characteristics representative of the subject's motion during the third portion of the time period that is after said impact; and

responsive to determining that the subject experienced said fall, generating, with the wearable wireless device, an alert indicating that the subject experienced said fall.

[0058y] According to an aspect of the invention is a method comprising:

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obtaining, with an accelerometer and a gyroscope of a wearable wireless device, motion data indicative of motion of a subject over a time period when the wearable wireless device is worn by the subject;

determining, based on at least a portion of said motion data, an impact experienced by the subject during the time period;

determining, based on at least a portion of said motion data, one or more first activity characteristics representative of the subject's motion during the time period and prior to said impact;

determining, based on at least a portion of said motion data, one or more second activity characteristics representative of the subject's motion during the time period and after said impact;

determining, based on at least a portion of said motion data, rotation of the subject during at least a portion of the time period and comparing said rotation to a first threshold;

determining that the subject experienced a fall based on said impact, said one or more first activity characteristics, said one or more second activity characteristics, and said rotation being above said first threshold; and

responsive to determining that the subject experienced said fall, generating an alert indicating that the subject experienced said fall.

[0058z] According to an aspect of the invention is a wearable device comprising:

one or more processors;

a non-transitory computer readable medium storing instructions that, when executed by the one or more processors, cause the one or more processors to perform operations comprising:

obtaining, from a motion sensor of the wearable device, motion data indicative of motion of a subject;

determining, based on at least a portion of the motion data, an impact experienced by the subject;

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determining, based on at least a portion of the motion data, one or more first activity characteristics associated with the subject's motion prior to said impact experienced by the subject;

determining, based on at least a portion of the motion data, rotation of the subject and comparing said rotation to a first threshold;

determining, based on at least a portion of the motion data, one or more second activity characteristics associated with the subject's motion after said impact experienced by the subject;

determining that the subject experienced a fall based on said impact experienced by the subject, said one or more first activity characteristics, said rotation exceeding said first threshold, and said one or more second activity characteristics; and

responsive to determining that the subject experienced said fall, generating a notification indicating that the subject experienced said fall.

[0058AA] According to an aspect of the invention is a wearable wireless sensor for monitoring a thermal energy of a patient and at least one of pressure ulcer risk, fall detection, or fall risk, said wearable wireless sensor comprising:

a housing including a predetermined position for at least a first sensor and a second sensor,

one or more accelerometers responsive to an acceleration of said patient and configured to output one or more signals indicative of at least one of said pressure ulcer risk, said fall detection, or said fall risk;

a base including a first aperture;

a circuit layer including a first through-hole via extending through said circuit layer; and

a temperature sensor responsive to said thermal energy of said patient, said temperature sensor mounted on said circuit layer, said temperature sensor including a thermal contact in thermal communication with said circuit layer, wherein said temperature sensor is at least one of the first sensor or the second sensor;

wherein said first through-hole via is aligned with said thermal contact of said temperature sensor and with said first aperture of said base, said first through-hole via

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is configured to provide a structure to transmit said thermal energy across a length of the first through-hole via from said patient to said temperature sensor,

wherein said first aperture and said first through-hole via include a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said base corresponding to said first aperture, and

wherein the housing is configured to operably position the base and the circuit layer.

[0058BB] According to an aspect of the invention is a wearable physiological sensor for monitoring one or more physiological parameters of a patient, the sensor comprising:

a base substrate having a top surface and a bottom surface opposite the top surface, the bottom surface comprising an adhesive configured to secure the base substrate to skin of the patient, the base substrate further comprising a first opening;

a housing configured to cover at least a portion of the base substrate;

a circuit board positioned within the housing, the circuit board comprising a first surface and a second surface, the second surface positioned closer to the base substrate than the first surface, the circuit board including a second opening;

a temperature sensor responsive to a thermal energy of the patient and positioned within the housing, said temperature sensor vertically aligned with the second opening in the circuit board and the first opening of the base substrate, said temperature sensor in thermal contact with a portion of the skin of the patient located proximate the first opening of the base substrate, wherein the first opening of the base substrate and the second opening in the circuit board provide a structure to transmit the thermal energy from the portion of the skin of the patient to the temperature sensor;

an ECG sensor responsive to electrical signals generated by said patient's heart, said ECG sensor comprising a first electrode and a second electrode, the first electrode positioned within the housing and coupled to a first portion of the circuit board, the second electrode positioned outside of the housing and coupled to a second portion of the circuit board; and

a processor in communication with the temperature sensor and the ECG sensor, the processor configured to generate one or more signals representative of said thermal energy and electrical signals.

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[0058CC] According to an aspect of the invention is a wearable physiological sensor for monitoring one or more physiological parameters of a patient, the sensor comprising:

a substrate having a top surface and a bottom surface opposite the top surface, the bottom surface comprising an adhesive configured to secure the substrate to skin of the patient, the substrate further comprising a first opening;

a housing configured to cover at least a portion of the substrate;

a circuit board positioned within the housing, the circuit board comprising a first surface and a second surface, the second surface positioned closer to the substrate than the first surface, the circuit board including a second opening; and

a temperature sensor responsive to a thermal energy of the patient and positioned within the housing, said temperature sensor vertically aligned with the second opening in the circuit board and the first opening of the substrate, said temperature sensor in thermal contact with a portion of the skin of the patient located proximate the first opening of the substrate, wherein the first opening of the substrate and the second opening in the circuit board provide a structure to transmit the thermal energy from the portion of the skin of the patient to the temperature sensor.

[0058DD] According to an aspect of the invention is a wireless physiological sensor for measuring one or more physiological parameters of a patient, the wireless physiological sensor comprising:

a base including a bottom surface and a top surface, said base also including a first aperture and a second aperture, wherein each of said first and second apertures extends between said bottom surface and said top surface of said base;

a substrate layer including conductive tracks and connection pads, a top side, and a bottom side, said bottom side of said substrate layer being disposed above said top surface of said base, said substrate layer also including a first through-hole via and a second through-hole via, wherein each of said first and second through-hole vias extends through said substrate layer between said top and bottom sides of said substrate layer;

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a temperature sensor responsive to thermal energy of said patient, said temperature sensor mounted on said top side of said substrate layer, said temperature sensor including a thermal contact in thermal communication with said top side of said substrate layer, wherein said first through-hole via is aligned with said thermal contact of said temperature sensor on said top side of said substrate layer and with said first aperture of said base on said bottom side of said substrate layer, and wherein said first aperture of said base and said first through-hole via of said substrate layer are filled with at least a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said bottom surface of said base corresponding to said first aperture;

an electrocardiogram (ECG) sensor mounted on said top side of said substrate layer, said ECG sensor responsive to electrical signals generated by said patient's heart, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG sensor also including an electrical contact in electrical communication with said top side of said substrate layer, wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said top side of said substrate layer and with said second aperture of said base on said bottom side of said substrate layer, and wherein said second aperture of said base and said second through-hole via of said substrate layer are filled with at least an electrically conductive material to cause said ECG sensor to be in electrical communication with a portion of said bottom surface of said base corresponding to said second aperture; and

an accelerometer, mounted on said substrate layer, said accelerometer responsive to a linear acceleration of said patient.

[0058EE] According to an aspect of the invention is a wearable wireless sensor for monitoring at least one physiological parameter, said wearable wireless sensor comprising:

a base including a first aperture, the base configured to be positioned proximate skin of a patient when the wearable wireless sensor is in use;

a housing secured to the base;

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a circuit layer enclosed by at least a portion of the housing and including a first side, a second side opposite the first side, and at least one through-hole via extending through said circuit layer;

a temperature sensor responsive to a thermal energy of the patient, said temperature sensor mounted on said first side of said circuit layer, said temperature sensor configured to be in thermal communication with a portion of the skin of the patient proximate the first aperture of the base when the wearable wireless sensor is in use, wherein said at least one through-hole via is positioned between said temperature sensor and said first aperture of said base, said at least one through-hole via configured to allow said thermal energy to pass through the circuit layer to the temperature sensor; and

a thermally conductive material configured to be positioned between said portion of the skin of the patient and said at least one through-hole via when the wearable wireless sensor is in use, said thermally conductive material configured to transmit said thermal energy from the portion of the skin of said patient to the at least one through-hole via of the circuit layer.

[0058FF] According to an aspect of the invention is a wearable physiological sensor for measuring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

a housing;

a base secured to the housing and including a first opening and a second opening spaced from the first opening, the base configured to be positioned proximate skin of the patient when the wearable physiological sensor is in use;

a circuit layer;

a first ECG electrode located at least partially within the first opening of the base and in electrical communication with the circuit layer, the first ECG electrode

configured to transmit one or more electrical signals to said circuit layer responsive to electrical activity of the patient's heart;

a second ECG electrode positioned outside the housing and electrically connected to said circuit layer via an ECG lead, the second ECG electrode configured

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to transmit one or more electrical signals to said circuit layer responsive to electrical activity of the patient's heart;

a temperature sensor responsive to a thermal energy of the patient, said temperature sensor configured to be in thermal communication with a portion of skin of the patient proximate the second opening of the base when the wearable physiological sensor is in use; and

a thermally conductive material configured to be positioned between said portion of the skin of the patient and said temperature sensor when the wearable physiological sensor is in use.

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[0059] For purposes of summarizing the disclosure, certain aspects, advantages, and novel features have been described herein. Of course, it is to be understood that not necessarily all such aspects, advantages, or features will be embodied in any particular embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0060] Various embodiments will be described hereinafter with reference to the accompanying drawings. The drawings and the associated descriptions are provided to illustrate embodiments of the present disclosure and do not limit the scope of the claims. In the drawings, similar elements have similar reference numerals.

[0061] FIG. 1A is a perspective view of an embodiment of the disclosed patient monitoring system including a patient-worn wireless sensor in proximity to a patent monitor.

[0062] FIG. 1B is a functional block diagram of an embodiment of the display of the disclosed patient monitor.

[0063] FIG. 1C is a functional block diagram of an embodiment of the disclosed patient monitoring system.

[0064] FIG. 1D is a functional block diagram of an embodiment of the disclosed patient monitoring system.

[0065] FIG. 1E is a functional block diagram of an embodiment of the disclosed patient monitoring system.

[0066] FIG. 1F is a functional block diagram of an embodiment of the disclosed patient monitoring system.

[0067] FIG. 2A is a functional block diagram of an embodiment of the disclosed wireless sensor.

[0068] FIG. 2B is a functional block diagram of an embodiment of the disclosed wireless sensor including optional sensing components.

[0069] FIG. 3A is a schematic exploded perspective view of an embodiment of the disclosed wireless sensor.

[0070] FIG. 3B is a schematic assembled perspective view of the embodiment of the disclosed wireless sensor of FIG. 3A.

[0071] FIG. 3C is a schematic side view of the embodiment of the disclosed wireless sensor of FIGS. 3A and 3B.

[0072] FIG. 4A is a schematic cross-sectional view of an embodiment of the disclosed wireless sensor which includes a temperature sensor.

[0073] FIG. 4B is a schematic bottom view of the embodiment of the disclosed wireless sensor of FIG. 4A.

[0074] FIG. 4C is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor of FIGS. 4A-B.

[0075] FIG. 5A is a schematic cross-sectional view of an embodiment of the disclosed wireless sensor which includes an acoustic respiration sensor.

[0076] FIG. 5B is a schematic bottom view of the embodiment of the disclosed wireless sensor of FIG. 5A.

[0077] FIG. 5C is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor of FIGS. 5A-B.

[0078] FIG. 6A is a schematic cross-sectional view of an embodiment of the disclosed wireless sensor which includes a temperature sensor and an acoustic respiration sensor.

[0079] FIG. 6B is a schematic bottom view of the embodiment of the disclosed wireless sensor of FIG. 6A.

[0080] FIG. 6C is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor of FIGS. 6A-B.

[0081] FIG. 7A is a perspective view of an embodiment of the disclosed patient monitoring system including a patient-worn wireless sensor having an ECG sensor in proximity to a patent monitor.

[0082] FIG. 7B is a schematic assembled perspective view of the embodiment of the disclosed wireless sensor of FIG. 7A.

[0083] FIG. 7C is a schematic side view of the embodiment of the disclosed wireless sensor of FIGS. 7A and 7B.

[0084] FIG. 7D is a cross-sectional view of an embodiment of the disclosed wireless sensor of FIGS. 7A-C.

[0085] FIG. 7E is a schematic bottom perspective view of the embodiment of the disclosed wireless sensor of FIGS. 7A-D

[0086] FIG. 7F is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor of FIGS. 7A-7E.

[0087] FIG. 8A is a schematic exploded perspective view of an embodiment of the disclosed wireless sensor having a temperature sensor, an acoustic respiration sensor, and an ECG sensor.

[0088] FIG. 8B is a schematic bottom view of the disclosed wireless sensor of FIG. 8A.

[0089] FIG. 9 is a flow diagram describing a process to associate a wireless sensor with a patient monitor according to an embodiment of the present disclosure.

[0090] FIG. 10 is a flow diagram describing a process to determine whether a patient has changed orientation according to an embodiment of the present disclosure.

[0091] FIG. 11A is an exemplary plot of processed accelerometer data over time used to determine a patient's orientation according to an embodiment of the present disclosure.

[0092] FIG. 11B is an exemplary plot of the duration of a patient's orientation according to an embodiment of the present disclosure.

[0093] FIG. 12 is a flow diagram describing a process to determine whether a patient has fallen according to an embodiment of the present disclosure.

[0094] FIGS. 13A-F illustrate embodiments of displays reflecting a patient's position according to an embodiment of the present disclosure.

[0095] FIG. 14 illustrates an example display of a patient monitor incorporating the icons illustrated in FIGS. 13A-F according to an embodiment of the present disclosure.'

[0096] FIGS. 15A-15H illustrate various configurations of a room display displayed on a patient display monitor according to an embodiment of the present disclosure.

[0097] FIG. 16 illustrates an example method according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0098] Embodiments of the present disclosure will now be described with reference to the accompanying figures, wherein like numerals refer to like elements throughout. The following description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. It should be understood that steps within a method may be executed in different order without altering the principles of the present disclosure. Furthermore, embodiments disclosed herein can include several novel features, no single one of which is solely responsible for its desirable attributes or which is essential to practicing the systems, devices, and methods disclosed herein.

[0099] The present disclosure relates to systems, devices, methods, and computer-readable media to monitor and manage the position, orientation, and movement of a patient who is at risk of forming one or more pressure ulcers. In one embodiment, the system comprises a patient-worn, wireless sensor including one or more sensors configured to obtain position, orientation and movement information from the patient. The one or more sensors can include one or more accelerometers, gyroscopes, and magnetometers (*i.e.*, compasses). Illustratively, the sensors continuously or periodically (*e.g.*, every second) obtain information that describes the patient's orientation in three dimensions. The wireless sensor includes a processor that is configured to process the obtained sensor information. The wireless sensor also includes a transceiver configured to wirelessly transmit the processed sensor data, and/or information representative of the sensor data, to a patient monitor (or other processing device) for further processing. The patient monitor can be configured to store and further process the received information, to display information indicative of or derived from the received data, and to transmit

information -- including displays, alarms, alerts, and notifications -- to other patient care systems including a multi-patient monitoring system which may be accessible from, for example, a nurses' station.

[0100] FIG. 1A is a perspective illustration of an embodiment of the disclosed patient monitoring system 100 in a clinical setting. The patient monitoring system 100 includes a wireless sensor 102 worn by a patient, in proximity to a patient monitor 106 located on a table 116 at the side of the patient's bed 118. The wireless sensor 102 may also be referred to herein as "a wireless physiological sensor 102," "a patient-worn sensor 102," "a movement sensor 102," and "a wearable wireless sensor 102." The wireless sensor 102 includes one or more sensors configured to measure the patient's position, orientation, and motion. In some embodiments, the wireless sensor 102 includes an accelerometer configured to measure linear acceleration of the patient and a gyroscope configured to measure angular velocity of the patient. The measured linear acceleration and angular velocity information can be processed to determine the patient's orientation in three dimensions. In some embodiments, a magnetometer is included in the wireless sensor 102 to measure the Earth's gravitational field. Information measured by the magnetometer can be used to improve accuracy of the determined orientation of the patient.

[0101] The wireless sensor 102 also includes a wireless transceiver 206 (shown in FIGS. 2A and 2B) which can transmit to the patient monitor 106 information representative of sensor data obtained by the wireless sensor 102 from the patient. Advantageously, the patient is not physically coupled to the bedside patient monitor 106 and can therefore move freely into different positions on the bed 118.

[0102] In accordance with certain embodiments of the present disclosure, the wireless sensor 102 is affixed to the skin of the patient's body under the patient's garment as reflected in FIG. 1A by the phantom drawing of the wireless sensor 102. More particularly, the wireless sensor 102 can be placed on the patient's chest over the patient's manubrium, the broad upper portion of the sternum. In this position, the wireless sensor 102 is approximately centered relative to the longitudinal axis of the

patient's body and near the patient's center of mass, a position that is useful in determining the patient's orientation when, for example, the patient is in bed.

[0103] The wireless sensor 102 can be affixed to the patient's skin using any form of medically-appropriate adherent material, including a pressure-sensitive adhesive that is coated or applied to the bottom surface of the wireless sensor 102. One skilled in the art will appreciate that many other materials and techniques can be used to affix the wireless sensor 102 to the patient without departing from the scope of the present disclosure.

[0104] Frequently in clinical settings, multiple medical sensors are attached or adhered to a patient to concurrently monitor multiple physiological parameters. Some examples of medical sensors include, but are not limited to, position, orientation, and movement sensors, temperature sensors, respiration sensors, heart rate sensors, blood oxygen sensors (such as pulse oximetry sensors), acoustic sensors, EEG sensors, ECG sensors, blood pressure sensors, sedation state sensors, to name a few. Typically, each sensor that is attached to a patient transmits, often by cable, the obtained physiological data to a nearby monitoring device configured to receive and process the sensor data, and transform it into clinical information to be used by the care providers to monitor and manage the patient's condition. When a patient is concurrently monitored by several physiological sensors, the number of cables and the number of bedside monitoring devices used can be excessive and can limit the patient's freedom of movement and impede care providers' access to the patient. The cables connecting the patient to the bedside monitoring devices can also make it more difficult to move the patient from room to room or to switch to different bedside monitors.

[0105] Advantageously, the disclosed wireless sensor 102 can transmit data, wirelessly, to a patient data processing environment 105 in which the sensor data can be processed using one or more processing capabilities. As illustrated in FIG. 1A, the wireless sensor 102 transmits data via a wireless communications link 104. The wireless communications link 104 can be received by the bedside patient monitor 106, and/or by an extender/repeater 107. Both the patient monitor 106 and expander/repeater 107 provide access, by way of high-speed and reliable

communications interfaces, to the patient data processing environment 105. For illustration purposes, both the patient monitor 106 and the extender/repeater 107 are illustrated in FIG. 1A. However, typically only one such device is required to establish a wireless connection between the wireless sensor 102 and the patient data processing environment 105. The wireless communications link 104 can use any of a variety of wireless technologies, such as Wi-Fi (802.1 1 x), Bluetooth, ZigBee, cellular telephony, infrared, RFID, satellite transmission, proprietary protocols, combinations of the same, and the like. The wireless sensor 102 can be configured to perform telemetry functions, such as measuring and reporting position, orientation, and movement information about the patient. According to one embodiment, the wireless sensor 102 uses the Bluetooth wireless communications standard to communicate wirelessly with the patient monitor 106.

[0106] The extender/repeater 107 can receive sensor data from the wireless sensor 102 by way of the wireless communications link 104 and forward the received sensor data, via the network 108, to one or more processing nodes within the patient data processing environment 105. For example, the extender/repeater 107 can forward the received sensor data to a patient monitor 106 that might be located beyond the range of the wireless communications link 104 of a particular wireless sensor 102. Alternatively, the extender/repeater 107 can route the sensor data to other processing nodes within the patient data processing environment 105, such as, for example, a multi-patient monitoring system 1 10 or a nurses' station system 1 13. A skilled artisan will appreciate that numerous processing nodes and systems can be used to process the data transmitted by the wireless sensor 102.

[0107] FIG. 1A also illustrates an embodiment of the patient monitor 106, which may also be referred to herein as "a processing device 106," "a portable computing device 106," and "a patient monitoring device 106." Examples of a patient monitor 106 are disclosed in U.S. Pat. Pub. Nos. 2013/0262730 and 2015/0099955, assigned to the assignee of the present disclosure. The patient monitor 106 is a processing device, and therefore includes the necessary components to perform the functions of a processing device, including at least one processor, a memory device, a storage

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device, input/output devices, and communications connections, all connected via one or more communication buses. Thus, in certain embodiments, the patient monitor 106 is configured to process the sensor data provided by the wireless sensor 102. In other embodiments, processing of the sensor data can be performed by other processing nodes within the patient data processing environment 105. The patient monitor 106 is configured to wirelessly communicate with the wireless sensor 102. The patient monitor 106 includes a display 120, and a docking station, which is configured to mechanically and electrically mate with a portable patient monitor 122 also having a display 130. The patient monitor 106 is housed in a movable, mountable, and portable housing formed in a generally upright, inclined shape configured to rest on a horizontal flat surface, as shown in FIG. 1A. Of course, a person skilled in the art will appreciate that the housing can be affixed in a wide variety of positions and mountings and can comprise a wide variety of shapes and sizes.

[0108] In an embodiment, the display 120, alone or in combination with the display 130 of the portable patient monitor 122, may present a wide variety of measurement and/or treatment data in numerical, graphical, waveform, or other display indicia. For example, the display 120 can display a variety of patient-specific configurations and/or parameters, such as the patient's weight, age, type of treatment, type of disease, type of medical condition, nutrition, hydration and/or length of stay, among others. In an embodiment, the display 120 occupies much of a front face of the housing, although an artisan will appreciate the display 120 may comprise a table or tabletop horizontal configuration, a laptop-like configuration, or the like. Other embodiments may include communicating display information and data to a tablet computer, smartphone, television, or any display system recognizable to an artisan. Advantageously, the upright inclined configuration of the patient monitor 106, as illustrated in FIG. 1A, displays information to a caregiver in an easily viewable manner.

[0109] The portable patient monitor 122 of FIG. 1A may advantageously include an oximeter, co-oximeter, respiratory monitor, depth of sedation monitor, noninvasive blood pressure monitor, vital signs monitor or the like, such as those

commercially available from Masimo Corporation of Irvine, CA, and/or disclosed in U.S. Pat. Pub. Nos. 2002/0140675, 2010/0274099, 201 1/0213273, 2012/02261 17, 2010/0030040; U.S. Pat. App. Ser. Nos. 61/242,792, 61/387457, 61/645,570, 13/554,908 and U.S. Pat. Nos. 6,157,850, 6,334,065. The portable patient monitor 122 may communicate with a variety of non-invasive and/or minimally invasive devices such as, by way of non-limiting example, wireless sensor 102, optical sensors with light emission and detection circuitry, acoustic sensors, devices that measure blood parameters from a finger prick, cuffs, ventilators, and the like. The portable patient monitor 122 may include its own display 130 presenting its own display indicia. The display indicia may change based on a docking state of the portable patient monitor 122. When undocked, the display 130 may include parameter information and may alter its display orientation based on information provided by, for example, a gravity sensor or an accelerometer. Although disclosed with reference to particular portable patient monitors 122, an artisan will recognize from the disclosure herein there is a large number and wide variety of medical devices that may advantageously dock with the patient monitor 106.

[0110] FIG. 1 B is a functional block diagram of an embodiment of the display 120 of the disclosed patient monitor 106 and the display 130 of the portable patient monitor 122. Display 120 of the patient monitor 106 can be configured to present patient physiological data 124, patient turn data 126, and/or additional, optional patient data 128. Patient physiological data can include, by way of non-limiting example, oxygen saturation, pulse rate, respiration rate, fractional arterial oxygen saturation, total hemoglobin, plethysmograph variability index, methemoglobin, carboxyhemoglobin, perfusion index, and oxygen content. Advantageously, the display 120 is configurable to permit the user to adjust the manner by which the physiologic parameters 124, patient turn data 126, and optional patient data 128 are presented on the display 120. In particular, information of greater interest or importance to the clinician may be displayed in larger format and may also be displayed in both numerical and graphical formats to convey the

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current measurement as well as the historical trend of measurements for a period of time, such as, for example, the preceding hour.

[0111] As illustrated by dotted lines in FIG. 1B, the display 130 of the portable patient monitor 130 is an optional feature of the patient monitor 106 which may be configured to present patient physiological data 134, patient turn data 136, and additional, optional patient data 138.

[0112] FIG. 1C is a simplified functional block diagram of an embodiment of the disclosed patient monitoring system 100. The system includes the patient-worn wireless sensor 102 having one or more sensors, a wireless communications link 104, through which sensor data from the wireless sensor 102 accesses the patient data processing environment 105 which includes a patient monitor 106, a communications network 108, a multi-patient monitoring system 110, a hospital or facility information system 112, one or more nurses' station systems 113, and one or more clinician devices 114. An artisan will appreciate that numerous other computing systems, servers, processing nodes, display devices, printers, and the like can be included in the disclosed patient monitoring system 100.

[0113] The wireless sensor 102 is worn by a patient who has been determined to be at risk of forming one or more pressure ulcers, *e.g.*, a patient who is confined to bed for an extended period of time. The wireless sensor 102 is capable of monitoring on a continuous or periodic (*e.g.*, every second) basis the orientation of the patient to help determine whether the patient is repositioned frequently enough to reduce the patient's risk of forming a pressure ulcer. In certain embodiments, the wireless sensor 102 minimally processes measured acceleration and/or angular velocity data and wirelessly transmits the minimally-processed data to the patient monitor 106 by way of the wireless communications link 104.

[0114] The wireless sensor 102 and the patient monitor 106 can be configured to utilize different wireless technologies to form the wireless communications link 104. In certain scenarios, it may be desirable to transmit data over Bluetooth or ZigBee, for example, when the distance between the wireless sensor 102 and the patient monitor 106 is within range of Bluetooth or ZigBee communication. Transmitting data using Bluetooth or ZigBee is advantageous

because these technologies require less power than other wireless technologies. Accordingly, longevity of embodiments of the disclosed wireless sensor 102 using batteries may be increased by using Bluetooth or ZigBee protocols.

[0115] In other scenarios, it may be desirable to transmit data using Wi-Fi or cellular telephony, for example, when the distance between the wireless sensor 102 and the patient monitor 106 is out of range of communication for Bluetooth or ZigBee. A wireless sensor 102 may be able to transmit data over a greater distance using Wi-Fi or cellular telephony than other wireless technologies. In still other scenarios, it may be desirable to transmit data using a first wireless technology and then automatically switching to a second wireless technology in order to maximize data transfer and/or energy efficiency.

[0116] In some embodiments, the wireless sensor 102 automatically transmits data over Bluetooth or ZigBee when the wireless sensor 102 is within a pre-determined distance from the bedside patient monitor 106. The wireless sensor 102 automatically transmits data over Wi-Fi or cellular telephony when the wireless sensor 102 is beyond a pre-determined distance away from the bedside patient monitor 106. In certain embodiments, the wireless sensor 102 can automatically convert from Bluetooth or ZigBee to Wi-Fi or cellular telephony, and vice versa, depending on the distance between the wireless sensor 102 and the bedside patient monitor 106.

[0117] In some embodiments, the wireless sensor 102 automatically transmits data over Bluetooth or ZigBee when the Bluetooth or ZigBee signal strength is sufficiently strong or when there is interference with Wi-Fi or cellular telephony. The wireless sensor 102 automatically transmits data over Wi-Fi or cellular telephony when the Bluetooth or ZigBee signal strength is not sufficiently strong. In certain embodiments, the wireless sensor 102 can automatically convert from Bluetooth or ZigBee to Wi-Fi or cellular telephony, and vice versa, depending on signal strength.

[0118] The patient monitor 106 can be operable to receive, store and process the measured acceleration and angular velocity data transmitted by the wireless sensor 102 to determine the patient's orientation. Once determined, the

patient monitor 106 can display the patient's current orientation. In some embodiments, the patient monitor 106 displays the patient's current orientation along with the patient's previous orientations over time, thereby providing the user the ability to view a historical record of the patient's orientation. In certain embodiments, e.g., as illustrated in FIGS. 13A-F and 14, the patient orientation is displayed by icons, such stick figures, enabling the clinician to readily understand the patient's present positional state and the patient's positional history. The patient monitor 106 can also be configured to keep track of the length of time the patient remains in a particular orientation. In some embodiments the patient monitor 106 displays the amount of time the patient has been in the current orientation. Additionally, the patient monitor 106 can determine when the patient remains in a particular orientation for a duration greater than that prescribed by a clinician according to a repositioning protocol. Under such conditions, the patent monitor 106 can issue alarms, alerts, and/or notifications to the patient and/or to caregivers indicating that the patient should be repositioned to adhere to the prescribed repositioning protocol to reduce the risk of pressure ulcer formation.

[0119] As illustrated in FIG. 1C, the patient monitor 106 communicates over a network 108 with a patient data processing environment 105 that includes a multi-patient monitoring system 110, a hospital/facility system 112, nurses' station systems 113, and clinician devices 114. Examples of network-based clinical processing environments, including multi-patient monitoring systems 110, are disclosed in U.S. Pat. Pub. Nos. 2011/0105854, 2011/0169644, and 2007/0180140. In general, the multi-patient monitoring system 110 communicates with a hospital/facility system 112, the nurses' station systems 113, and clinician devices 114. The hospital/facility system 112 can include systems such as electronic medical record (EMR) and/or and admit, discharge, and transfer (ADT) systems. The multi-patient monitoring system 110 may advantageously obtain through push, pull or combination technologies patient information entered at patient admission, such as patient identity information, demographic information, billing information, and the like. The patient monitor 106 can access this information to associate the monitored patient with the

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hospital/facility systems 112. Communication between the multi-patient monitoring system 110, the hospital/facility system 112, the nurses' station systems 113, the clinician devices 114, and the patient monitor 106 may be accomplished by any technique recognizable to an artisan from the disclosure herein, including wireless, wired, over mobile or other computing networks, or the like.

[0120] FIG. 1D is a simplified functional block diagram of the disclosed patient monitoring system 100 of FIG. 1C expanded to illustrate use of multiple wireless sensors 102 with multiple patients within a caretaking environment. Advantageously, the patient monitoring system 100 can provide individual patient information on, for example, a patient monitor 106, as well as aggregated patient information on, for example, a nurses' station server or system 114. Thus a caretaker can have an overview of positional information corresponding to a population of patients located, for example, in a hospital floor or unit.

[0121] In some circumstances, there may not be the need, desire, or resources available to employ a bedside patient monitor 106 associated with a wireless sensor 102 being worn by a patient. For example, the clinical environment might be staffed such that patient data are collected, analyzed, displayed, and monitored at a central observation station, such as a nurses' station, rather than at the patient's bedside. Moreover, when the information is to be accessed by a clinician at the bedside, portable clinician devices 114, such as, for example, tablets, PDAs or the like, may be used by caregivers to access the required patient-specific information while at the patient's bedside.

[0122] In such situations, as illustrated in FIGS. 1E and 1F, the wireless sensor 102 can communicate to the various systems of the clinical computing environment by way of a signal extender/repeater 107. The extender/repeater 107 is located within range of the wireless sensor 102 (*e.g.,* near the patient's bed 118) and configured to relay data, via the network 108, between the wireless sensor 102 and one or more computing systems capable of processing, storing, displaying, and/or transmitting the data collected by the wireless sensor 102. Advantageously, a relatively low cost extender/repeater 107 can be used to receive signals transmitted from one or more wireless sensors 102 over the wireless communications

link(s) 104 using a shorter-range, lower-power-consuming transmission mode, such as for example, Bluetooth or ZigBee. The extender/repeater 107 can then retransmit the received signals to one or more computing systems in the patient data processing environment 105 over the network 108. In accordance with some embodiments, the extender/repeater 107 is a Bluetooth-to-Ethernet gateway that retransmits signals received from the wireless sensor 102 to computing nodes, such as, for example, the multi-patient monitoring system 110, over the network 108. In some embodiments, the extender/repeater 107 is a Bluetooth-to-WiFi bridge that provides access to the network 108 for the wireless sensor 102. Of course, a skilled artisan will recognize that there are numerous ways to implement the extender/repeater 107.

[0123] FIG. 2A illustrates a simplified hardware block diagram of an embodiment of the disclosed wireless sensor 102. As shown in FIG. 2A, the wireless sensor 102 can include a processor 202, a data storage device 204, a wireless transceiver 206, a system bus 208, an accelerometer 210, a gyroscope 212, a battery 214, and an information element 215. The processor 202 can be configured, among other things, to process data, execute instructions to perform one or more functions, such as the methods disclosed herein, and control the operation of the wireless sensor 102. The data storage device 204 can include one or more memory devices that store data, including without limitation, random access memory (RAM) and read-only memory (ROM). The wireless transceiver 206 can be configured to use any of a variety of wireless technologies, such as Wi-Fi (802.11x), Bluetooth, ZigBee, cellular telephony, infrared, RFID, satellite transmission, proprietary protocols, combinations of the same, and the like. The components of the wireless sensor 102 can be coupled together by way of a system bus 208, which may represent one or more buses. The battery 214 provides power for the hardware components of the wireless sensor 102 described herein. As illustrated in FIG. 2A, the battery 214 communicates with other components over system bus 208. One skilled in the art will understand that the battery 214 can communicate with one or more of the hardware functional components depicted in FIG. 2A by one or more separate electrical connections. The information element 215 can be a memory

storage element that stores, in non-volatile memory, information used to help maintain a standard of quality associated with the wireless sensor 102. Illustratively, the information element 215 can store information regarding whether the sensor 102 has been previously activated and whether the sensor 102 has been previously operational for a prolonged period of time, such as, for example, four hours. The information stored in the information element 215 can be used to help detect improper re-use of the wireless sensor 102.

[0124] In some embodiments, the accelerometer 210 is a three-dimensional (3D) accelerometer. The term 3D accelerometer as used herein includes its broad meaning known to a skilled artisan. The accelerometer 210 provides outputs responsive to acceleration of the wireless sensor 102 in three orthogonal axes, sometimes denoted as the "X," "Y," and "Z" axes. An accelerometer 210 may measure acceleration that it experiences relative to Earth's gravity. An accelerometer 210 may provide acceleration information along three axes, and it and may provide acceleration information which is the equivalent of inertial acceleration minus local gravitational acceleration. Accelerometers 210 are well known to those skilled in the art. The accelerometer 210 may be a micro-electromechanical system (MEMS), and it may include piezo-resistors, among other forms of implementation. The accelerometer 210 may be a high-impedance charge output or a low-impedance charge output accelerometer 210. In some embodiments, the accelerometer 210 may be a tri-axis accelerometer, and the output of the accelerometer 210 may include three signals, each of which represents measured acceleration in particular axis. The output of the accelerometer 210 may be 8-bit, 12-bit, or any other appropriate-sized output signal. The outputs of the accelerometer may be in analog or digital form. The accelerometer 210 may be used to determine the position, orientation, and/or motion of the patient to which the wireless sensor 102 is attached.

[0125] In some embodiments, the gyroscope 212 is a three-axis digital gyroscope with angle resolution of two degrees and with a sensor drift adjustment capability of one degree. The term three-axis gyroscope as used herein includes its broad meaning known to a skilled artisan. The gyroscope 212 provides outputs

responsive to sensed angular velocity of the wireless sensor 102 (as affixed to the patient) in three orthogonal axes corresponding to measurements of pitch, yaw, and roll. A skilled artisan will appreciate that numerous other gyroscopes 212 can be used in the wireless sensor 102 without departing from the scope of the disclosure herein. In certain embodiments, the accelerometer 210 and gyroscope 212 can be integrated into a single hardware component which may be referred to as an inertial measurement unit (IMU). In some embodiments, the IMU can also include an embedded processor that handles, among other things, signal sampling, buffering, sensor calibration, and sensor fusion processing of the sensed inertial data. In other embodiments, the processor 202 can perform these functions. And in still other embodiments, the sensed inertial data are minimally processed by the components of the wireless sensor 102 and transmitted to an external system, such as the patient monitor 106, for further processing, thereby minimizing the complexity, power consumption, and cost of the wireless sensor 102, which may be a single-use, disposable product.

[0126] FIG. 2B is a simplified hardware functional block diagram of an embodiment of the disclosed wireless sensor 102 that includes the following optional (as reflected by dotted lines) sensing components: a magnetometer 216 which may also be referred to as a compass, a temperature sensor 218, an acoustic respiration sensor 220, an electrocardiogram (ECG) sensor 222, one or more oximetry sensors 224, a moisture sensor 226, and an impedance sensor 228. In some embodiments, the magnetometer 216 is a three-dimensional magnetometer that provides information indicative of magnetic fields, including the Earth's magnetic field. While depicted in FIG. 2B as separate functional elements, a skilled artisan will understand that the accelerometer 210, gyroscope 212, and magnetometer 214 can be integrated into a single hardware component such as an inertial measurement unit.

[0127] According to an embodiment, a system and method are described herein to calculate three-dimensional position and orientation of an object derived from inputs from three sensors attached to the object: an accelerometer 210 configured to measure linear acceleration along three axes; a gyroscope 212

configured to measure angular velocity around three axes; and a magnetometer 214 configured to measure the strength of a magnetic field (such as the Earth's magnetic field) along three axes. In an embodiment, the three sensors 210, 212, and 214 are attached to the wireless sensor 102 which is affixed to the patient. According to an embodiment, the sensors 210, 212, and 214 are sampled at a rate between approximately 10 Hz and approximately 100 Hz. One skilled in the art will appreciate that the sensors 210, 212, and 214 can be sampled at different rates without deviating from the scope of the present disclosure. The sampled data from the three sensors 210, 212, and 214, which provide nine sensor inputs, are processed to describe the patient's position and orientation in three-dimensional space. In an embodiment, the patient's position and orientation are described in terms of Euler angles as a set of rotations around a set of X-Y-Z axes of the patient.

[0128] Also illustrated in FIG. 2B is a temperature sensor 218 which may be used to measure the patient's body core temperature which is a vital sign used by clinicians to monitor and manage patients' conditions. The temperature sensor 218 can include a thermocouple, a temperature-measuring device having two dissimilar conductors or semiconductors that contact each other at one or more spots. A temperature differential is experienced by the different conductors. The thermocouple produces a voltage when the contact spot differs from a reference temperature. Advantageously, thermocouples are self-powered and therefore do not require an external power source for operation. In an embodiment, the temperature sensor 218 includes a thermistor. A thermistor is a type of resistor whose resistance value varies depending on its temperature. Thermistors typically offer a high degree of precision within a limited temperature range.

[0129] The acoustic respiration sensor 220 can be used to sense vibrational motion from the patient's body (*e.g.*, the patient's chest) that are indicative of various physiologic parameters and/or conditions, including without limitation, heart rate, respiration rate, snoring, coughing, choking, wheezing, and respiratory obstruction (*e.g.*, apneic events). The ECG sensor 222 can be used to measure the patient's cardiac activity. According to an embodiment, the ECG sensor 222 includes two electrodes and a single lead. The oximetry sensor(s) 224 can be

used to monitor the patient's pulse oximetry, a widely accepted noninvasive procedure for measuring the oxygen saturation level of arterial blood, an indicator of a person's oxygen supply. A typical pulse oximetry system utilizes an optical sensor clipped onto a portion of the patient's body (such as, for example, a fingertip, an ear lobe, a nostril, and the like) to measure the relative volume of oxygenated hemoglobin in pulsatile arterial blood flowing within the portion of the body being sensed. Oxygen saturation (SpO2), pulse rate, a plethysmograph waveform, perfusion index (PI), pleth variability index (PVI), methemoglobin (MetHb), carboxyhemoglobin (CoHb), total hemoglobin (tHb), glucose, and/or otherwise can be measured and monitored using the oximetry sensor(s) 224. The moisture sensor 226 can be used to determine a moisture content of the patient's skin which is a relevant clinical factor in assessing the patient's risk of forming a pressure ulcer. The impedance sensor 228 can be used to track fluid levels of the patient. For example, the impedance sensor 228 can monitor and detect edema, heart failure progression, and sepsis in the patient.

[0130] FIG. 3A is a schematic exploded perspective view of an embodiment of the disclosed wireless sensor 102 including a bottom base 310, a removable battery isolator 320, a mounting frame 330, a circuit board 340, a housing 350, and a top base 360. The bottom base 310 is a substrate having a top surface on which various components of the wireless sensor 102 are positioned, and a bottom surface that is used to affix the wireless sensor 102 to the patient's body. The bottom base 310 and top base 360 can be made of medical-grade foam material such as white polyethylene, polyurethane, or reticulated polyurethane foams, to name a few. As illustrated in the embodiment illustrated in Fig. 3A, the bottom base 310 and the top base 360 are each in a substantially oval shape, with a thickness of approximately 1 mm. The top base 360 includes a cut-out 362 through which the housing 350 fits during assembly. Of course, a skilled artisan will understand that there are numerous sizes and shapes suitable for the top and bottom bases 310 and 360 that can be employed without departing from the scope of the present disclosure. The bottom surface of the bottom base 310 is coated with a high tack, medical-grade adhesive, which when applied to the patient's skin, is

suitable for long-term monitoring, such as, for example two days or longer. Portions of the top surface of the bottom base 310 are also coated with a medical-grade adhesive, as the bottom base 310 and the top base 360 are adhered together during assembly of the wireless sensor 102.

[0131] The removable battery isolator 320 is a flexible strip made of an electrically insulating material that serves to block electrical communication between the battery 214 and an electrical contact (not shown) on the circuit board 340. The battery isolator 320 is used to preserve battery power until the wireless sensor 102 is ready for use. The battery isolator 320 blocks electrical connection between the battery 214 and the circuit board 340 until the battery isolator 320 is removed from the wireless sensor 102. The battery isolator 320 can be made of any material that possesses adequate flexibility to be slidably removed from its initial position and adequate dielectric properties so as to electrically isolate the battery from the circuit board 340. For example, the battery isolator can be made of plastic, polymer film, paper, foam, combinations of such materials, or the like. The battery isolator 320 includes a pull tab 322 that extends through a slot 352 of the housing 350 when the wireless sensor 102 is assembled. The pull tab 322 can be textured to provide a frictional surface to aid in gripping and sliding the pull tab 322 out of its original assembled position. Once the battery isolator 320 is removed the battery 214 makes an electrical connection with the battery contact to energize the electronic components of the wireless sensor 102.

[0132] The mounting frame 330 is a structural support element that helps secure the battery 214 to the circuit board 340. The mounting frame 340 has wings 342 that, when assembled are slid between battery contacts 342 and the battery 214. Additionally, the mounting frame 330 serves to provide rigid structure between the circuit board 340 and the bottom base 310. According to some embodiments that include an acoustic respiratory sensor, the rigid structure transmits vibrational motion (vibrations) emanating from the patient (such as, for example, vibrational motions related to respiration, heartbeat, snoring, coughing, choking, wheezing, respiratory obstruction, and the like) to the accelerometer 210 positioned on the circuit board 340.

[0133] The circuit board 340, which may also be referred to herein as a substrate layer 340 and a circuit layer 340, mechanically supports and electrically connects electrical components to perform many of the functions of the wireless sensor 102. The circuit board 340 includes conduction tracks and connection pads. Such electrical components can include without limitation, the processor 202, the storage device 204, the wireless transceiver 206, the accelerometer 210, the gyroscope 212, the magnetomer 214, the temperature sensor 218, the acoustic respiration sensor 220, the ECG sensor 222, the oximetry sensor 224, the moisture sensor 226, and the impedance sensor 228. In an embodiment, the circuit board 340 is double sided having electronic components mounted on a top side and a battery contact (not shown) on a bottom side. Of course a skilled artisan will recognize other possibilities for mounting and interconnecting the electrical and electronic components of the wireless sensor 102.

[0134] As illustrated in FIG. 3A, a battery holder 342 is attached to two sides of the top portion circuit board 340 and extends (forming a support structure) under the bottom side of the circuit board 340 to hold the battery 214 in position relative to the circuit board 340. The battery holder 342 is made of electrically conductive material. In some embodiments, the battery 214 is a coin cell battery having a cathode on the top side and an anode on the bottom side. Electrical connection between the anode of the battery 214 and the circuit board 340 is made by way of the battery holder which is in electrical contact with the anode of the battery 214 and the circuit board 340. The cathode of the battery 214 is positioned to touch a battery contact (not shown) on the bottom side of the circuit board 340. In some embodiments, the battery contact includes a spring arm that applies force on the battery contact to ensure that contact is made between the anode of the battery 214 and the battery contact. During assembly and prior to use, the battery isolator 320 is inserted between the anode of the battery 214 and the battery connector to block electrical contact.

[0135] The housing 350 is a structural component that serves to contain and protect the components of the wireless sensor 102. The housing 350 can be made of any material that is capable of adequately protecting the electronic

components of the wireless sensor 102. Examples of such materials include without limitation thermoplastics and thermosetting polymers. The housing 350 includes a slot 352 through which the battery isolator 320 is inserted during assembly. The housing 350 also includes a rim 354 that extends around the outer surface of the housing 350. The rim 354 is used to secure the housing 350 in position relative to the bottom base 310 and the top base 360 when the wireless sensor 102 is assembled.

[0136] Assembly of the wireless sensor 102 is as follows: The circuit board 340 and battery holder 342 holding the battery 214 are placed into the housing 350. The wings 332 of the mounting frame 330 are inserted in between the battery 214 and the battery holder 342, so as to align the mounting frame 330 with the circuit board 340. The battery isolator 320 is then positioned between the battery contact and the battery 214. The pull tab 322 of the battery isolator 320 is then fed through the slot 352 in the housing 350. The top base 360 is then positioned over the housing 350, which now houses the assembled circuit board 340, battery holder 342, battery 214, mounting frame 330, and battery isolator 320, using the cut-out 362 for alignment. The rim 354 of the housing 350 adheres to the bottom surface of the top base 360, which is coated with high tack, medical-grade adhesive. The partial assembly, which now includes the top base 360, the housing 350, the circuit board 340, the battery holder 342, the battery 214, the mounting frame 330, and the battery isolator 320, is positioned centrally onto the top surface of the bottom base 310, aligning the edges of the base top 360 with the edges of the base bottom 310. In some embodiments, a coupon (or die cutting tool) is used to cut away excess portions of the now combined top and bottom bases 360 and 310 to form a final shape of the wireless sensor 102. The bottom surface of the bottom base 310 is then coated with a high tack, medical-grade adhesive, and a release liner (not shown) is placed on the bottom surface of the bottom base 3310 to protect the adhesive until it is time for use.

[0137] A schematic perspective view of the assembled wireless sensor 102 is illustrated in FIG. 3B. Also illustrated in FIG. 3B is a button/switch 324 located on a top portion of the housing 350. The button/switch 324 can be used to change

modes of the wireless sensor 102. For example, in some embodiments, pressing and holding the button/switch 324 can cause the wireless sensor 102 to switch into a pairing mode of operation. The pairing mode is used to associate the wireless sensor 102 with a patient monitor 106 or with an extender/repeater 107. FIG. 3C provides a schematic side view of an embodiment of the assembled wireless sensor 102 with cross-section line A-A identified.

[0138] Referring now to FIGS. 4A and 4B, an embodiment of the wireless sensor 102 is disclosed which includes a temperature sensor 218. FIG. 4A is a schematic cross-sectional view, sectioned along line A-A of FIG. 3C, illustrating an assembled embodiment of the disclosed wireless sensor 102 which includes the temperature sensor 218. For easier visibility, the battery isolator 320 and the battery holder 342 are not illustrated. FIG. 4B is a schematic bottom view of the embodiment of the disclosed wireless sensor of FIG. 4A. The bottom surface of the bottom base 310 is illustrated. Also illustrated in phantom (*i.e.*, dotted lines) is the outline of cut-out 362 which also indicates the position of the housing 350 in relation to the bottom surface of the bottom base 310.

[0139] As explained above with respect to the assembly of the wireless sensor 102, the top surface of the bottom base 310 is in contact with and adhered to the bottom surface of the top base 360. The rim 354 of the housing 350 is sandwiched between the two bases 310 and 360 to secure the housing 350. The housing 350 also protrudes through the cut-out 362 of the top base 360. Within the housing, the battery 214 and the mounting frame 330 are adjacent the top surface of the bottom base 310.

[0140] As illustrated in FIG. 4A, the temperature sensor 218 is mounted on the circuit board 340. To perform its temperature sensing function, the temperature sensor 218 is in thermal contact with the patient's skin. To achieve this, structure to transmit thermal energy from the patient's body to the temperature sensor 218 is provided. In particular, inputs to the temperature sensor 218 are thermally connected to multiple through-hole vias 410 located in the circuit board 340. A through-hole via is a small vertical opening or pathway in the circuit board 340 through which thermally and/or electrically conductive material can be placed,

thereby permitting transmission of thermal and/or electrical energy from one side of the circuit board 340 to the other side. Under the through-hole vias 410 is an aperture or opening 404 which extends through the mounting frame 330 (to form a mounting frame aperture) and through the bottom base 310 of the wireless sensor 102. The aperture 404 provides access from the temperature sensor 218 to the patient's skin when the wireless sensor 102 is worn by the patient. The aperture 404 and the through-hole vias 410 are filled with thermally conductive material 402. Thermally conductive materials are well known in the art and can include, by way of non-limiting example, thermally conductive elastomers, polymers, and resins, to name a few. Illustratively, in operation, the wireless sensor 102 is affixed to the patient's skin. The thermally conductive material 402, exposed to the patient's skin, transmits thermal energy from the patient's body through the aperture 404 and the through-hole vias 410 to arrive at the inputs to the temperature sensor 218.

[0141] Advantageously, the disclosed wireless sensor 102 can measure the patient's body core temperature (an established and useful vital sign) with the temperature sensor 218 using a technique by which deep tissue temperature can be measured from the skin surface. In the human body, there is a natural heat flux between the body core and the skin surface because the body core temperature is typically at a higher temperature than that of the skin surface. Thus heat flows from the body core to the skin. By insulating the skin surface at and around the point at which the skin temperature is measured -- thereby blocking heat from escaping -- the temperature gradient between the body core and the skin surface will decrease. The skin temperature, under the insulated area will rise until it reaches equilibrium with the warmest region (*i.e.,* the body core) under the insulation, thereby approaching the body core temperature. When equilibrium is reached, the skin temperature is equal to the core body temperature. Advantageously, the bottom base 310 and top base 360 of the wireless sensor 102, which are in contact with the patient's skin around the temperature sensor 218, possess thermal insulation properties. Illustratively, by way of non-limiting example, the bottom base 310 and top base 360 can be made thermally insulating materials including polyurethane foam, polystyrene foam, neoprene foam, neoprene rubber, polyester (Mylar),

polytetrafluoroethylene (PTFE), silicone foam, silicone rubber, or the like. Accordingly, the temperature sensor 218 can measure the patient's body core temperature.

[0142] FIG. 4C is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor of FIGS. 4A and 4B. As shown, the temperature sensor 218 is mounted on the top surface of the circuit board 340. The aperture 404 extends through the mounting frame 330 and the bottom base 310 and is aligned vertically with the through-hole vias 410 (not shown in FIG. 4C) and the temperature sensor 218. The aperture 404 and the through-hole vias 410 are filled with thermally conductive material 402. Thus the disclosed structure provides thermal connectivity between the patient's skin and the temperature sensor 218.

[0143] Referring now to FIGS. 5A and 5B, an embodiment of the wireless sensor 102 is disclosed which includes an acoustic respiration sensor 220. FIG. 5A is a schematic cross-sectional view, sectioned along line A-A of FIG. 3C, illustrating an assembled embodiment of the disclosed wireless sensor 102 which includes the acoustic respiration sensor 220. For easier visibility, the battery isolator 320 and the battery holder 342 are not illustrated. FIG. 5B is a schematic bottom view of the embodiment of the disclosed wireless sensor of FIG. 5A. The bottom surface of the bottom base 310 is illustrated. Also illustrated in phantom (*i.e.*, dotted lines) is the outline of cut-out 362 which indicates the position of the housing 350 in relation to the bottom surface of the bottom base 310.

[0144] As illustrated in FIG. 5A, the acoustic respiration sensor 220 is mounted underneath the battery 214. Operationally, the acoustic respiration sensor 220 detects vibratory motion emanating from the patient's body (*e.g.*, the patient's chest) and mechanically transmits the detected vibratory motion to the accelerometer 210. The accelerometer 210 senses the mechanically transmitted vibratory motion. The signal collected by accelerometer 210 can be processed to extract the vibratory motion from other sensed acceleration signals. Examples of such vibratory motion can include, without limitation, heart beats, respiration activity, coughing, wheezing, snoring, choking, and respiratory obstruction (*e.g.*, apneic events). To mechanically transmit the sensed vibratory motion effectively, the

acoustic respiration sensor 220 is in rigid structural contact with the accelerometer 210. To achieve this, the acoustic respiration sensor 220 is mounted to the bottom side of the battery 214. In particular, the acoustic respiration sensor 220 includes a rim 221 that is sandwiched between the bottom surface of the battery 214 and the bottom base 310. Accordingly, the rim 221 serves to rigidly secure the acoustic respiration sensor 220 to the bottom surface of the battery 214.

[0145] As illustrated in FIG. 5A, the acoustic respiration sensor 220 protrudes through an aperture or opening 502 in the bottom base 310, beyond the plane created by the bottom base 310. This is to ensure that the acoustic respiration sensor 220 is in direct contact with the patient's body (*e.g.*, chest) so as to sense the vibrational motion emanating from the patient. Within the acoustic respiration sensor 220 is a flexible wire or other such structure under slight tension such that when the wire is exposed to vibratory motion, it will vibrate in a manner that is proportional to the sensed vibratory motion with respect to both frequency and magnitude of the sensed vibratory motion. The acoustic respiration sensor 220 is configured to transmit the sensed vibratory motion through rigid structures of the wireless sensor 102 such that the transmitted vibratory motion is sensed by the accelerometer 210. The rigid structure includes the battery 214 and the circuit board 340.

[0146] FIG. 5C is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor of FIGS. 5A-B. As shown, the accelerometer 210 is mounted on the top surface of the circuit board 340 over the battery 214 which is secured underneath the circuit board 340. The acoustic respiration sensor 220 (not shown in FIG. 5C) fits between the battery 214 and the bottom base 310. The aperture 502 extends through the bottom base 310 and is aligned vertically with battery 214 such that the acoustic respiration sensor 220 is secured to rigid structure of the wireless sensor 102. Thus the disclosed structure provides the ability for the acoustic respiration sensor 220 to mechanically transmit vibratory motion from the patient's chest to the accelerometer 210.

[0147] FIGS. 6A-C illustrate an embodiment of the disclosed wireless sensor 102 which includes a temperature sensor 218 and an acoustic respiration sensor 220. FIG. 6A is a schematic cross-sectional view, sectioned along line A-A of

FIG. 3C, illustrating an assembled embodiment of the disclosed wireless sensor 102 which includes the temperature sensor 218 and acoustic respiration sensor 220. For easier visibility, the battery isolator 320 and the battery holder 342 are not illustrated. FIG. 6B is a schematic bottom view of the embodiment of the disclosed wireless sensor of FIG. 6A. FIG. 6C is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor 102 of FIGS. 6A and 6B.

[0148] Structurally, the embodiment depicted in FIGS. 6A-C is a combination of the embodiments depicted in FIGS. 4A-C and 5A-C. As illustrated in FIGS. 6A-B, the temperature sensor 218 is mounted on the circuit board 340. As previously described, inputs to the temperature sensor 218 are thermally coupled to multiple through-hole vias 410 located in the circuit board 340. Under the through-hole vias 410 is an aperture 404 which extends through the mounting frame 330 and through the bottom base 310 of the wireless sensor 102. The aperture 404 provides access from the temperature sensor 218 to the patient's skin when the wireless sensor 102 is worn by the patient. The aperture 404 and the through-hole vias 410 are filled with thermally conductive material 402. In operation, the wireless sensor 102 is affixed to the patient's skin. The thermally conductive material 402, exposed to the patient's skin, transmits thermal energy from the patient's body through the aperture 404 and the through-hole vias 410 to arrive at the inputs to the temperature sensor 218.

[0149] Also as illustrated in FIGS. 6A-B, the acoustic respiration sensor 220 is mounted underneath the battery 214. In particular, the acoustic respiration sensor 220 includes rim 221 that is sandwiched between the bottom surface of the battery 214 and the bottom base 310. Accordingly, the rim 221 serves to rigidly secure the acoustic respiration sensor 220 to the bottom surface of the battery 214. The acoustic respiration sensor 220 protrudes through the aperture 502 in the bottom base 310, beyond the plane created by the bottom base 310. The acoustic respiration sensor 220 is configured to transmit vibratory motion sensed from the patient (*e.g.*, from the patient's chest) through rigid structures of the wireless sensor 102 such that the transmitted vibratory motion is sensed by the accelerometer 210. The rigid structure includes the battery 214 and the circuit board 340.

[0150] FIG. 6C is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor of FIGS. 6A and 6B. As shown, the temperature sensor 218 is mounted on the top surface of the circuit board 340. The aperture 404 extends through the mounting frame 330 and the bottom base 310 and is aligned vertically with the through-hole vias 410 (not shown in FIG. 4C) and the temperature sensor 218. The aperture 404 and the through-hole vias 410 are filled with thermally conductive material 402. Additionally, the accelerometer 210 is mounted on the top surface of the circuit board 340 over the battery 214 which is secured underneath the circuit board 340. The acoustic respiration sensor 220 (not shown in FIG. 6C) fits between the battery 214 and the bottom base 310. In some embodiments, the acoustic respiration sensor 220 abuts against the mounting frame 330 in a manner such that the acoustic respiration sensor 220, the mounting frame 330, the battery 214 and the circuit board 340 form a rigid structure capable of mechanically transmitting vibratory motion sensed by the acoustic respiration sensor 220 to the accelerometer 210 mounted on the circuit board 340. The aperture 502 extends through the bottom base 310 and is aligned vertically with battery 214 such that the acoustic respiration sensor 220 is secured to rigid structure of the wireless sensor 102. Thus the disclosed embodiment provides thermal connectivity between the patient's skin and the temperature sensor 218 and the ability for the acoustic respiration sensor 220 to mechanically transmit vibratory motion from the patient's chest to the accelerometer 210.

[0151] Advantageously, the embodiment disclosed in FIGS. 6A-C is capable of providing, among other things, three vital signs: body core temperature, pulse rate, and respiration rate. Vital signs are measurements of the body's most basic functions and are used routinely by healthcare providers to assess and monitor a patient's status. The patient's body core temperature can be provided by the temperature sensor 218. The patient's pulse rate and respiration rate can be provided by the acoustic respiration sensor 220 in combination with the accelerometer 210.

[0152] Referring to FIGS. 7A-F, an embodiment of the disclosed wireless sensor 102 is shown which includes an electrocardiogram (ECG) sensor 222.

Chip-scale and/or component-scale ECG sensors, suitable for mounting on circuit boards are known in the art. Illustratively, by way of non-limiting example, solid state ECG sensors are offered by Texas Instruments and by Plessy Semiconductors Ltd., to name a few. FIG. 7A is a perspective view of the embodiment of the disclosed patient-worn wireless sensor 102 having an ECG sensor 222 including an ECG lead 706 that extends from the housing 350. The wireless sensor 102 is adhered to the patient's chest, for example, over the manubrium as illustrated in FIG. 7A. The ECG lead 706 extends from the housing 350 of the wireless sensor 102 to a location on the patient's chest suitable to sense electrical signals generated by the patient's heart. The ECG lead 706 is in electrical communication with an ECG electrode 707 which, in operation, is adhered to the patient's chest. In certain embodiments, the ECG electrode 707 includes conducting gel embedded in the middle of a self-adhesive pad. The ECG electrode 707 the senses electrical signals from the patient's chest and transmits the sensed signals, via the lead 706, to the ECG sensor 222. The electrode 707 adheres to the patient's skin and senses electrical signals therefrom. A skilled artisan will appreciate that many structures, forms, and formats of ECG electrodes are well known in the art and can be used to implement the ECG electrode 707.

[0153] As illustrated in FIG. 7A, the ECG lead 706 extends to the left side of the patient's chest to a position across the heart from where the wireless sensor 102 is located. Another ECG electrode 702 (described below), also in contact with the patient's skin, is formed beneath the housing 350 at the bottom base 310. Thus, a vector is formed between the ECG lead electrode 707 and the ECG electrode 702 by which the electrical signals of the patient's heart can be sensed. Illustratively, when the electrodes 702 and 707 are positioned as depicted in FIG. 7A, the ECG sensor 222 can sense ECG signals that are similar in morphology to ECG signals detected on Lead I or Lead II of a standard 12-lead ECG.

[0154] FIG. 7B is a schematic assembled perspective view of the embodiment of the disclosed wireless sensor 102 of FIG. 7A. The ECG lead 706 is connected to the ECG sensor 222 (shown in FIG. 7D) which is mounted on the circuit board 340. As illustrated in FIG. 7B, the ECG lead extends through the

housing 350 to a lockable retractable reel 708 that stores the ECG lead 706 in a coil when not in use. The ECG lead 706 can be extended from the reel 708 and locked in the desired position, thereby enabling placement of the ECG lead electrode 707 at a desired location on the patient's chest. In some embodiments, the locking mechanism is engaged and disengaged by applying a pulling force on the lead 706. Various forms and versions of lockable retractable reels are well known in the art and may be used to implement the reel 708.

[0155] FIG. 7C provides a schematic side view of the embodiment of the assembled wireless sensor 102 of FIGS. 7A and 7B with cross-section line B-B identified. FIG. 7D is a cross-sectional view of the embodiment of FIGS. 7A-C sectioned along line B-B. As illustrated in FIG. 7D, the ECG sensor 222 is mounted on the circuit board 340. To perform its sensing function, the ECG sensor 222 is in electrical contact with at least two points on the patient's skin. Two electrodes 702 and 707 are provided to achieve this purpose. While ECG electrode 707 has been described above, description of the ECG electrode 702 follows herewith.

[0156] ECG electrode 702 is located within the bottom base 310 of the wireless sensor 102. An input to the ECG sensor 222 is electrically connected to multiple through-hole vias 710 located in the circuit board 340. As previously described, through-hole vias are small vertical openings, or pathways, in the circuit board 340 through which electrically conductive material can be placed, thereby permitting transmission of electrical signals from one side of the circuit board 340 to the other side. Under the through-hole vias 710 is an aperture or opening 704 which extends through the mounting frame 330 (to form a mounting frame aperture) and through the bottom base 310 of the wireless sensor 102. The aperture 704 provides access from the ECG sensor 222 to the patient's skin when the wireless sensor 102 is worn by the patient. The aperture 704 and the through-hole vias 710 are filled with electrically conductive material to form the ECG electrode 702. Electrically conductive materials are well known in the art and can include, by way of non-limiting example, electrically conductive silicones, elastomers, polymers, epoxies, and resins, to name a few. In operation, the wireless sensor 102 is affixed to the patient's skin and the ECG electrode 702, exposed to the patient's skin, senses and

transmits electrical signals from the patient's skin surface through the aperture 704 and the through-hole vias 710 to arrive at an input to the ECG sensor 222.

[0157] FIG. 7E is a schematic bottom view of the embodiment of the disclosed wireless sensor of FIGS. 7A-D. The bottom surface of the bottom base 310 is illustrated. Also illustrated in phantom (*i.e.*, dotted lines) are the outline of cut-out 362 which also indicates the position of the housing 350 in relation to the bottom surface of the bottom base 310, and the lockable retractable reel 708. The ECG electrode 702 is also illustrated as it is positioned to make contact with the patient's skin. In some embodiments, the ECG electrode may be coated with a conducting gel to improve the electrode-to-skin interface.

[0158] FIG. 7F is a schematic exploded perspective view of the embodiment of the disclosed wireless sensor of FIGS. 7A-7E. As shown, the ECG sensor 222 is mounted on the top surface of the circuit board 340. The aperture 704 extends through the mounting frame 330 and the bottom base 310 and is aligned vertically with the through-hole vias 710 (not shown in FIG. 7F) and the ECG sensor 222. The aperture 704 and the through-hole vias 710 are filled with electrically conductive material to form electrode 702. Thus the disclosed structure provides electrical connectivity between the patient's skin and the ECG sensor 222.

[0159] FIG. 8A is a schematic exploded perspective view of an embodiment of the disclosed wireless sensor having a temperature sensor 218, an acoustic respiration sensor 220, and an ECG sensor 222. FIG. 8B is a schematic bottom view of the disclosed wireless sensor of FIG. 8A. Structurally, the embodiment depicted in FIGS. 8A-B is a combination of the embodiments depicted in FIGS. 4A-C and 5A-C and 7A-F. As illustrated in FIGS. 8A-B, the temperature sensor 218 is mounted on the circuit board 340. As previously described, inputs to the temperature sensor 218 are thermally coupled to multiple through-hole vias 410 located in the circuit board 340. Under the through-hole vias 410 is an aperture 404 which extends through the mounting frame 330 and through the bottom base 310 of the wireless sensor 102. The aperture 404 provides access from the temperature sensor 218 to the patient's skin when the wireless sensor 102 is worn by the patient.

The aperture 404 and the through-hole vias 410 are filled with thermally conductive material 402.

[0160] The acoustic respiration sensor 220 is mounted underneath the battery 214, held in place by rim 221 that is sandwiched between the bottom surface of the battery 214 and the bottom base 310. Accordingly, the rim 221 serves to rigidly secure the acoustic respiration sensor 220 to the bottom surface of the battery 214. The acoustic respiration sensor 220 protrudes through the aperture 502 in the bottom base 310, beyond the plane created by the bottom base 310. The acoustic respiration sensor 220 transmits vibratory motion sensed from the patient (*e.g.,* from the patient's chest) through rigid structures of the wireless sensor 102 such that the transmitted vibratory motion is sensed by the accelerometer 210. The rigid structure through which the vibratory motion is transmitted includes the battery 214 and the circuit board 340.

[0161] The ECG electrode 702 is located within the bottom base 310 of the wireless sensor 102. An input to the ECG sensor 222 is electrically coupled to multiple through-hole vias 710 located in the circuit board 340. Under the through-hole vias 710 is an aperture or opening 704 which extends through the mounting frame 330 and through the bottom base 310 of the wireless sensor 102. The aperture 704 provides access from the ECG sensor 222 to the patient's skin when the wireless sensor 102 is worn by the patient. The aperture 704 and the through-hole vias 710 are filled with electrically conductive material to form the ECG electrode 702.

[0162] In operation, the wireless sensor 102 is affixed to the patient's skin. The thermally conductive material 402, exposed to the patient's skin, transmits thermal energy from the patient's body through the aperture 404 and the through-hole vias 410 to arrive at the inputs to the temperature sensor 218. The acoustic respiratory sensor 220 senses vibratory motion from the patient and mechanically transmits the vibratory motion to the accelerometer 210 mounted on the circuit board. And the ECG electrodes 702 and 707, exposed to the patient's skin, sense and transmit electrical signals from the patient's skin surface to arrive at inputs to the ECG sensor 222.

[0163] FIG. 8B is a schematic bottom view of the embodiment of the disclosed wireless sensor of FIGS. 8A. The bottom surface of the bottom base 310 is illustrated. Also illustrated in phantom (*i.e.*, dotted lines) are the outline of cut-out 362 and the lockable retractable reel 708. Three sensor access points are shown in FIG 8B. The thermally conductive material 402 provides a pathway for thermal energy to be transmitted from the patient's skin the temperature sensor 218 mounted on the circuit board 340. The acoustic respiration sensor 220 is in direct contact with the patient's skin and in rigid structural contact with the accelerometer 210 so as to mechanically transmit sensed vibratory motion emanating from the patient to the accelerometer 210 mounted on the circuit board 340. And the ECG electrode 702 provides a pathway for electrical signals to be transmitted from the patient's skin to the ECG sensor 220 mounted on the circuit board 340.

[0164] In some scenarios, it may be desirable to pair, or associate, the wireless sensor 102 with the bedside patient monitor 106 to avoid interference from other wireless devices and/or to associate patient-specific information (stored, for example, on the patient monitor 106) with the sensor data that is being collected and transmitted by the wireless sensor 102. Illustratively, such patient-specific information can include, by way of non-limiting example, the patient's name, age, gender, weight, identification number (*e.g.*, social security number, insurance number, hospital identification number, or the like), admission date, length of stay, physician's name and contact information, diagnoses, type of treatment, perfusion rate, hydration, nutrition, pressure ulcer formation risk assessments, patient turn protocol instructions, treatment plans, lab results, health score assessments, and the like. One skilled in the art will appreciate that numerous types of patient-specific information can be associated with the described patient-worn sensor without departing from the scope of the present disclosure. Additionally, pairing the wireless sensor 102 with the patient monitor 106 can be performed to provide data security and to protect patient confidentiality. Some wireless systems require the care provider to program the wireless sensor 102 to communicate with the correct patient monitor 106. Other wireless systems require a separate token or encryption key and several steps to pair the wireless device 102 with the correct bedside patient

monitors 106. Some systems require the token to be connected to the bedside patient monitor 106, then connected to the wireless device 102, and then reconnected to the bedside patient monitor 106. In certain scenarios, it may be desirable to share wireless communication information between a wireless sensor 102 and a bedside patient monitor 106 without a separate token or encryption key. For security purposes, it may be desirable to use security tokens to ensure that the correct bedside patient monitor 106 receives the correct wirelessly transmitted data. Security tokens prevent the bedside patient monitor 106 from accessing the transmitted data unless the wireless sensor 102 and bedside patient monitor 106 share the same password. The password may be a word, passphrase, or an array of randomly chosen bytes.

[0165] FIG. 9 illustrates an exemplary method of associating a wireless sensor 102 with a patient monitor 106, which may be referred to as "pairing." At block 902 the wireless sensor 102 is set to operate in a pairing mode. In an embodiment, a user initiates the pairing mode of operation for the wireless sensor 102. This may include powering on the wireless sensor 102, switching the wireless sensor 102 to a special paring state, and/or the like. For example, in certain embodiments, the wireless sensor 102 may include a battery isolator 320 which, when removed, activates the wireless sensor 102. Upon activation, the default mode of operation is the pairing mode. In some embodiments, the wireless sensor 102 may have a button/switch 324 that can be used to activate the wireless sensor 102 and place it in the pairing mode of operation. For example, a depressible button/switch 324 can be located on the top portion of the housing 350. When the button/switch 324 is depressed and continuously held down, the wireless sensor 102 enters into the pairing mode of operation and remains in the pairing mode of operation for as long as the button/switch 324 is depressed.

[0166] As reflected at block 904, the wireless sensor 102 transmits a pairing signal indicating that it is ready to pair, or associate, with a patient monitor 106. According to some embodiments, the wireless transceiver 206 of the wireless sensor 102 is configured to emit a low-power pairing signal having a limited pairing signal transmission range. The limited pairing signal transmission range helps to

prevent unintended or incidental association of the wireless sensor 102 with a patient monitor 106 that might be nearby but which is not intended to be paired with the wireless sensor 102. Such circumstances can occur in hospitals, healthcare facilities, nursing homes, and the like where patients, sensors 102 patient monitors 106 are located in close physical proximity to one another. In certain embodiments, the low-power pairing signal has a pairing signal transmission range of up to approximately three inches. In other embodiments, the low-power pairing signal has a pairing signal transmission range of up to approximately six inches. In other embodiments, the low-power pairing signal has a pairing signal transmission range of up to approximately one foot (*i.e.*, twelve inches). A skilled artisan will recognize that other ranges can be used for the pairing signal transmission range.

[0167] Next, at block 906, the patient monitor 106, when within the pairing signal transmission range, receives the pairing signal from the wireless sensor 102. Upon detection of the pairing signal, the patient monitor 106, at block 908, associates with the wireless sensor 102 thereby configuring the wireless sensor 102 and patient monitor 106 to communicate with each other. Once the pairing is completed, the patient monitor 106 transmits a confirmation signal confirming that the patient-worn sensor 102 is associated with the patient monitor 106, thereby indicating that the paring process has been successfully completed, as reflected in block 910. At block 912, the wireless sensor 102 receives the confirmation signal. And at block 914, the wireless sensor 102 exits the pairing mode of operation and enters into a patient parameter sensing mode of operation. In the patient parameter sensing mode of operation, the patient-worn sensor 102 transmits a patient parameter sensing signal having a patient parameter sensing signal transmission range. The wireless sensor 102 increases the power of the patient parameter sensing signal transmission range to a standard operating range, such as for example, approximately three meters. In some embodiments, the patient parameter sensing signal transmission range is approximately ten feet. In some embodiments, the patient parameter sensing signal transmission range is approximately thirty feet. In certain embodiments, the paring signal transmission range is between approximately three and twelve inches, while the patient parameter sensing signal

transmission range is approximately ten feet. In such embodiments, there is at least an order of magnitude difference between the pairing signal transmission range and the patient parameter sensing signal transmission range. Thus, the pairing signal transmission range is substantially less than the patient parameter sensing transmission range. Once the wireless sensor 102 enters into the patient parameter sensing mode of operation, the wireless sensor 102 is then in condition to be placed on the patient to perform sensing and monitoring functions.

[0168] In certain embodiments, an extender/repeater 107 is used to communicate with the wireless sensor 102 instead of than a patient monitor 106. Pairing with the booster/repeater may be performed in the same manner described above with respect to FIG. 9.

[0169] According to certain embodiments, the disclosed patient monitoring system 100 helps to manage a patient that is at risk of forming one or more pressure ulcers by, among other things, detecting changes in the patient's orientation and by determining how long the patient remains in the present orientation. Advantageously, the system 100 can detect when the patient is repositioned and begin timing the duration that the patient remains in that new orientation. Thus, if the patient repositions on his own without the observation of a care provider, the monitoring system 100 can detect the repositioning event and restart a timer.

[0170] The patient monitoring system 100 can aid in the administration of a clinician-established turning protocol for the patient. For example, if the patient remains in an orientation beyond a predefined, clinician-prescribed duration, the system 100 can notify the patient and/or caretakers that the patient is due to be repositioned. The wireless sensor 102 obtains sensor information indicative of the patient's orientation (*e.g.*, acceleration data), pre-processes the sensed data, and transmits it to a processing device capable of processing the measurement data, such as, for example, the patient monitor 106. Other devices capable of processing the measurement data include, without limitation, clinician devices 114, nurses' station systems 113, the multi-patient monitoring system 110, a dedicated processing node, or the like. For ease of illustration, the description herein will

describe the processing device as the patient monitor 106; however, a skilled artisan will appreciate that a large number of processing devices may be used to perform the described functions without departing from the scope of the present disclosure.

[0171] The patient monitor 106 stores and further processes the received data to determine the patient's orientation. According to some embodiments, the patient monitor 106 can determine whether the patient is standing, sitting, or lying in the prone, supine, left side, or right side positions. The patient monitor 106 can store the determined orientation information and keep track of how long the patient remains in each determined orientation, thereby creating a continuous record of the patient's positional history. In certain embodiments, the information received from the wireless sensor 102 can be used to create a time-sequenced representation of the patient's positional history. This representation can be displayed on the patient monitor 106 or transmitted to a nurses' station or other processing node to enable caregivers to monitor the patient's position in bed. The time-sequenced representation can be viewed in real time and/or be accessed for playback. For example, if an alarm alerts the caregiver that the patient has exceeded the maximum amount of time to remain in the present orientation, the caregiver can access and review the historical sequence of the patient's orientations prior to and during that period of time to determine the next orientation to which the patient may be repositioned. In some embodiments, the system 100 suggests the orientation to which the patient may be repositioned.

[0172] Illustratively, the patient monitor 106 counts the number of in-bed turns performed by the patient and displays the amount of time that has elapsed since the patient last turned. When the elapsed time exceeds a clinician-defined duration (*e.g.*, two hours), the patient monitor 106 displays an indication that the maximum time between patient turns has been exceeded. The patient monitor 106 can also transmit a notification to clinicians responsible for caring for the patient via, for example, the multi-patient monitoring system 110, a clinician notification device 114, or the like. The patient monitor 106 can also determine and display statistical information, such as the average, minimum, and maximum amount of time between turns for a given clinician-defined time period, such as for example, twenty-four

hours. The patient monitor 106 can also determine and display the number of patient turns in the same orientation over a clinician-defined period of time. Similarly, the patient monitor 106 can display the total amount of time the patient has remained in each specific orientation within a clinician-defined period. Moreover, the patient monitor 106 can determine the frequency and duration of periods that the patient remained in clinically-defined acceptable orientations.

[0173] In some embodiments of the present disclosure, the patient monitor 106 accesses the patient's health records and clinician input via the network 108. Illustratively, the patients' positional history data, analyzed in view of the patient's health records, may reveal or suggest a turning protocol (or other treatment protocol) that will likely yield favorable clinical outcomes for the particular patient. Accordingly, the patient monitor 106 analyzes the accessed information in conjunction with the received information from the wireless sensor 102 to determine a recommended patient turn protocol (or other treatment protocol) for the patient.

[0174] According to some embodiments of the present disclosure, the patient monitor 106 assesses caregiver and facility compliance with the clinician-defined turning protocol established for the patient. For example, the patient monitor 106 can identify the number of times that the patient remains in a position for a period greater than the prescribed duration, as well as the length of each such overexposure. The patient monitor 106 can also track the time between issuance of a notification, alert, or alarm and action taken in response to the event that triggered the issuance, corresponding to clinician response time.

[0175] FIG. 10 illustrates a method 1000 of estimating and monitoring the orientation of a patient in bed according to an embodiment of the present disclosure. The method 1000 also identifies when the patient changes orientation and keeps track of the amount of time the patient spends in in that orientation. The patient orientations that may be determined include, without limitation, whether the patient is prone, supine, on the left side, on the right side, sitting, and lying. In some embodiments, the patient monitor 106 determines the precise orientation of the patient's body. For example, the patient monitor 106 can determine the degree to which the patient's body is inclined, vertically and/or horizontally, thereby generating

an accurate description of the patient's orientation relative to the support structure (such as a bed) upon which the patient lies.

[0176] According to an embodiment of the present disclosure, measurements from the accelerometer 210 of the wireless sensor 102 are used to determine the patient's orientation. The accelerometer 210 measures linear acceleration of the patient with respect to gravity. In some embodiments the accelerometer 210 measures linear acceleration in three axes. One axis, referred to as "roll," corresponds to the longitudinal axis of the patient's body. Accordingly, the roll reference measurement is used to determine whether the patient is in the prone position (*i.e.*, face down), the supine position (*i.e.*, face up), or on a side. Another reference axis of the accelerometer 210 is referred to as "pitch." The pitch axis corresponds to the locations about the patient's hip. Thus, the pitch measurement is used to determine whether the patient is sitting up or lying down. A third reference axis of the accelerometer 210 is referred to as "yaw." The yaw axis corresponds to the horizontal plane in which the patient is located. When in bed, the patient is supported by a surface structure that generally fixes the patient's orientation with respect to the yaw axis. Thus, in certain embodiments of the disclosed method 1000, the yaw measurement is not used to determine the patient's orientation when in bed.

[0177] Illustratively, the described method 1000 continuously or periodically (*e.g.*, every second) determines the patient's orientation based on the measurements of pitch and roll provided by the accelerometer 210. The measurements are tracked over time, and the current measurement is compared to one or more measurements in the recent past (*e.g.*, the previous few seconds) to determine whether an orientation change event has occurred.

[0178] The method 1000 is described in further detail herein with respect to FIG. 10. The method 1000 begins at block 1002 in which acceleration measurement data are received from the wireless sensor 102 by a device capable of processing the measurement data, such as, for example, the patient monitor 106. Other devices capable of processing the measurement data include, without limitation, clinician devices 114, nurses' station systems 113, the multi-patient

monitoring system 110, a processing node, or the like. For ease of illustration, the description herein will describe the processing device as the patient monitor 106; however, a skilled artisan will appreciate that a large number of devices may be used to perform the described method 1000 without departing from the scope of the present disclosure.

[0179] The acceleration measurement data may be provided directly from the wireless sensor 102 to the patient monitor 106, or the measurement data may be relayed over a network such as network 108, by an extender/repeater 107, for example. The acceleration measurement data may be initially sampled at a sampling rate suitable to provide an acceptable degree of precision, such as for example, 100 Hz. In some embodiments, the measured data are sub-sampled by the wireless sensor 102 before being transmitted in order to reduce power consumption of the battery 214 of the wireless sensor 102. In an embodiment, the acceleration measurement data are initially sampled at 100 Hz and subsequently down-sampled, for transmission purposes, to a rate of 26 Hz. In an embodiment, the acceleration measurement data are initially sampled at a range between approximately 10Hz and approximately 200 Hz and subsequently down-sampled, for transmission purposes, at a rate between approximately 5Hz and approximately 40Hz. A skilled artisan will understand that many other sampling rates and sub-sampling rates may be used.

[0180] At block 1004, the patent monitor 106 determines the present orientation of the patient. The received acceleration measurement data are processed to determine orientation values for the roll and pitch axes. The processed acceleration measurement data are provided in units of degrees, ranging from -180 degrees to +180 degrees. A lookup table, based on empirical data, provides a correlation between pairs of roll and pitch measurements and patient orientations. Illustratively, by way of non-limiting example, a roll measurement of 180 degrees can mean that the patient is on his back, and a pitch measurement of 0 degrees can mean that the patient is lying down. Thus the combination of a roll measurement of 180 degrees and a pitch measurement of 0 degrees can correspond to an orientation in which the patient is lying down on his back. Similarly, a combination of

a roll measurement of 180 degrees and a pitch measurement of 90 degrees can correspond to an orientation in which the patient is lying on his right side.

[0181] FIG. 11A illustrates an exemplary plot 1100 of processed accelerometer 210 data over time (from 0 to 450 seconds) used to determine a patient's orientation according to an embodiment of the present disclosure. Initially, at for example, 50 seconds, the data corresponding to the roll (*i.e.*, body length) axis 1102 is at approximately 180 degrees, indicating that the patient is on his back (*i.e.*, in the supine orientation). The data corresponding to the pitch (*i.e.*, hip rotation) axis 1104 is at approximately 0 degrees, indicating that the patient is reclining. Thus, combining the orientation information provided by the accelerometer 210 with respect to the roll and pitch axes 1102 and 1104, the patient is determined to be lying on his back. At approximately 360 seconds on the plot, denoted by vertical line 1106, we see that the patient changes orientation. During a short transition period, the data oscillates, as illustrated in the data representing the pitch axis at transition point 1108 and in the data representing the roll axis at transition point 1110. The oscillations can be caused by, among other things, jostling of the patient while moving from one position to the next. Shortly thereafter, the data achieves a steady state, as reflected by relatively stable graphs 112 and 114. Notably, the data indicative of the pitch axis 1102 has moved from approximately 180 degrees to approximately 90 degrees. This corresponds to a ninety-degree rotation of the patient's longitudinal body axis to the patient's right side. The data indicative of the roll axis remains at approximately zero degrees, indicating that the patient remains in the reclining position. Thus, combining the orientation information provided by the accelerometer 210 with respect to the roll and pitch axes 1112 and 1114, the patient is determined to be lying on his right side. In this manner, a lookup table of patient orientation change actions can be created. The table identifies profiles (*e.g.*, combinations of pitch and roll axis measurements, within certain tolerances) of various possible orientations that a patient can assume while in bed. The table of profiles of patient orientation change actions can be based on empirical data that is collected and analyzed.

[0182] Referring back to FIG. 10, at block 1006, previous patient orientation determinations are extracted and combined with the current orientation determinations to form a time window of patient orientation information. For example, the time window can include information indicative of the patient's orientation from one or more time periods that are in close temporal proximity to the present information indicative of the patient's orientation, such as for example, the previous few seconds. Of course, any number of previous patient orientations can be selected for the time window. In an embodiment, the patient's orientation determinations for the previous two seconds are combined with the present determination to create a three-second time window of the patient's orientation. The purpose for creating the time window is to determine whether the patient has recently repositioned.

[0183] At block 1008, the time window is divided into segments for purposes of analysis. Any number of segments can be used for such analysis of the time window data. In an embodiment, the time window is segmented into three segments. In another embodiment, the time window is segmented into two segments. As illustrated in FIG. 11A at transition points 1108 and 1110, it is possible that the measured data used for the time window contains multiple sources of noise, some of which can have spikes of notable magnitude. To reduce the impact of the noise in the analysis, a segment value for each segment is determined. As disclosed at block 1010, the median value of the sampled data within each segment is used to determine the segment values for each segment. By taking the median value of each segment, a segment value is determined with minimal impact of potential noisy spikes. In certain embodiments, the segment value is a vector comprising values corresponding to each axis of measured data. Illustratively, by way of non-limiting example, each segment value comprises a vector including a roll axis segment component and a pitch axis segment component. According to some embodiments, the units of the determined segment values and/or segment components are in units of degrees ranging from -180 degrees to +180 degrees.

[0184] At block 1012 the median values of each segment are pairwise compared. Illustratively, by way of non-limiting example, a time window that is

segmented into three sections would have three pairwise comparisons: the first segment value compared to the second segment value, the first segment value compared to the third segment value, and the second segment value compared to the third segment value.

[0185] At block 1014, each pairwise comparison is analyzed to determine whether an orientation change event occurred. The determination is made by comparing the magnitude of the difference of each pairwise comparison with a predetermined threshold value. If the magnitude of the difference of a pairwise comparison exceeds the threshold, then an orientation change event is considered to have occurred. If the magnitude of the difference of a pairwise comparison does not exceed the threshold, then no change in orientation is considered to have occurred. Thus, a change that exceeds a certain threshold in the roll dimension corresponds to an orientation change event that includes a rotation about the longitudinal axis of the patient's body. Similarly, a change that exceeds a certain threshold in the pitch dimension corresponds to an orientation change event that includes a transition from sitting up to lying down, or vice versa. A change that exceeds a certain threshold in both the roll and pitch dimensions corresponds to and orientation change event that includes a rotation about the longitudinal axis of the patient's body and a transition from sitting up to lying down, or vice versa. According to an embodiment, the threshold is 45 degrees and thus, if the magnitude of difference between any two segment values is greater than 45 degrees, then an orientation change event is determined to have occurred. In another embodiment, an additional comparison is made between consecutive one-second segments of data to determine whether a change of at least 30 degrees has occurred. This is to prevent repeated posture changes, when for instance, the patient is in a posture near 135 degrees, that is, right in the middle between two postures.

[0186] If an orientation change event is determined to have occurred, then at block 1016, the detected event is classified. Reference is made to a look-up table of events which includes a set of profiles of orientation change actions or activities. In an embodiment, each profile includes four data points: a "before" and an "after" measurement for the roll axis, and a "before" and an "after" measurement for the

pitch axis. For example, as illustrated in FIG. 11A, the profile of the orientation event activity of turning from lying on the back to lying on the right side can be as follows:

Roll Before	Roll After	Pitch Before	Pitch After
180 degrees	90 degrees	0 degrees	0 degrees

Table 1

[0187] As illustrated in Table 1, the roll axis changes from 180 degrees to 90 degrees indicating that the patient rotated from lying on his back to lying on his right side. The pitch axis does not change because the patient remains in a reclining orientation. The table of events is developed and updated off-line and is based on the analysis of empirical data of known orientation change events. Accordingly, classification of orientation change events can be performed by identifying in the look-up table of events the orientation event profile that matches the data of the pairwise comparison when the magnitude of the difference of the pairwise comparison exceeds the predetermined threshold.

[0188] At block 1018, a vote is placed for the classified event. Illustratively, for the example described with respect to Table 1, the vote would be for the orientation change event profile of turning from lying on the back to lying on the right side. At block 1020, the method 1000 repeats the acts of determining whether an orientation change event occurred, classifying the orientation change event (if an event occurred), and voting for the classified orientation change event (again, if an event occurred), for each pairwise comparison. The maximum number of iterations for these blocks will be equal to the number of segments in the time window.

[0189] Once all of the pairwise comparisons have been analyzed, at block 1022, the method 1000 tallies the votes recorded at block 1018. The orientation change event that has the most votes is determined to be the orientation change event that occurred. The determined orientation change event is then reported as the orientation of the patient. At block 1024, an orientation duration timer is reset to keep track of the time the patient remains in the new orientation. The method 1000

then returns to block 1002 to begin the analysis again with respect to the next incremental (*e.g.*, second) of measurement data.

[0190] If at block 1014, none of the pairwise comparisons result in a detected orientation change event (*i.e.*, the patient has remained in the same orientation throughout the entire time window) then the method 1000 progresses to block 1026 to determine whether the patient has remained in the present orientation for a period of time greater than a predefined maximum duration, which may also be referred to herein as a predetermined duration or a predetermined maximum duration. If not, the method 1000 returns to block 1002 to begin the analysis again with respect to the next incremental set (*e.g.*, second) of measurement data. If the patient has remained in the present orientation for a period of time greater than the predefined maximum duration, then at block 1028, an alert is sent to, for example, the patient's caregiver, to notify the caregiver that the patient should be repositioned. The method 1000 then returns to block 1002 to begin the analysis again with respect to the next incremental (*e.g.*, second) of measurement data.

[0191] FIG. 11B is an exemplary plot of an embodiment of a patient position monitoring paradigm for determining when a patient's orientation needs to be changed, according to an embodiment of the present disclosure. In an embodiment, the plot 1102B may be part of a display to a caregiver on a bedside monitor, a multi-room monitor, both, or the like. The plot can be updated in real time, at predefined intervals, and/or manually. In other embodiments, the paradigm may be illustrative of the signal processing performed by a signal processor to determine when to activate an alarm informing a caregiver of the potential of a pressure ulcer if a patient is not repositioned. In these embodiments, each portion of the paradigm may be customized to a particular patient, patient demographics, hospital protocol, unit protocol such as, for example, a protocol specific to a surgical ICU or other hospital unit, home care, or the like.

[0192] In the illustrated embodiment, a patient's position is monitored over time. A vertical axis 1105B represents time and a horizontal axis 1107B represents a patient movement event, such as, for example, In the illustrated embodiment, an alarm is set to alert a caregiver when a patient has been in a certain position for 3

hours or more. The illustrated embodiment is a non-limiting example, as the alarm can be set to alert the caregiver at 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, 7 hours, 8 hours, 9 hours, and/or 10 or more hours. The alarm can include a noise, color, and/or other indicator that will alert the caregiver. In some embodiments, the alarm can indicate to the caregiver that the patient has remained in the same position for a threshold amount of time (e.g., 3 hours). The threshold amount of time can be predefined or adjusted over time. In some embodiments, the alarm indicates to the caregiver that the patient has fallen, moved into an incorrect position, left the bed and/or the like. In an embodiment, empirical data about a particular patient, or a group of like patients, can be used to customized some or all of the parameters for the alarm discussed herein.

[0193] As shown in Figure 11B, the monitor begins monitoring a patient as the patient is in Position 1 (e.g., the patient is lying on their back, side, front, sitting slightly up, sitting mostly up, or the like). As the patient remains in Position 1, a timing mechanism starts and a line 1101B as its growth line. The slope of the line 1101B depicts a growth rate as the patient remains in the same position. As shown in the illustrated embodiment, the growth rate can be depicted linearly. In some embodiments, the grown rate can be linear, non-linear, exponential, and/or the like. In some embodiments, the growth rate is predefined. In some embodiments, the growth rate can change in real time and/or adjust to various physiological parameters and/or empirical data, as described below. The growth rate can depend on a number of factors and empirical data already known and/or determined by the system, depending on for example, how the patient's skin reacts to remaining in a single position, how fast negative effects experienced by the patient (e.g., pressure sores) form or heal, the particular position the patient is lying in, and/or demographic information about the patient, including the patient's age, health, blood perfusion rates, hydration, and/or nutrition, among others. Accordingly, in some embodiments, the growth rate can indicate a growth rate of the effects (e.g. bed sores) as the patient remains in the same position (e.g., Position 1) over a period of time.

[0194] As illustrated in Figure 11B, the patient remains in Position 1 for approximately 2 hours. At that time, the patient turns and/or is turned by a caregiver to Position 2. In the illustrated embodiment, Position 2 is a different position from Position 1. When the patient turns and/or is turned, the timing mechanism can restart a new line 1102B and begin to measure, track, monitor, and/or calculate the amount of time the patient remains in Position 2.

[0195] A the same time, line 1101B transforms into its decay line. The decay line of line 1101B can comprise data relating to a decay rate of a bed sore, potential bed sore, particular area of a patient's skin, and/or the amount of time the patient or a group of like patients, or all patients, takes to recover from remaining in a particular position (e.g., Position 1), among other things. Similar to the growth rate, the decay rate can be linear, non-linear, and/or exponential, among others. In some embodiments, the decay rate is predefined. In some embodiments, the decay rate can change in real time and/or adjust to various physiological parameters and/or empirical data, as described below. The decay rate may depend on a number of factors and empirical data, depending on for example, how the patient's skin reacts to remaining in a single position, how fast negative effects experienced by the patient (e.g., pressure sores) heal, how quickly the patient recovers, the particular position the patient is lying in, and/or demographic information about the patient, including the patient's age, health, blood perfusion rates, hydration, and/or nutrition, among others. As shown in the illustrated embodiment, when the patient is in one or more positions that are not Position 1, the decay line of Position 1 continues to decay at the decay rate. That is, in an embodiment, the decay line of Position 1 will continue to decay at its decay rate through one or multiple other positions until it approaches zero so long as that other one or multiple positions do not include Position 1. In this example, the decay rate, or recovery rate for example, approaches zero more quickly the longer the patient remains not in Position 1.

[0196] In the illustrated embodiment, the patient turns and/or is turned again at Turn 2. Turn 2 occurs at a time before the threshold amount of time is reached, and therefore, before the alarm alerts the caregiver to turn the patient. At Turn 2, the patient turns/is turned to Position 3. In some examples, Position 3 is the same

as Position 1. In such embodiments, because the decay line of line 1101B associated with the previous Position 1 has reached zero, a line 1104B starts at zero as its growth line for Position 3/1. However in some examples, Position 3 is a different position from Position 1. In the illustrated example, Position 3 is different from Position 1 and its growth rate for line 1104B is different from that of Position 1. In some examples, the decay line of Position 1 can continue to decay as the decay line of Position 2 continues to decay when the patient turns and/or is turned to Position 3 as long as Position 3 is different from Positions 1 and 2. In this example, the patient can continue to heal as a result of the effects of remaining in both Positions 1 and 2. In some examples, Position 1 continues to decay as the patient turned and/or is turned to multiple positions, such as a second, third, fourth, and/or fifth or more positions.

[0197] As shown in the illustrated embodiment, the patient remains in Position 3 for a relatively short period of time. During that time, any effects of remaining in Position 2 begin to decay. Thereafter, however the patient turns and/or is turned back to Position 2. Advantageously, rather than restarting at time zero, the system can determine that the patient has turned back to Position 2 and the timing mechanism begins timing from the current value of the decay line of Line 1102B, which corresponds to point or time 1103B. Time 1103B is greater than zero in this example, but less than the threshold amount of time. Additionally, in this example, the time 1103B is less than the amount of time the patient originally remained in Position 2. In some embodiments time 1103B can be equal to the time the patient turned from Position 2. However, in the illustrated embodiment, the system can take into account the decay rate and the time the patient has spent recovering from remaining in Position 2. Thus, in the illustrated embodiment, Time 1103B can be determined by the system through a number of methods. For example, the system can subtract the recovery time from the growth time, and/or count down from the time of the turn (e.g., Turn 2), among other methods. Advantageously, the preferred embodiment of the system can ensure the patient does not exceed the threshold total time, taking into account the growth and decay rate, a patient spends in a particular location. Although in an embodiment, the system restarts the timer at

each turn, without accounting for the previous time the patient spent at a particular position, such embodiments may not be as precise in allowing adequately recovery of tissue, blood pooling, or the like caused by the previous position, and therefore, a patient may be more likely to experience negative effects (e.g., bed sores). Accordingly, the preferred embodiment of the system can more precisely reduce a likelihood of a patient developing harmful effects, such as bed sores by ensuring a patient would not remain in a particular position for too long. Once the total time spent in a position, taking into account the patient's growth and decay rates, reaches the threshold time (e.g. 3 hours in this example), an alarm can alert the caregiver.

[0198] In some embodiments, the alarm will alert the caregiver until the patient turns and/or is turned again, for example as illustrated by Turn 4 in Fig. 11B. In some embodiments, the growth line will continue to grow, thus requiring longer for the line to decay, when a patient has not been turned within the threshold time. Such continued growth ensures that a patient will not be too soon returned to a position where the patient spent too much time and can help ensure that the corresponding tissue has sufficient time to recover from a particular patient position. In an embodiment, the decay rate of the line is adjusted to account for exceed the threshold limit. As shown in the illustrated embodiment, the decay rate is reduced after exceed a threshold, meaning it will take longer for the line corresponding to the alarmed position to reach zero.

[0199] As discussed, in an embodiment, when the patient turns and/or is turned after the time of the alarm, the growth line will exceed the threshold time, as indicated by the plot of Fig. 11B. Once the patient turns and/or is turned, the decay line can be shown above the threshold (e.g. alarm) line. In some examples, the patient may take longer to recover when the time spent in a particular position exceeds the threshold time. In some examples, the alarm can alert the caregiver that the decay line has reached the threshold time as the line continues to decay towards zero and the patient remains in a different position. In some embodiments, the alarm does not alert the caregiver that the decay line has passed the threshold time.

[0200] According to certain embodiments of the present disclosure, the patient monitor 106 determines the mobility status of the patient, *e.g.*, whether the patient is ambulatory, standing, sitting, reclining, or falling. The wireless monitoring system 100 can include an alert system to alert the caregiver that the patient is falling, getting out of bed, or otherwise moving in a prohibited manner or in a manner that requires caregiver attention. The alert can be an audible and/or visual alarm on the monitoring system or transmitted to a caregiver (*e.g.*, nurses' station system 113, clinician device 114, pager, cell phone, computer, or otherwise). Illustratively, the patient monitor 106 can display the patient's mobility status and transmit a notification that the patient is active and away from the bed. In some circumstances, the patient monitor 106 can determine whether the patient contravenes a clinician's order, such as, for example, instructions to remain in bed, or to walk to the bathroom only with the assistance of an attendant. In such circumstances, a notification, alert, or alarm can be transmitted to the appropriate caregivers.

[0201] In certain aspects, the information received from the wireless sensor 102 can be used to create a time-sequenced representation of the patient's movement. This representation can be displayed on the patient monitor or transmitted to a nurses' station or other processing node to enable the caregiver to monitor the patient. The time-sequenced representation can be viewed in real time and/or be recorded for playback. For example, if an alarm alerts the caregiver that the patient has fallen, the caregiver can access and review the historical sequence of the patient's movements prior to and during that period of time.

[0202] In some embodiments, the patient monitoring system 100 can predict a patient's risk of falling based on analysis of the patient's movement (*e.g.*, gait) and other information (such as, for example, the patient's current medication regimen). When the patient monitor 106 determines that the patient's risk of falling is above a predetermined threshold, the patient monitor 106 can issue an alarm or alert to notify care providers of the identified risk in an effort to anticipate and therefore prevent a patient fall. Additionally, the patient monitor 106 can determine when a patient has fallen and issue the appropriate alarms and alerts to summon care provider assistance.

[0203] FIG. 12 illustrates a method 1200 of determining whether a patient has fallen according to an embodiment of the present disclosure. The method 1200 uses, among other things, information sensed by the accelerometer 210 and by the gyroscope 212 of the wireless sensor 102 to determine whether the patient has fallen. The method 1200 can be performed by the wireless sensor 102, using its processor 202 and storage device 204, or it can be performed by an external processing device that receives the sensed information from the wireless sensor 102, such as, for example, the patient monitor 106.

[0204] According to an embodiment of the present disclosure, measurements from the accelerometer 210 and the gyroscope 212 of the wireless sensor 102 are used, among other things, to determine whether the patient has fallen. As discussed above, the accelerometer 210 measures linear acceleration of the patient with respect to gravity in three axes. The three axes of the accelerometer 210 are represented in fixed, inertial references. The roll axis corresponds to the longitudinal axis of the patient's body. Accordingly, the roll reference measurement is used to determine whether the patient is in the prone position (*i.e.*, face down), the supine position (*i.e.*, face up), or on a side. The pitch axis corresponds to the locations about the patient's hip. Thus, the pitch measurement is used to determine whether the patient is upright or lying down. Advantageously, the pitch axis provided by the accelerometer 210 can be a useful source of information in determining whether a patient has fallen because it can indicate a change in the patient's orientation from standing to lying, a frequently-seen scenario when a patient falls. The yaw axis corresponds to the horizontal plane in which the patient is located.

[0205] The gyroscope 212 provides outputs responsive to sensed angular velocity of the wireless sensor 102, as positioned on the patient, in three orthogonal axes corresponding to measurements of pitch, yaw, and roll. In contrast to the fixed, inertial reference frame relative to gravity of the accelerometer 210, the frame of reference provided by the gyroscope is relative to the patient's body, which moves.

[0206] At block 1202, the method 1200 begins in which acceleration measurement data and angular velocity data are received from the wireless sensor 102 by a device capable of processing the measurement data, such as, for

example, the patient monitor 106. Other devices capable of processing the measurement data include, without limitation, clinician devices 114, nurses' station systems 113, the multi-patient monitoring system 110, or the like. For ease of illustration, the description herein will describe the processing device as the patient monitor 106. A skilled artisan will appreciate that a large number of devices may be used to perform the described method 1200 without departing from the scope of the present disclosure.

[0207] At block 1204, the received data are normalized, which may also be referred to as "scaling," to adjust values measured on different scales to a common scale, prior to further processing. According to an embodiment, training data are used to normalize the received data. The training data can include empirical data of multiple fall scenarios as well as non-fall scenarios that can be challenging to discriminate from fall scenarios. The training data are collected and analyzed to serve as the basis for establishing a weight vector (discussed below with respect to block 1208) used to determine whether a patient has fallen. The training data can include multiple falling and non-falling scenarios, performed multiple times, by multiple subjects. Illustratively, by way of non-limiting example, the training data can include the fall and non-fall scenarios described in Table 2.

Fall and Non-Fall Scenarios
Fall forward from vertical, ending in left/right lateral position
Fall forward from vertical, ending in prone position
Fall backward, from vertical, ending in left/right lateral position
Fall backward from vertical, ending in supine position
Fall to left/right from vertical, ending in left/right lateral position
Fall to left/right from vertical, ending in prone position
Fall to left/right rom vertical falling, ending in supine position
Collapse from vertical, ending in left/right lateral position
Collapse from vertical, ending in prone position
Collapse from vertical, ending in supine position
Fall from vertical onto knees
Fall from vertical to the left/right against a wall, sliding down
Take a step down repeatedly from a podium with left foot first
Take a step down repeatedly from a podium with right foot first
In bed: roll onto left/right side, falling out of bed
Sit down from vertical into a chair
Jump off mattress repeatedly
Stand quietly
Stumble vigorously and fall onto mattress

Table 2

[0208] As with the received data, each sample of the training data includes six dimensions of information, corresponding to the three axes of

accelerometer 210 data, and the three axes of gyroscope 212 data. Normalizing the received data standardizes the range of the variables of the received data. Since the range of values of raw data can vary widely, analytical algorithms may not work properly without normalization. For example, many classifiers calculate the distance between two points. If one of the independent variables has a broad range of values, the distance will be governed by this particular variable. Therefore, the range of all variables can be normalized so that each feature contributes approximately proportionately to the final distance. Normalization causes the values of each variable in the data to have zero-mean (when subtracting the mean in the numerator) and unit-variance. This can be performed by calculating standard scores. The general method of calculation is to determine the distribution mean and standard deviation for each variable of the entire set of training data. Next each determined mean is subtracted from the corresponding variable of the received data. Then the new value of each variable (having the mean already subtracted) is divided by the determined standard deviation. The result is a normalized set of values that can be further processed by the method 1200.

[0209] At block 1206, the normalized set of values is processed to determine features that are useful in determining whether a patient is falling. According to an embodiment, the method determines the following five features: the magnitude of the acceleration data (provided by the accelerometer 210), the magnitude of the angular velocity data (provided by the gyroscope 212), the magnitude of the jerk (*i.e.*, the rate of change of acceleration); the fall duration which is used to characterize a fall starting point and a fall impact point, and the change in pitch between two consecutively received data points. Other features can features can be used in determining whether a patient is falling such as, by way of non-limiting example, vertical velocities.

[0210] The magnitude of the received acceleration data is determined by calculating the Euclidian norm of the three-dimensional vector made up of the measurements from the accelerometer's 210 three axes. As is well understood by an artisan, this corresponds to the square root of the sum of the squares of the three accelerometer values, pitch, roll and yaw. Similarly, the magnitude of the angular

velocity data is determined by calculating the Euclidian norm of the three-dimensional vector made up of the measurements from the gyroscope's 212 three axes. The magnitude of the jerk, which can also be referred to as "jolt," "surge," or "lurch," is calculated by taking the derivative of the acceleration vector, and then calculating the Euclidean norm of the derivative.

[0211] The fall duration, which is a scalar value, is determined by evaluating the acceleration magnitude profile of the patient's motion over a short duration of time. In particular, as the fall begins, acceleration of the patient relative to gravity decreases because the patient is falling. (A patient that is not falling would register an acceleration value in the up and down dimension equal to the force of gravity (*i.e.*, 1*g* or approximately 9.80665 m/s^2). Thus, if the magnitude of the acceleration is below a first threshold, then it is considered to be a starting point of a fall, and the value of the fall duration is incremented by 1. If the magnitude of the acceleration is above the first threshold, then the value of the fall duration is decremented by 1. In an embodiment, the first threshold is 0.6*g* (or approximately 5.88399 m/s^2). A second threshold is used to determine the impact point of the fall. In an embodiment, the second threshold is 0.8*g* (or approximately 7.84532 m/s^2). If the magnitude of the acceleration is below the second threshold, then it is considered to be an impact point of the fall, and the value of the fall duration is incremented by 1. If the magnitude of the acceleration is above the second threshold, then the value of the fall duration is decremented by 1.

[0212] The pitch change feature is the result of a comparison of the present pitch orientation (as determined by the accelerometer 210 data) with the pitch orientation determined one second earlier. As discussed above, the pitch dimension of the accelerometer data is useful in detecting a fall because it distinguishes between the patient being in an upright position (*e.g.*, standing up or sitting up) and reclining. Thus a change in pitch from being upright to reclining can indicate that a fall has occurred. The output of block 1206 is a five-dimensional feature vector made up of the five determined features.

[0213] At block 1208, a weight vector of values is applied to the determined features. According to certain embodiments, the inner product of the

received five-dimensional feature vector and a weight vector is calculated. In certain embodiments, the weight vector is derived using a machine learning algorithm. Machine learning is a sub-field of computer science based on the study of pattern recognition and computational learning theory in artificial intelligence. It includes the development of algorithms that can learn from and make predictions on data. Algorithms developed through machine learning operate by building a model from example inputs in order to make data-driven predictions or decisions, rather than following strictly static program instructions. Machine learning is employed in a range of computing tasks where use of explicit computer programs is infeasible. When employed in industrial contexts, machine learning methods may be referred to as predictive analytics or predictive modelling. As applied in the present disclosure, the machine learning system includes supervised learning, where the machine learning algorithm is presented with training data that include example inputs and their known outputs, given by a "teacher", and the goal is to learn a general rule that maps the inputs to the outputs. In an embodiment, Fisher's linear discriminant is employed to derive the weight vector. Fisher's linear discriminant is a method used to find a linear combination of features that characterizes or separates two or more classes of objects or events. The resulting combination may be used as a linear classifier or for dimensionality reduction before later classification. Other methods of machine learning that can be used with the present disclosure include, without limitation, linear discriminant analysis, analysis of variance, regression analysis, logistic regression, and probit regression, to name a few. A skilled artisan will recognize that many other machine learning algorithms can be used to determine the weight vector without departing from the scope of the present disclosure.

[0214] The training data, described above, include empirical data collected from multiple fall and non-fall scenarios which can be used to identify the predictive indicators of patient falls. Illustratively, for each training scenario, the five features described above with respect to block 1206 are determined and provided as input to the machine learning system. Additionally, an output is provided for each training scenario that identifies whether the scenario describes a falling event or a non-falling event. The machine learning system analyzes the training data to derive a

rule that maps the inputs to the outputs. According to certain embodiments of the present disclosure, the output of the machine learning system is five-dimensional weight vector that weights each of the five features according to their relative value in determining whether or not a fall has occurred. The weight vector is determined off-line and is provided as a fixed, five-dimensional vector to the method 1200. Of course, the weight vector can be updated, based on analysis of additional empirical data.

[0215] The inner product (also referred to as the "dot product" and the "scalar product") of the received five-dimensional feature vector and the weight vector is calculated in a manner well understood by skilled artisans. The inner product yields a scaler value, also referred to herein as an activation value, that may be either positive or negative. At block 1210, the method 1200 determines whether a fall has been detected. According to some embodiments, the sign of the inner product of the received five-dimensional feature vector and the weight vector indicates whether a fall has occurred. If the inner product is less than zero, then no fall has been detected, and the method returns to block 1202 to begin analyzing the next set of data from the wireless sensor 102. If the inner product is greater than zero, then a fall has been detected and the method 1200 progresses to block 1214, where a notification, alarm, and/or alert indicating that the patient has fallen is transmitted to, for example, clinician devices 114, nurses' station systems 113, multi-patient monitoring system 110, and the like. The method returns to block 1202 to begin analyzing the next set of data from the wireless sensor 102.

[0216] In some embodiments, the system can determine a spatial location of the patient within the patient's room. The system can monitor the room and spatially monitor and/or calculate how long the patient has been in a position, when the patient was in the position, and/or how long the patient was in the position, among other parameters. As discussed above, the system uses, among other things, information sensed by the accelerometer 210 and by the gyroscope 212 of the wireless sensor 102 to track the patient. This method can be performed by the wireless sensor 102, using its processor 202 and storage device 204, or it can be

performed by an external processing device that receives the sensed information from the wireless sensor 102, such as, for example, the patient monitor 106.

[0217] In some embodiments, the system can determine the position of the patient within the patient's room, relative to certain features of the patient's room, such as the patient's bed, a bathroom, a monitor, a doorway, and/or a window, among other room feature. In particular, using methods described herein, the system can determine a patient's vertical position, vertical displacement, horizontal position, horizontal displacement, angular position and/or angular displacement in the patient's room. For example, the accelerometer 210 and/or the gyroscope 212 can monitor the patient's movements as the patient walks throughout the patient's room. The system can determine whether the patient is falling, getting out of bed, or otherwise moving in a prohibited manner or in a manner that requires caregiver attention.

[0218] According to some embodiments, measurements from the accelerometer 210 and the gyroscope 212 of the wireless sensor 102 are used, among other things, to determine whether the patient is bending down and/or has fallen and/or where the patient has fallen (for example, by measuring the vertical displacement of the patient and/or the height of the patient relative to the floor). In some embodiments in which the patient has fallen, the clinician can determine the location of the fall according to an embodiment of the present disclosure. As discussed above, the accelerometer 210 measures linear acceleration of the patient with respect to gravity in three axes. The three axes of the accelerometer 210 are represented in fixed, inertial references. The gyroscope 212 provides outputs responsive to sensed angular velocity of the wireless sensor 102, as positioned on the patient, in three orthogonal axes corresponding to measurements of pitch, yaw, and roll. Based on these measurements, the system can determine whether the patient has fallen according to methods described herein.

[0219] In such configurations, the system can record the position of the patient. In certain aspects, the information received from the wireless sensor 102 can be used to create a time-sequenced representation of the patient's movement. This representation can be displayed on the display 120 or transmitted to a nurses'

station or other processing node to enable the caregiver to monitor the patient. The time-sequenced representation can be viewed in real time and/or be recorded for playback. For example, if an alarm alerts the caregiver that the patient has fallen, the caregiver can access and review the historical sequence of the patient's movements prior to and during that period of time.

[0220] Figures 15A-H illustrate various configurations of a room display displayed on the patient display monitor. As illustrated in Figures 15A-H, the caregiver and/or patient can select any number of room items and/or configurations of the room items. The caregiver can select a room item, and place it within the room on the room display. The caregiver can rotate and/or place the room item in any configuration. In an embodiment, the caregiver could select the location of a major element of a room at a time. For example, the caregiver could select a position of the bed, then a position of the bathroom, then a position of the door, equipment, tables, chairs, couches, etc. In other embodiments, various room layout approximation are some to fully presented in selection screens and the determination of layout is made in one or just a few caregiver selections.

[0221] Figure 16 illustrates an example method 1600 for detecting and/or predicting a patient's fall, determining a particular location of a patient within a patient's room, and/or determining whether the patient has moved outside of a prescribed movement of the patient, among others, for example.

[0222] At block 1602, the caregiver can enter a room configuration. For example, the caregiver can select any number of room items to be displayed in any number of configurations within a patient room display. The room items can include a patient's bed, a bathroom, a monitor, a doorway, and/or a window, among other room items. The caregiver can select a room item by selecting, dragging, and/or dropping each room item around the room display. In some embodiments, the caregiver can select a certain size for each room item. In some embodiments, the caregiver can simply select a room item and select the location within the room display for the room item to be oriented and displayed. In some embodiments, the room item can be snapped into place in the room display.

[0223] At block 1604, the caregiver can optionally enter a movement prescription. For example, the caregiver can enter instructions to the patient, including instructions to remain in bed, and/or to walk to the bathroom only with the assistance of an attendant.

[0224] At block 1608, one or more of the sensors described herein can be activated. In some examples, the caregiver manually activates the one or more sensors. In some examples, the system activates the one or more sensors automatically to begin tracking, monitoring, measuring, and/or calculating certain physiological parameters, according to methods described herein.

[0225] At block 1610, the patient monitoring system 100 can predict and/or detect a patient's fall and/or risk of falling based on analysis of the patient's movement (*e.g.*, gait) and other information (such as, for example, the patient's current medication regimen). At block 1612, when the patient monitor 106 determines that the patient's risk of falling is above a predetermined threshold, the patient monitor 106 can issue an alarm or alert to notify care providers of the identified risk in an effort to anticipate and therefore prevent a patient fall. Additionally, the patient monitor 106 can determine when a patient has fallen and issue the appropriate alarms and alerts to summon care provider assistance. The alert system can alert the caregiver that the patient is falling, getting out of bed, or otherwise moving in a prohibited manner or in a manner that requires caregiver attention. The alert can be an audible and/or visual alarm on the monitoring system or transmitted to a caregiver (*e.g.*, nurses' station system 113, clinician device 114, pager, cell phone, computer, or otherwise).

[0226] If the patient monitoring system has not detected a patient's fall, the patient monitoring system 100 can optionally determine whether the patient has moved outside of the movement prescription. For example, as described above, the patient monitor 106 can determine the mobility status of the patient, *e.g.*, whether the patient is ambulatory, standing, sitting, reclining, or falling.

[0227] If the patient monitoring system 100 determines that the patient has contravened a caregiver's order, such as, for example, instructions to remain in bed,

or to walk to the bathroom only with the assistance of an attendant, a notification, alert, or alarm can be transmitted to the appropriate caregivers at block 1612.

[0228] If the patient monitoring system 100 determines that the patient has not contravened a caregiver's order, the system will return to block 1610 to detect and/or predict whether the patient has fallen.

[0229] FIGS. 13A-F illustrate embodiments of icon displays reflecting a patient's position according to an embodiment of the present disclosure. According to some embodiments, the graphical icons are used to visually depict the detected orientation of the patient. In particular, the icons of FIGS. 13A-F show, in stick figure-type format, the patient sitting, standing, and lying in the supine position (on the back), the prone position (on the belly), on the left side, and on the right side, respectively.

[0230] FIG. 14 illustrates an example of how the icons described with respect to FIGS. 13A-F can be presented on the display 120 of the patient monitor 106. Toward the bottom of the main display 120 are a set of 3 icons 1402, 1404, and 1406 indicating the patient's position. The left-most icon 1404 shows the patient lying on his right side. The two icons to the right of the left-most icon 1404 and 1406 show the patient lying on his back. According to certain embodiments, the display 120 of the patient monitor 106 can include a touchscreen interface. The touchscreen interface can enable finger controls, including a touch gesture, a touch and move gesture, and a flick gesture. Illustratively, a clinician may use the touch gesture on an icon 1406 to expand the icon in the display 120 to include additional information associated with that icon 1406. For example, additional information associated with the "touched" icon 1406 can include, the time at which the patient assumed the particular orientation, the time (if available) at which the patient moved from the orientation, the total duration of time the patient spent in the particular orientation, the number if discrete times that the patient has been in the particular orientation over a defined period (such as 24 hours), the total duration of time that the patient the patient has been in the particular orientation over a defined period (such as 24 hours), and the like. The clinician may also use the flick finger gesture

to scroll right and left, corresponding to moving forward and backward in time, to access the historical positional record of the patient.

[0231] The service life of the wireless sensor 102 disclosed herein can vary depending on, among other things, battery size, and data transmission characteristics such as data rate, frequency of transmission, and quantity of data transmitted. According to one embodiment, the wireless sensor 102 is configured to operate continuously or near continuously (*e.g.,* waking up every second or so to sense and transmit the patient's physiological data) for approximately two days, after which the wireless sensor 102 is to be disposed of properly. Other embodiments of the wireless sensor 102, equipped with a larger battery, for example, are configured to operate for longer periods of time before disposal. Some embodiments can be configured for sterilization and reuse.

[0232] Certain medical device manufacturers implement quality control measures for disposable medical devices, such as embodiments of the disclosed wireless sensor 102, to carefully control and manage the performance characteristics of their disposable devices. In particular, there is a risk that used and disposed-of wireless sensors 102 can be salvaged and refurbished or retrofitted for additional use beyond the defined and intended service life of the wireless sensor 102. Features can be included in the disclosed patient monitoring system 100 to help prevent improper use of the wireless sensor 102 beyond its defined service life.

[0233] According to one embodiment of the patient monitoring system 100, the wireless sensor 102 is configured to set an activation flag in the storage device 204 of the wireless sensor 102 upon initial activation, indicating that the wireless sensor 102 has been activated for use. In some embodiments, the activation flag is set in an information element 215 which is provided to store information about the usage of the wireless sensor 102 to help maintain quality control. Advantageously, the activation flag is set in nonvolatile memory of the storage device 204, or in the information element 215, so that disconnection from the battery 214 will not disrupt or erase the set activation flag. Thus, if the wireless sensor 102 is reconditioned such that it may be activated a second time, the activation flag will indicate, through a standard sensor 102 start-up routine, that the

sensor 102 has been previously activated. Upon detection of the activation flag, the wireless sensor 102 can transmit a prior activation message and/or alert which can serve as a warning notification that the quality of the sensor 102 may be compromised. The transmitted warning or alert can be received by, for example, a patient monitor 106 which can then provide a menu of actions that the user may take in response to the transmitted quality warning or alert. The menu of actions can include the option to shut down the wireless sensor 102. In certain situations it may be desirable to continue to use the wireless sensor 102. Illustratively, it is possible that the battery 214 connection to the wireless sensor 102 is established and then unintentionally disconnected. For example, a battery isolator 322 may be initially removed from the sensor 102 but then re-inserted so as to once again isolate the battery 214 from the electronic circuitry of the wireless sensor 102. Removing the battery isolator 322 a second time will result in transmission of a quality warning or alert as described above. In such a situation the user, being aware of the circumstances that led to the quality warning, may choose to continue to use the wireless sensor 102.

[0234] According to another embodiment, the wireless sensor 102 is configured to set a prolonged service flag, after the wireless sensor has been in an activated state for a predefined period of time, such as, for example, four hours. The prolonged service flag can serve to indicate upon start-up that the sensor 102 has previously been active for a prolonged duration of time. In another embodiment, the wireless sensor 102 tracks and records on the storage device 204 the duration of time that the sensor 102 has been active. Advantageously, the sensor 102 can issue notifications and/or alerts to the user that the sensor 102 is nearing the end of service life, providing the user an opportunity to take steps to replace the wireless sensor 102 before it ceases to operate. Additionally, the recorded duration of time that the sensor 102 has been active can serve to detect when a sensor 102 has been refurbished to operate beyond its intended service life. The appropriate warning can then be transmitted to the user. According to some embodiments, once the wireless sensor has been active for a period of time equal to a maximum service

life duration, the sensor 102 sets a flag in the storage device 204, or otherwise configures itself to prohibit the sensor 102 from operating further.

[0235] In other embodiments, the wireless sensor 102 transmits to the patient monitor 106 a unique identifier such as, for example, a product serial number that is encoded in one of the hardware components of the wireless sensor 102. Once the wireless sensor 102 is paired with a patient monitor or with an expander/repeater 107 and is operational, the patient monitor 106 or the expander/repeater 107 can transmit the sensor's 102 unique identifier to a central repository that lists the unique identifiers of sensors 102 known to have been operational. Illustratively, during the pairing operation, the patient monitor 106 or the expander/repeater 107 can check the central repository to determine whether the wireless sensor 102 that is attempting to pair has been listed on in the central repository, thereby indicating that the wireless sensor 102 might have quality issues.

[0236] In other various embodiments, the wireless sensor 102 includes a sensor information element 215, which can be provided through an active circuit such as a transistor network, memory chip, EEPROM (electronically erasable programmable read-only memory), EPROM (erasable programmable read-only memory), or other identification device, such as multi-contact single wire memory devices or other devices, such as those commercially available from Dallas Semiconductor or the like. The sensor information element 215 may advantageously store some or all of a wide variety of information, including, for example, sensor type designation, sensor configuration, patient information, sensor characteristics, software such as scripts or executable code, algorithm upgrade information, software or firmware version information, or many other types of data. In a preferred embodiment, the sensor information element 215 may also store useful life data indicating whether some or all of the sensor components have expired.

[0237] Many other variations than those described herein will be apparent from this disclosure. For example, depending on the embodiment, certain acts, events, or functions of any of the algorithms described herein can be performed in a different sequence, can be added, merged, or left out altogether (*e.g.*, not all described acts or events are necessary for the practice of the algorithms). Moreover,

in certain embodiments, acts or events can be performed concurrently, *e.g.*, through multi-threaded processing, interrupt processing, or multiple processors or processor cores or on other parallel architectures, rather than sequentially. In addition, different tasks or processes can be performed by different machines and/or computing systems that can function together.

[0238] The various illustrative logical blocks, modules, and algorithm steps described in connection with the embodiments disclosed herein can be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. The described functionality can be implemented in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the disclosure.

[0239] The various illustrative logical blocks and modules described in connection with the embodiments disclosed herein can be implemented or performed by a machine, such as a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor can be a microprocessor, but in the alternative, the processor can be a controller, microcontroller, or state machine, combinations of the same, or the like. A processor can include electrical circuitry configured to process computer-executable instructions. In another embodiment, a processor includes an FPGA or other programmable device that performs logic operations without processing computer-executable instructions. A processor can also be implemented as a combination of computing devices, *e.g.*, a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. A computing environment can include any type of

computer system, including, but not limited to, a computer system based on a microprocessor, a mainframe computer, a digital signal processor, a portable computing device, a device controller, or a computational engine within an appliance, to name a few.

[0240] The steps of a method, process, or algorithm described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module stored in one or more memory devices and executed by one or more processors, or in a combination of the two. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of non-transitory computer-readable storage medium, media, or physical computer storage known in the art. An example storage medium can be coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor. The storage medium can be volatile or nonvolatile. The processor and the storage medium can reside in an ASIC.

[0241] Conditional language used herein, such as, among others, "can," "might," "may," "*e.g.*," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment. The terms "comprising," "including," "having," and the like are synonymous and are used inclusively, in an open-ended fashion, and do not exclude additional elements, features, acts, operations, and so forth. Also, the term "or" is used in its inclusive sense (and not in its exclusive sense) so that when used, for example, to connect a list of elements, the term "or" means one, some, or all of the elements in the list. Further, the term "each," as used herein, in addition to

having its ordinary meaning, can mean any subset of a set of elements to which the term "each" is applied.

[0242] While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the systems, devices or methods illustrated can be made without departing from the spirit of the disclosure. As will be recognized, certain embodiments described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others.

[0243] The term "and/or" herein has its broadest, least limiting meaning which is the disclosure includes A alone, B alone, both A and B together, or A or B alternatively, but does not require both A and B or require one of A or one of B. As used herein, the phrase "at least one of" A, B, "and" C should be construed to mean a logical A or B or C, using a non-exclusive logical or.

[0244] The apparatuses and methods described herein may be implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on a non-transitory tangible computer readable medium. The computer programs may also include stored data. Non-limiting examples of the non-transitory tangible computer readable medium are nonvolatile memory, magnetic storage, and optical storage.

[0245] Although the foregoing disclosure has been described in terms of certain preferred embodiments, other embodiments will be apparent to those of ordinary skill in the art from the disclosure herein. Additionally, other combinations, omissions, substitutions and modifications will be apparent to the skilled artisan in view of the disclosure herein. Accordingly, the present invention is not intended to be limited by the description of the preferred embodiments, but is to be defined by reference to claims.

WHAT IS CLAIMED IS:

1. A wireless physiological sensor for measuring acceleration of a patient, the physiological sensor comprising:

a base including a bottom surface and a top surface, said base also including a first aperture, a second aperture, and a third aperture, wherein each of said first, second, and third apertures extends between said bottom surface and said top surface of said base;

a substrate layer including conductive tracks and connection pads, a top side, and a bottom side, said bottom side of said substrate layer being disposed above said top surface of said base, said substrate layer also including a first through-hole via and a second through-hole via, wherein each of said first and second through-hole vias extends through said substrate layer between said top and bottom sides of said substrate layer;

a temperature sensor responsive to thermal energy of said patient, said temperature sensor mounted on said top side of said substrate layer, said temperature sensor including a thermal contact in thermal communication with said top side of said substrate layer, wherein said first through-hole via is aligned with said thermal contact of said temperature sensor on said top side of said substrate layer and with said first aperture of said base on said bottom side of said substrate layer, and wherein said first aperture of said base and said first through-hole via of said substrate layer are filled with at least a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said bottom surface of said base corresponding to said first aperture;

an electrocardiogram (ECG) sensor mounted on said top side of said substrate layer, said ECG sensor responsive to electrical signals generated by said patient's heart, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG sensor also including an electrical contact in electrical communication with said top side of said substrate layer, wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said top side of said substrate layer and with said second aperture of said base on said bottom side of said substrate layer, and wherein said second aperture of said base and said second through-hole via of said substrate layer are filled with at least an electrically conductive material to cause said ECG sensor to be in electrical communication with a portion of said bottom surface of said base corresponding to said second aperture;

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an accelerometer mounted on said substrate layer, said accelerometer responsive to a linear acceleration of said patient; and

an acoustic respiration sensor responsive to vibrational motion generated by said patient, said acoustic respiration sensor being disposed on said bottom side of said substrate layer and extending through said third aperture in said base and beyond said bottom surface of said base, said acoustic respiration sensor being in structural communication with said substrate layer so as to mechanically transmit vibrational motion to said accelerometer.

2. The wireless physiological sensor of Claim 1, further comprising an information element configured to store information indicative of whether said physiological sensor has been previously activated.

3. The wireless physiological sensor of Claim 1 or 2, further comprising a gyroscope mounted on said substrate layer, said gyroscope responsive to an angular velocity of said patient.

4. The wireless physiological sensor of any one of Claims 1 to 3, wherein said base insulates a portion of said patient's body surrounding said portion of said bottom surface of said base corresponding to said first aperture.

5. The wireless physiological sensor of any one of Claims 1 to 4, further comprising a wireless transceiver configured to wirelessly transmit information representative of said thermal energy, said electrical signals, said linear acceleration, and said vibrational motion.

6. The wireless physiological sensor of Claim 5, wherein said wireless transceiver is configured to transmit a pairing signal.

7. The wireless physiological sensor of Claim 5, wherein said wireless transceiver is configured to transmit a message indicating that said physiological sensor has been previously activated.

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8. The wireless physiological sensor of Claim 5, wherein said wireless transceiver is configured to transmit a notification that a quality standard associated with said physiological sensor is compromised.

9. The wireless physiological sensor of Claim 5, wherein said wireless transceiver is configured to transmit a message indicating that said physiological sensor is nearing an end of service life.

10. The wireless physiological sensor of any one of Claims 1 to 9, further comprising:

a battery mounted on said bottom side of said substrate layer and between said bottom side of said substrate layer and said top surface of said base, said battery being in electrical contact with said substrate layer, wherein said battery forms a recess between a portion of said bottom side of said substrate layer and said top surface of said base; and

a mounting frame disposed to fill said formed recess, said mounting frame configured to provide rigid structural support between said base and said substrate layer.

11. The wireless physiological sensor of Claim 10, wherein said mounting frame further comprises:

a first mounting frame aperture aligned with said first through-hole via and with said first aperture of said base, wherein said first mounting aperture is at least filled with said thermally conductive material to cause said temperature sensor to be in thermal communication with said portion of said bottom surface of said base corresponding to said first aperture; and

a second mounting frame aperture aligned with said second through-hole via and with said second aperture of said base, wherein said second mounting aperture is at least filled with said electrically conductive material to cause said ECG sensor to be in electrical communication with said portion of said bottom surface of said base corresponding to said second aperture.

12. The wireless physiological sensor of any one of Claims 1 to 11, further comprising:

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a gyroscope mounted on said substrate layer, said gyroscope responsive to an angular velocity of said patient;

a magnetometer mounted on said substrate layer, said magnetometer responsive to a magnetic field;

a processor mounted on said substrate layer and in communication with said temperature sensor, ECG sensor, accelerometer, gyroscope, and magnetometer, said processor configured to generate signals representative of said thermal energy, electrical signals, linear acceleration, vibratory motion, angular velocity, and magnetic field; and

a wireless transceiver mounted on said substrate layer and in communication with said processor, said wireless transceiver configured to transmit said generated signals representative of said thermal energy, electrical signals, linear acceleration, vibrational motion, angular velocity, and magnetic field.

13. The wireless physiological sensor of Claim 12, further comprising:

an impedance sensor mounted on said substrate layer and in electrical communication with said portion of said bottom surface of said base corresponding to said second aperture.

14. The wireless physiological sensor of Claim 12, wherein said accelerometer is a three-dimensional accelerometer and said gyroscope is a three-dimensional gyroscope.

15. A wearable wireless sensor for monitoring at least one of pressure ulcer risk, fall detection, or fall risk, said wearable wireless sensor comprising:

a base including a first aperture;

a circuit layer including a first through-hole via extending through said circuit layer; and

a temperature sensor responsive to a thermal energy of a patient, said temperature sensor mounted on said circuit layer, said temperature sensor including a thermal contact in thermal communication with said circuit layer,

wherein said first through-hole via is aligned with said thermal contact of said temperature sensor and with said first aperture of said base, and

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wherein said first aperture and said first through-hole via include a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said base corresponding to said first aperture.

16. The wearable wireless sensor of Claim 15, wherein said base insulates a portion of said patient's body surrounding said portion of said base corresponding to said first aperture.

17. The wearable wireless sensor of Claim 15 or 16, further comprising:

a second aperture in said base;

a second through-hole via extending through said circuit layer between a top side and a bottom side of said circuit layer;

an electrocardiogram (ECG) sensor mounted on said circuit layer, said ECG sensor responsive to electrical signals, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG lead also including an electrical contact in electrical communication with said circuit layer,

wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said circuit layer and with said second aperture of said base, and

wherein said second aperture of said base and said second through-hole via of said circuit layer include an electrically conductive material, said ECG sensor in electrical communication with a portion of said base corresponding to said second aperture through said electrically conductive material.

18. The wearable wireless sensor of any one of Claims 15 to 17, further comprising:

an accelerometer mounted on said circuit layer, said accelerometer responsive to a linear acceleration of said patient;

a third aperture in said base; and

an acoustic respiration sensor responsive to vibrational motion of said patient, said acoustic respiration sensor being disposed on said circuit layer and extending through said third aperture in said base, wherein said acoustic respiration sensor is in rigid structural communication with said circuit layer so as to mechanically transmit sensed vibrational motion to said accelerometer.

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19. The wearable wireless sensor of any one of Claims 15 to 18, further comprising a gyroscope mounted on said circuit layer, said gyroscope responsive to an angular velocity of said patient.

20. The wearable wireless sensor of Claim 19, wherein said accelerometer comprises a three-dimensional accelerometer and said gyroscope comprises a three-dimensional gyroscope.

21. The wearable wireless sensor of any one of Claims 15 to 20, further comprising an information element configured to store information indicative of whether said physiological sensor has been previously activated.

22. A wearable wireless sensor for monitoring a thermal energy of a patient and at least one of pressure ulcer risk, fall detection, or fall risk, said wearable wireless sensor comprising:

a housing including a predetermined position for at least a first sensor and a second sensor;

one or more accelerometers responsive to an acceleration of said patient and configured to output one or more signals indicative of at least one of said pressure ulcer risk, said fall detection, or said fall risk;

a base including a first aperture;

a circuit layer including a first through-hole via extending through said circuit layer; and

a temperature sensor responsive to said thermal energy of said patient, said temperature sensor mounted on said circuit layer, said temperature sensor including a thermal contact in thermal communication with said circuit layer, wherein said temperature sensor is at least one of the first sensor or the second sensor,

wherein said first through-hole via is aligned with said thermal contact of said temperature sensor and with said first aperture of said base, said first through-hole via is configured to provide a structure to transmit said thermal energy across a length of the first through-hole via from said patient to said temperature sensor,

wherein said first aperture and said first through-hole via include a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said base corresponding to said first aperture, and

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wherein the housing is configured to operably position the base and the circuit layer.

23. The wearable wireless sensor of Claim 22, wherein said base insulates a portion of said patient's body surrounding said portion of said base corresponding to said first aperture.

24. The wearable wireless sensor of Claim 22, further comprising:

a second aperture in said base;

a second through-hole via extending through said circuit layer between a top side and a bottom side of said circuit layer; and

an electrocardiogram (ECG) sensor mounted on said circuit layer, said ECG sensor responsive to electrical signals, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG lead also including an electrical contact in electrical communication with said circuit layer,

wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said circuit layer and with said second aperture of said base, and

wherein said second aperture of said base and said second through-hole via of said circuit layer include an electrically conductive material, said ECG sensor in electrical communication with a portion of said base corresponding to said second aperture through said conductive material.

25. The wearable wireless sensor of Claim 24, wherein said one or more accelerometers are mounted on said circuit layer, said one or more accelerometers responsive to acceleration of said patient, said wearable wireless sensor further comprising:

a third aperture in said base; and

an acoustic respiration sensor responsive to vibrational motion of said patient, said acoustic respiration sensor being disposed on said circuit layer and extending through said third aperture in said base, wherein said acoustic respiration sensor is rigidly secured to said circuit layer so as to mechanically transmit sensed vibrational motion to said one or more accelerometers.

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26. The wearable wireless sensor of Claim 22, further comprising a gyroscope mounted on said circuit layer, said gyroscope responsive to an angular velocity of said patient.

27. The wearable wireless sensor of Claim 26, wherein said one or more accelerometers comprises a three-dimensional accelerometer and said gyroscope comprises a three-dimensional gyroscope.

28. The wearable wireless sensor of Claim 27, further comprising non-volatile memory configured to store information indicative of whether said wearable wireless sensor has been previously activated.

29. The wearable wireless sensor of Claim 22, wherein the second sensor is said one or more accelerometers.

30. The wearable wireless sensor of Claim 22, wherein the housing includes a predetermined position for at least a third sensor.

31. The wearable wireless sensor of Claim 30, wherein the housing includes a predetermined position for at least a fourth sensor.

32. The wearable wireless sensor of Claim 31, wherein the third and fourth sensors include one or more of an acoustic sensor, an electrocardiogram sensor, a respiration sensor, a heart rate sensor, and a blood oxygen sensor.

33. A wireless physiological sensor for measuring one or more physiological parameters of a patient, the wireless physiological sensor comprising:

a base including a bottom surface and a top surface, said base also including a first aperture and a second aperture, wherein each of said first and second apertures extends between said bottom surface and said top surface of said base;

a substrate layer including conductive tracks and connection pads, a top side, and a bottom side, said bottom side of said substrate layer being disposed above said top surface of said base, said substrate layer also including a first through-hole via and a second through-hole via, wherein each of said first and second through-hole vias

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extends through said substrate layer between said top and bottom sides of said substrate layer;

a temperature sensor responsive to thermal energy of said patient, said temperature sensor mounted on said top side of said substrate layer, said temperature sensor including a thermal contact in thermal communication with said top side of said substrate layer, wherein said first through-hole via is aligned with said thermal contact of said temperature sensor on said top side of said substrate layer and with said first aperture of said base on said bottom side of said substrate layer, and wherein said first aperture of said base and said first through-hole via of said substrate layer are filled with at least a thermally conductive material to cause said temperature sensor to be in thermal communication with a portion of said bottom surface of said base corresponding to said first aperture;

an electrocardiogram (ECG) sensor mounted on said top side of said substrate layer, said ECG sensor responsive to electrical signals generated by said patient's heart, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG sensor also including an electrical contact in electrical communication with said top side of said substrate layer, wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said top side of said substrate layer and with said second aperture of said base on said bottom side of said substrate layer, and wherein said second aperture of said base and said second through-hole via of said substrate layer are filled with at least an electrically conductive material to cause said ECG sensor to be in electrical communication with a portion of said bottom surface of said base corresponding to said second aperture; and

an accelerometer mounted on said substrate layer, said accelerometer responsive to a linear acceleration of said patient.

34. The wireless physiological sensor of Claim 33, further comprising an information element configured to store information indicative of whether said wireless physiological sensor has been previously activated.

35. The wireless physiological sensor of Claim 33 or Claim 34, further comprising a gyroscope mounted on said substrate layer, said gyroscope responsive to an angular velocity of said patient.

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36. The wireless physiological sensor of any one of Claims 33 to 35, wherein said base insulates a portion of said patient's body surrounding said portion of said bottom surface of said base corresponding to said first aperture.

37. The wireless physiological sensor of any one of Claims 33 to 36, further comprising a wireless transceiver configured to wirelessly transmit information representative of said thermal energy, said electrical signals, and said linear acceleration.

38. The wireless physiological sensor of Claim 37, wherein said wireless transceiver is configured to transmit a pairing signal.

39. The wireless physiological sensor of Claim 37, wherein said wireless transceiver is configured to transmit a message indicating that said physiological sensor has been previously activated.

40. The wireless physiological sensor of Claim 37, wherein said wireless transceiver is configured to transmit a notification that a quality standard associated with said wireless physiological sensor is compromised.

41. The wireless physiological sensor of Claim 37, wherein said wireless transceiver is configured to transmit a message indicating that said physiological sensor is nearing an end of service life.

42. The wireless physiological sensor of any one of Claims 33 to 41, further comprising:

a battery mounted on said bottom side of said substrate layer and between said bottom side of said substrate layer and said top surface of said base, said battery being in electrical contact with said substrate layer, wherein said battery forms a recess between a portion of said bottom side of said substrate layer and said top surface of said base; and

a mounting frame disposed to fill said formed recess, said mounting frame configured to provide rigid structural support between said base and said substrate layer.

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43. The wireless physiological sensor of Claim 42, wherein said mounting frame further comprises:

a first mounting frame aperture aligned with said first through-hole via and with said first aperture of said base, wherein said first mounting aperture is at least filled with said thermally conductive material to cause said temperature sensor to be in thermal communication with said portion of said bottom surface of said base corresponding to said first aperture; and

a second mounting frame aperture aligned with said second through-hole via and with said second aperture of said base, wherein said second mounting aperture is at least filled with said electrically conductive material to cause said ECG sensor to be in electrical communication with said portion of said bottom surface of said base corresponding to said second aperture.

44. The wireless physiological sensor of any one of Claims 33 to 43, further comprising:

a gyroscope mounted on said substrate layer, said gyroscope responsive to an angular velocity of said patient;

a magnetometer mounted on said substrate layer, said magnetometer responsive to a magnetic field;

a processor mounted on said substrate layer and in communication with said temperature sensor, ECG sensor, accelerometer, gyroscope, and magnetometer, said processor configured to generate signals representative of said thermal energy, electrical signals, linear acceleration, vibratory motion, angular velocity, and magnetic field; and

a wireless transceiver mounted on said substrate layer and in communication with said processor, said wireless transceiver configured to transmit said generated signals representative of said thermal energy, electrical signals, linear acceleration, angular velocity, and magnetic field.

45. The wireless physiological sensor of Claim 44, further comprising:

an impedance sensor mounted on said substrate layer and in electrical communication with said portion of said bottom surface of said base corresponding to said second aperture.

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46. The wireless physiological sensor of Claim 44, wherein said accelerometer is a three-dimensional accelerometer and said gyroscope is a three-dimensional gyroscope.

47. A wearable wireless sensor for monitoring at least one physiological parameter, said wearable wireless sensor comprising:

a base including a first aperture, the base configured to be positioned proximate skin of a patient when the wearable wireless sensor is in use;

a housing secured to the base;

a circuit layer enclosed by at least a portion of the housing and including a first side, a second side opposite the first side, and at least one through-hole via extending through said circuit layer;

a temperature sensor responsive to a thermal energy of the patient, said temperature sensor mounted on said first side of said circuit layer, said temperature sensor configured to be in thermal communication with a portion of the skin of the patient proximate the first aperture of the base when the wearable wireless sensor is in use, wherein said at least one through-hole via is positioned between said temperature sensor and said first aperture of said base, said at least one through-hole via configured to allow said thermal energy to pass through the circuit layer to the temperature sensor; and

a thermally conductive material configured to be positioned between said portion of the skin of the patient and said at least one through-hole via when the wearable wireless sensor is in use, said thermally conductive material configured to transmit said thermal energy from the portion of the skin of said patient to the at least one through-hole via of the circuit layer.

48. The wearable wireless sensor of Claim 47, wherein said base insulates a portion of said patient's skin surrounding said first aperture of said base.

49. The wearable wireless sensor of Claim 47 or 48, further comprising:

a second aperture in said base;

wherein the at least one through-hole via comprises a first through-hole via aligned with said temperature sensor and a second through-hole via extending through said circuit layer and spaced from the first through-hole via;

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an electrocardiogram (ECG) sensor mounted on said circuit layer, said ECG sensor responsive to electrical signals, said ECG sensor including an extendible lead with an electrode responsive to said electrical signals, said ECG lead also including an electrical contact in electrical communication with said circuit layer,

wherein said second through-hole via is aligned with said electrical contact of said ECG sensor on said circuit layer and with said second aperture of said base, and

wherein said second aperture of said base and said second through-hole via of said circuit layer include an electrically conductive material to cause said ECG sensor to be in electrical communication with a portion of the skin of said patient proximate the second aperture of said base when said wearable wireless sensor is in use.

50. The wearable wireless sensor of any one of Claims 47 to 49, further comprising:

an accelerometer mounted on said circuit layer, said accelerometer responsive to a linear acceleration of said patient.

51. The wearable wireless sensor of any one of Claims 47 to 50, further comprising a gyroscope mounted on said circuit layer, said gyroscope responsive to an angular velocity of said patient.

52. The wearable wireless sensor of Claim 51, wherein said accelerometer comprises a three-dimensional accelerometer and said gyroscope comprises a three-dimensional gyroscope.

53. The wearable wireless sensor of any one of Claims 47 to 52, further comprising an information element configured to store information indicative of whether said wearable wireless sensor has been previously activated.

54. The wearable wireless sensor of Claim 47, wherein the housing is positioned within an outer perimeter of the base, and wherein the housing extends above a top surface of the base.

55. The wearable wireless sensor of Claim 47, wherein the base comprises a top layer and a bottom layer, the top layer including an opening configured to receive a

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portion of the housing, and the housing includes a rim extending around a perimeter of the housing, the rim positioned between the top and bottom layers of the base.

56. The wearable wireless physiological sensor of Claim 55, wherein the bottom layer of the base comprises the first aperture.

57. The wearable wireless sensor of Claim 50, further comprising:

a third aperture in said base; and

an acoustic respiration sensor responsive to vibrational motion of said patient, said acoustic respiration sensor being disposed on said circuit layer and extending through said third aperture in said base, wherein said acoustic respiration sensor is in rigid structural communication with said circuit layer so as to mechanically transmit sensed vibrational motion to said accelerometer.

58. The wireless physiological sensor of Claim 33, wherein the base further includes a third aperture extending between said bottom surface and said top surface of said base, and wherein the wireless physiological sensor further comprises:

an acoustic respiration sensor responsive to vibrational motion generated by said patient, said acoustic respiration sensor being disposed on said bottom side of said substrate layer and extending through said third aperture in said base and beyond said bottom surface of said base, said acoustic respiration sensor being in structural communication with said substrate layer so as to mechanically transmit vibrational motion to said accelerometer.

59. The wearable wireless physiological sensor of Claim 47, wherein at least a portion of the base comprises foam.

60. The wearable wireless physiological sensor of Claim 47, wherein the wireless physiological sensor is configured to wirelessly transmit temperature data over a Bluetooth wireless communication standard to a separate device.

61. A wearable physiological sensor for measuring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

a housing;

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a base secured to the housing and including a first opening and a second opening spaced from the first opening, the base configured to be positioned proximate skin of the patient when the wearable physiological sensor is in use;

a circuit layer;

a first electrocardiogram (ECG) electrode located at least partially within the first opening of the base and in electrical communication with the circuit layer, the first ECG electrode configured to transmit one or more electrical signals to said circuit layer responsive to electrical activity of the patient's heart;

a second electrocardiogram (ECG) electrode positioned outside the housing and electrically connected to said circuit layer via an electrocardiogram (ECG) lead, the second ECG electrode configured to transmit one or more electrical signals to said circuit layer responsive to electrical activity of the patient's heart;

a temperature sensor responsive to a thermal energy of the patient, said temperature sensor configured to be in thermal communication with a portion of skin of the patient proximate the second opening of the base when the wearable physiological sensor is in use; and

a thermally conductive material configured to be positioned between said portion of the skin of the patient and said temperature sensor when the wearable physiological sensor is in use.

62. The wearable physiological sensor of Claim 61, wherein the wearable physiological sensor comprises a wireless transceiver configured to allow the wearable physiological sensor to wirelessly interact with separate devices.

63. The wearable physiological sensor of Claim 61, wherein the ECG lead is coupled to a lockable retractable reel configured to store the ECG lead in a coil when not in use.

64. The wearable physiological sensor of Claim 61, wherein the first ECG electrode comprises an electrically conductive material formed within the first opening of the base.

65. The wearable physiological sensor of Claim 61, wherein the base comprises one or more substrates.

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66. The wearable physiological sensor of Claim 61, wherein the circuit layer is a double-sided circuit board including conduction tracks and connection pads.

67. The wearable physiological sensor of Claim 61, further comprising an accelerometer responsive to linear acceleration of said patient, said accelerometer configured to output one or more signals indicative of orientation of the patient.

68. The wearable physiological sensor of Claim 67, wherein said accelerometer is configured to sense vibratory motion emanating from the patient's body, and wherein the wearable physiological sensor further comprises a processor configured to process one or more signals generated by said accelerometer responsive to the sensed vibratory motion to determine respiration activity of said patient.

69. The wearable physiological sensor of Claim 61, further comprising a gyroscope responsive to angular velocity of said patient.

70. The wearable physiological sensor of Claim 61, wherein the second ECG electrode is configured to adhere to the patient's skin.

71. The wearable physiological sensor of Claim 61, wherein the ECG lead extends through the housing.

72. The wearable physiological sensor of Claim 61, wherein the second ECG electrode comprises conducting gel embedded in an adhesive pad.

73. A wearable physiological sensor for monitoring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

a housing;

a base configured to secure the housing to skin of the patient;

a circuit board positioned within the housing, the circuit board comprising a first surface and a second surface opposite the first surface, the second surface configured to be positioned closer to the patient's skin than the first surface when the base and housing are secured to the patient's skin, the circuit board including at least one

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opening spaced from a perimeter of the circuit board and extending through the circuit board;

a temperature sensor positioned within the housing above the first surface of the circuit board and said at least one opening extending through the circuit board; and

thermally conductive material positioned below the second surface of the circuit board and said at least one opening extending through the circuit board, said thermally conductive material configured to transmit thermal energy of the patient toward said at least one opening, said at least one opening configured to allow said thermal energy to pass through the circuit board toward said temperature sensor.

74. The wearable physiological sensor of Claim 73, wherein the base comprises a top substrate and a bottom substrate.

75. The wearable physiological sensor of Claim 73, further comprising a mounting frame configured to provide rigid structural support between said base and said circuit board.

76. The wearable physiological sensor of Claim 73, further comprising a release liner.

77. A wearable physiological sensor for monitoring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

a substrate having a top surface and a bottom surface opposite the top surface, the bottom surface comprising an adhesive configured to secure the substrate to skin of the patient, the substrate further comprising an opening spaced inward from a perimeter of the substrate;

a housing configured to cover at least a portion of the substrate, the housing configured to be secured to the patient via the substrate;

a circuit board positioned within the housing, the circuit board comprising a first surface and a second surface, the second surface positioned closer to the substrate than the first surface, the circuit board including a plurality of openings spaced inward from a perimeter of the circuit board and extending through the circuit board; and

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a temperature sensor responsive to thermal energy of the patient and positioned within the housing, said temperature sensor positioned above the first surface of the circuit board and the plurality of openings in the circuit board,

thermally conductive material positioned below the second surface of the circuit board and said plurality of openings in the circuit board, wherein, when the wearable physiological sensor is in use, said temperature sensor is in thermal contact with a portion of the skin of the patient located proximate the opening of the substrate via said plurality of openings, said thermally conductive material, and the opening of the substrate.

78. The wearable physiological sensor of Claim 77, further comprising an electrocardiogram (ECG) sensor responsive to electrical signals generated by said patient's heart, said ECG sensor comprising a first electrode and a second electrode, the first electrode positioned within the housing and coupled to a first portion of the circuit board, the second electrode positioned outside of the housing and coupled to a second portion of the circuit board.

79. The wearable physiological sensor of Claim 78, further comprising a processor in communication with the temperature sensor and the ECG sensor, the processor configured to generate one or more signals representative of said thermal energy and electrical signals.

80. The wearable physiological sensor of Claim 77, wherein the substrate comprises a thermally insulating material, the substrate configured to insulate a region of the patient's skin surrounding the portion located proximate the opening of the substrate.

81. The wearable physiological sensor of Claim 77, wherein, when the wearable physiological sensor is assembled, the housing is spaced inwards from an exterior perimeter of the substrate.

82. A wearable physiological sensor for monitoring one or more physiological parameters of a patient, the wearable physiological sensor comprising:

a housing;

a base configured to secure the housing to skin of the patient;

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a circuit board positioned within the housing, the circuit board comprising a first surface and a second surface opposite the first surface, the second surface configured to be positioned closer to the patient's skin than the first surface when the base and housing are secured to the patient's skin, the circuit board including a plurality of openings spaced from a perimeter of the circuit board and extending through the circuit board;

a temperature sensor positioned within the housing above the first surface of the circuit board and said plurality of openings extending through the circuit board;

thermally conductive material positioned below the second surface of the circuit board and said plurality of openings, said thermally conductive material configured to transmit thermal energy of the patient toward said plurality of openings, said plurality of openings configured to allow said thermal energy to pass through the circuit board toward said temperature sensor;

a first electrode positioned within at least one of the housing and the base and in electrical communication with the circuit board, the first electrode configured to transmit one or more electrical signals responsive to electrical activity of a heart of the patient;

a second electrode positioned away from the housing and the base and configured for electrical communication with the circuit board via a lead, the second electrode configured to transmit one or more electrical signals responsive to electrical activity of the patient's heart; and

a processor in communication with the temperature sensor and the first and second electrodes, the processor configured to generate one or more signals responsive to said thermal energy and said one or more electrical signals.

83. The wearable physiological sensor of Claim 82, wherein the lead extends through an opening in the housing.

84. The wearable physiological sensor of Claim 83, further comprising a retractable reel positioned outside the housing, wherein the lead extends through the opening in the housing to the retractable reel, the retractable reel configured to store the lead in a coil when not in use.

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85. The wearable physiological sensor of Claim 82, wherein the circuit board further comprises an electrode opening and the base comprises an electrode opening, and wherein the first electrode is formed by electrically conductive material positioned within the electrode openings of the circuit board and base.

86. The wearable physiological sensor of Claim 82, further comprising an accelerometer, said accelerometer responsive to a linear acceleration of said patient.

87. The wearable physiological sensor of Claim 82, further comprising an acoustic respiration sensor responsive to vibrational motion of said patient, said acoustic respiration sensor being positioned on said circuit board, wherein said acoustic respiration sensor is in rigid structural communication with said circuit board so as to mechanically transmit sensed vibrational motion to an accelerometer.

88. The wearable physiological sensor of Claim 82, further comprising a wireless transceiver in communication with said processor, said wireless transceiver configured to transmit said generated signals responsive to said thermal energy and electrical signals.

89. The wearable physiological sensor of Claim 82, further comprising:

a battery electrically connected to the circuit board and positioned within the housing; and

a mounting frame, said mounting frame configured to provide rigid structural support between said base and said circuit board.

90. The wearable physiological sensor of Claim 82, wherein, when the wearable physiological sensor is assembled, the housing is spaced inwards from an exterior perimeter of the base.

91. The wearable physiological sensor of Claim 82, the base comprising a top substrate and a bottom substrate, the top substrate configured for placement over a portion of the housing and the bottom substrate.

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92. The wearable physiological sensor of Claim 91, wherein the portion of the housing is a rim of the housing, the rim extending around an outer surface of the housing.

93. A system comprising:

a wearable device comprising:

a housing comprising an interior;

a base configured to secure the housing to a chest of a subject, the base comprising a foam material and an adhesive material configured to adhere to skin of the subject's chest, the base configured to insulate a portion of the subject's skin when the base is secured to the subject's chest;

a circuit board positioned within the interior of the housing;

a battery positioned within the interior of the housing adjacent said circuit board;

an inertial measurement unit positioned within the interior of the housing and coupled to the circuit board, the inertial measurement unit configured to generate a first set of signals responsive to acceleration of the subject and a second set of signals responsive to angular velocity of the subject;

a temperature sensor positioned within the interior of the housing and coupled to the circuit board, the temperature sensor configured to generate one or more signals responsive to thermal energy radiating from the portion of the subject's skin insulated by the base; and

a thermally conductive material positioned below the circuit board and said temperature sensor, said thermally conductive material configured to transmit said thermal energy toward said temperature sensor; and

one or more processors configured to receive and process said first and second sets of signals generated by said inertial measurement unit to determine orientation of the subject relative to a bed when the subject is laying in said bed, said one or more processors further configured to determine body temperature of the subject based on said one or more signals generated by said temperature sensor responsive to said thermal energy.

94. The system of Claim 93, wherein:

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said first set of signals are responsive to acceleration of the subject relative to a roll axis, a pitch axis, and a yaw axis;

said second set of signals are responsive to angular velocity of the subject relative to said roll axis, said pitch axis, and said yaw axis; and

said roll axis corresponds to a longitudinal axis extending along a length of said subject's body, said pitch axis corresponds to hips of said subject, and said yaw axis corresponds to a horizontal plane in which said subject is located.

95. The system of Claim 93 or 94, wherein said wearable device further comprises a button on a portion of the housing, said button configured for changing a mode of the wearable device.

96. The system of any one of Claims 93 to 95, wherein said wearable device further comprises an oximetry sensor for measuring oxygen saturation of the subject.

97. The system of any one of Claims 93 to 96, wherein said wearable device further comprises an electrocardiogram sensor for monitoring cardiac activity of the subject.

98. The system of any one of Claims 93 to 97, wherein said temperature sensor comprises a thermistor.

99. The system of any one of Claims 93 to 98, further comprising a portable computing device, said portable computing device comprising said one or more processors and a wireless transceiver configured to receive, from a wireless transceiver of said wearable device, said first and second sets of signals generated by said inertial measurement unit and said one or more signals generated by said temperature sensor.

100. The system of Claim 99, wherein said one or more processors are configured to determine a score indicative of a wellness state of the subject based upon at least said received one or more signals generated by said temperature sensor.

101. The system of Claim 99, wherein said portable computing device is a patient monitor comprising said one or more processors, said wireless transceiver, a display,

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and a docking station configured to mechanically and electrically mate with another portable computing device.

102. The system of Claim 93, wherein said wearable device comprises said one or more processors.

103. A system comprising:

a wearable device comprising:

a housing comprising an interior;

a base configured to secure the housing to a chest of a subject, the base comprising a foam material and an adhesive material configured to adhere to skin of the subject's chest, wherein the base is configured to insulate a portion of the subject's skin when the base is secured to the subject's chest;

a circuit board positioned within the interior of the housing;

a battery positioned within the interior of the housing adjacent said circuit board;

a temperature sensor positioned within the interior of the housing and coupled to the circuit board, the temperature sensor configured to generate one or more signals responsive to thermal energy radiating from the portion of the subject's skin insulated by the base;

a thermally conductive material positioned below the circuit board and said temperature sensor, said thermally conductive material configured to transmit said thermal energy toward said temperature sensor; and

a sensor for determining at least one of heart rate and respiration rate of the subject based on vibrations emanating from the subject's chest; and

one or more processors configured to receive one or more signals generated based upon said vibrations emanating from the subject's chest and said one or more signals generated by said temperature sensor responsive to said thermal energy, said one or more processors further configured to determine a score indicative of a wellness state of the subject based upon said one or more signals generated based upon said vibrations and said one or more signals generated by said temperature sensor.

104. The system of Claim 103, further comprising a portable computing device, said portable computing device comprising said one or more processors and a wireless

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transceiver configured to receive, from a wireless transceiver of said wearable device, said one or more signals generated based upon said vibrations and said one or more signals generated by said temperature sensor.

105. The system of Claim 104, wherein said portable computing device is a patient monitor comprising said one or more processors, said wireless transceiver, a display, and a docking station configured to mechanically and electrically mate with another portable computing device.

106. The system of Claim 104, wherein said wearable device further comprises an oximetry sensor for measuring oxygen saturation of the subject.

107. The system of Claim 104, wherein said wearable device further comprises an electrocardiogram sensor for monitoring cardiac activity of the subject.

108. The system of Claim 104, wherein said wearable device comprises said one or more processors.

109. A system comprising:

a wearable device comprising:

a housing comprising an interior;

a base configured to secure the housing to skin of a subject;

a circuit board positioned within the interior of the housing;

an inertial measurement unit positioned within the interior of the housing and coupled to the circuit board, the inertial measurement unit configured to generate one or more signals responsive to at least one of acceleration and angular velocity of the subject;

a temperature sensor positioned within the interior of the housing and coupled to the circuit board, the temperature sensor configured to generate one or more signals responsive to thermal energy radiating from a portion of the subject's skin underneath the base;

a thermally conductive material positioned below the circuit board and said temperature sensor, said thermally conductive material configured to transmit said thermal energy toward said temperature sensor; and

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one or more processors configured to receive and process said one or more signals generated by said inertial measurement unit to determine at least one of orientation and movement of the subject, said one or more processors further configured to determine body temperature of the subject based on said one or more signals generated by said temperature sensor responsive to said thermal energy.

110. The system of Claim 109, wherein said wearable device further comprises an oximetry sensor for measuring oxygen saturation of the subject and an electrocardiogram sensor for monitoring cardiac activity of the subject.

111. The system of Claim 109 or 110, wherein said base is configured to secure the housing to skin of the subject's chest, and wherein said wearable device is configured to determine at least one of heart rate and respiration rate of the subject based on vibrations emanating from the subject's chest.

112. The system of any one of Claims 109 to 111, wherein said one or more processors are configured to receive and process said one or more signals generated by said inertial measurement unit to determine an amount of time the subject is in a supine position, a left side position, and a right side position.

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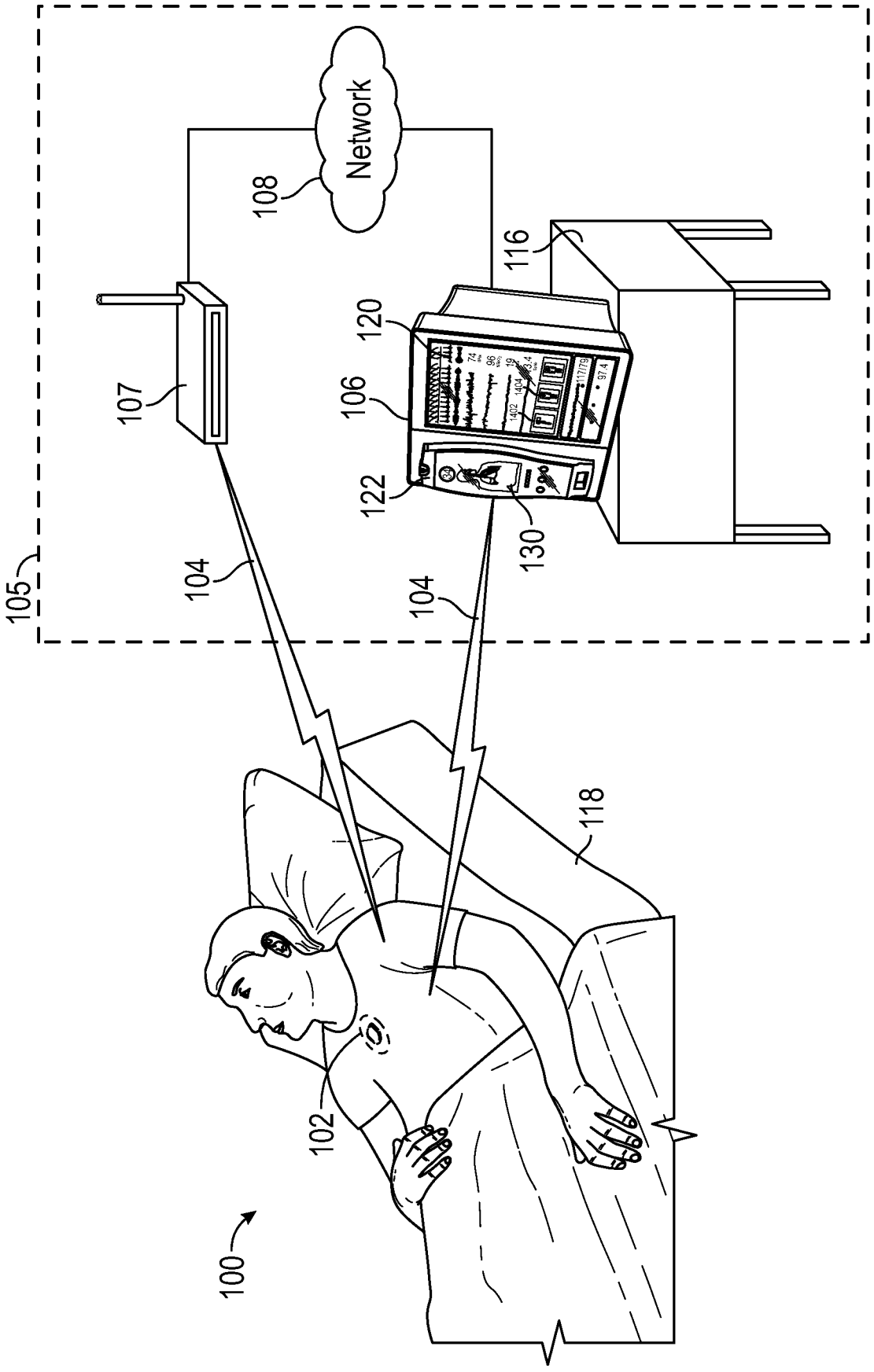


FIG. 1A

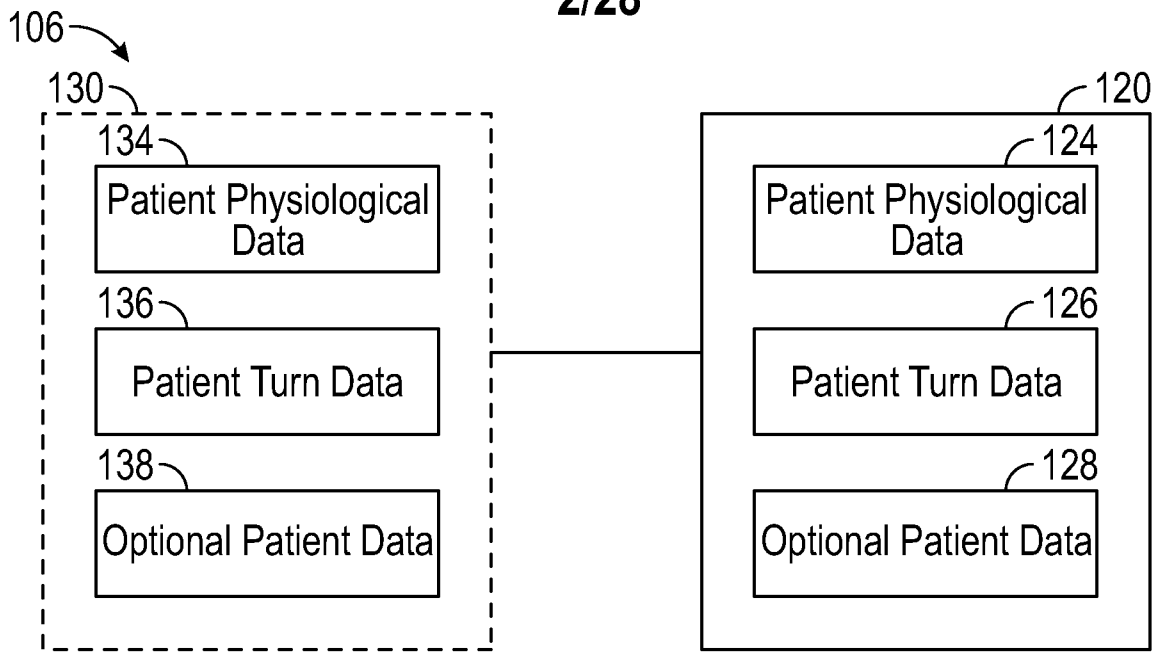

106
130
134
Patient Physiological Data
136
Patient Turn Data
138
Optional Patient Data
120
124
Patient Physiological Data
126
Patient Turn Data
128
Optional Patient Data

FIG. 1B

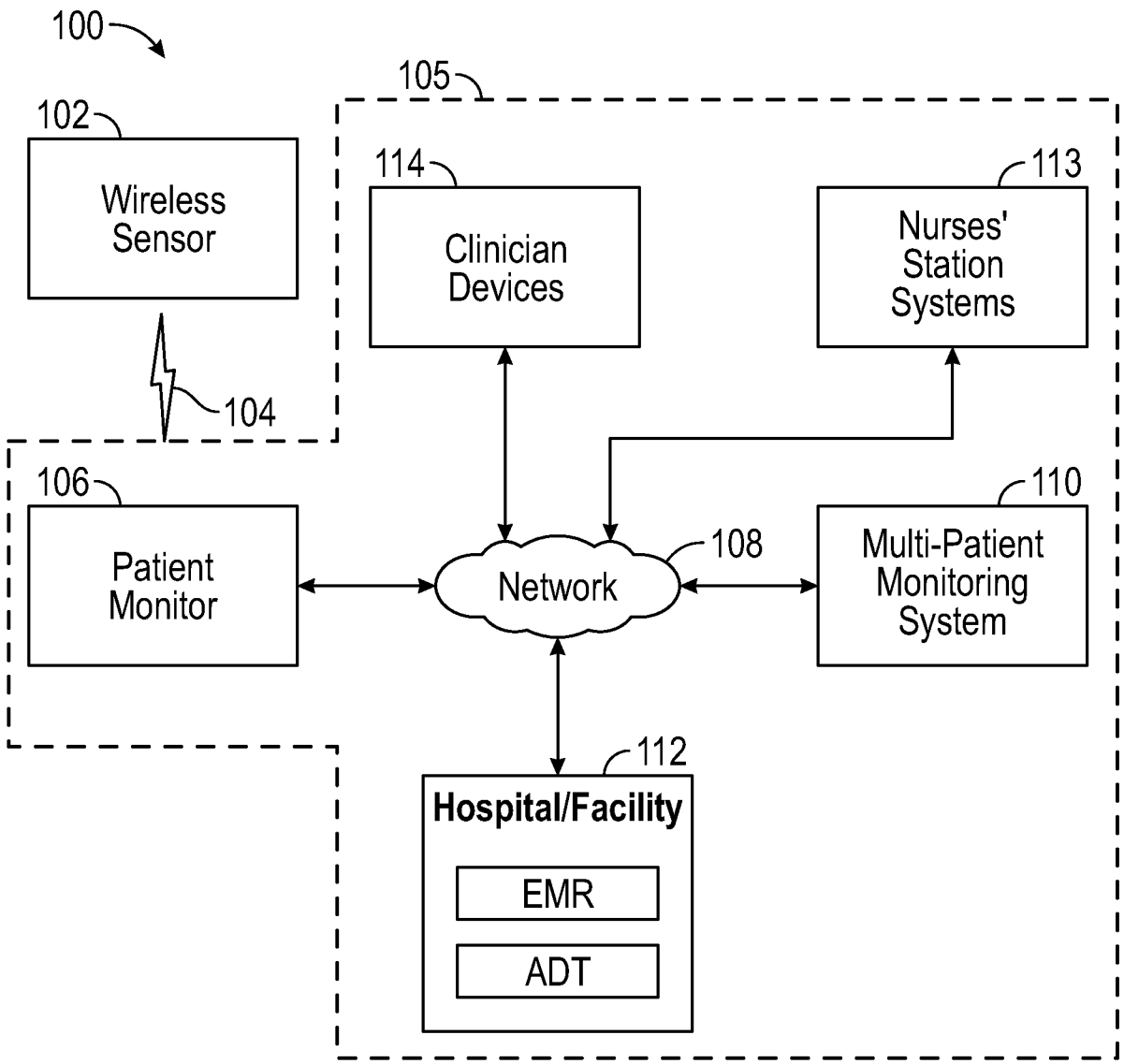

100
105
102
Wireless Sensor
104
114
Clinician Devices
113
Nurses' Station Systems
106
Patient Monitor
Network
108
110
Multi-Patient Monitoring System
112
Hospital/Facility
EMR
ADT

FIG. 1C

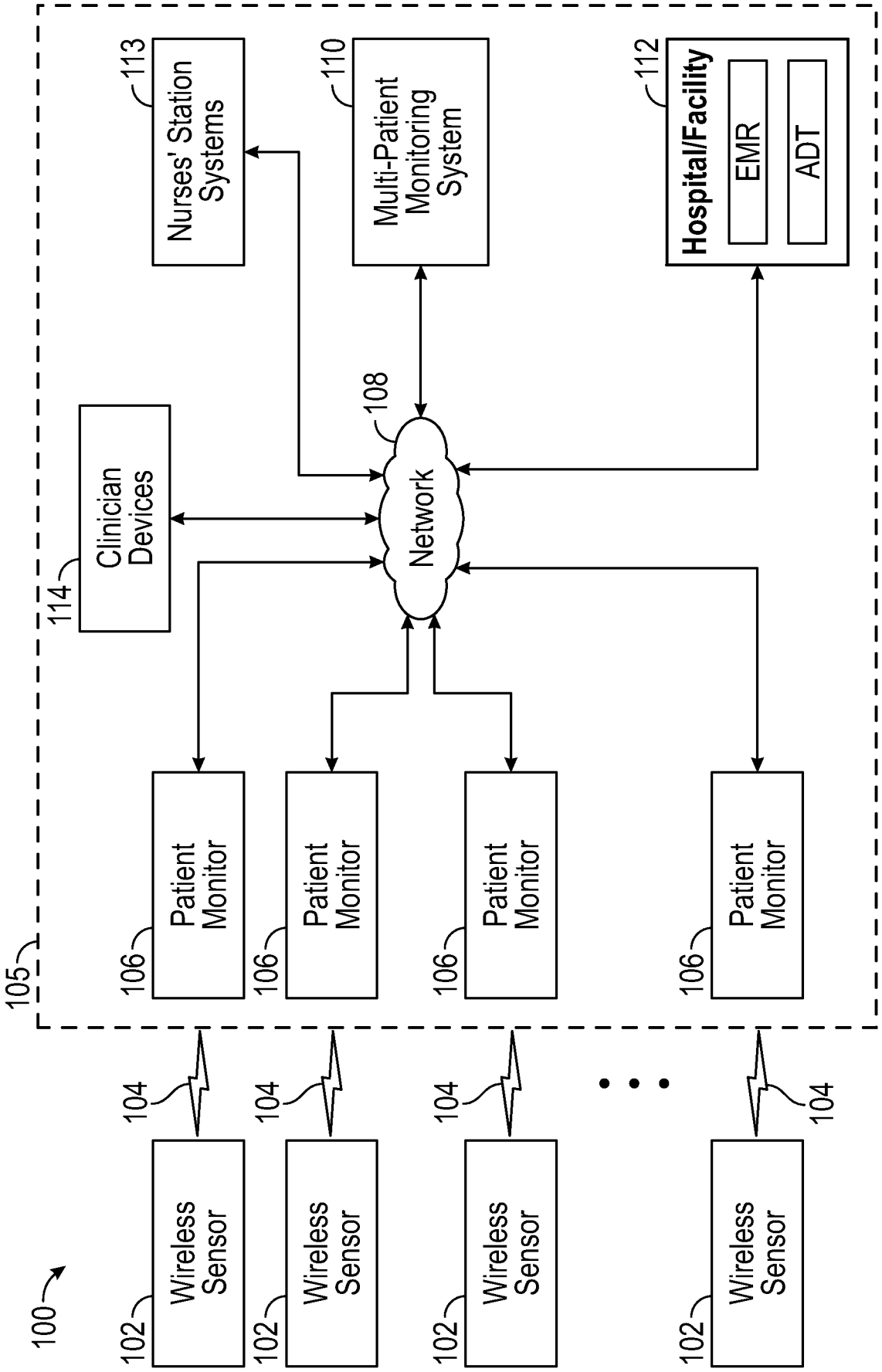

100
102
Wireless Sensor
104
105
106
Patient Monitor
108
Network
110
Multi-Patient Monitoring System
112
Hospital/Facility
EMR
ADT
113
Nurses' Station Systems
114
Clinician Devices

FIG. 1D

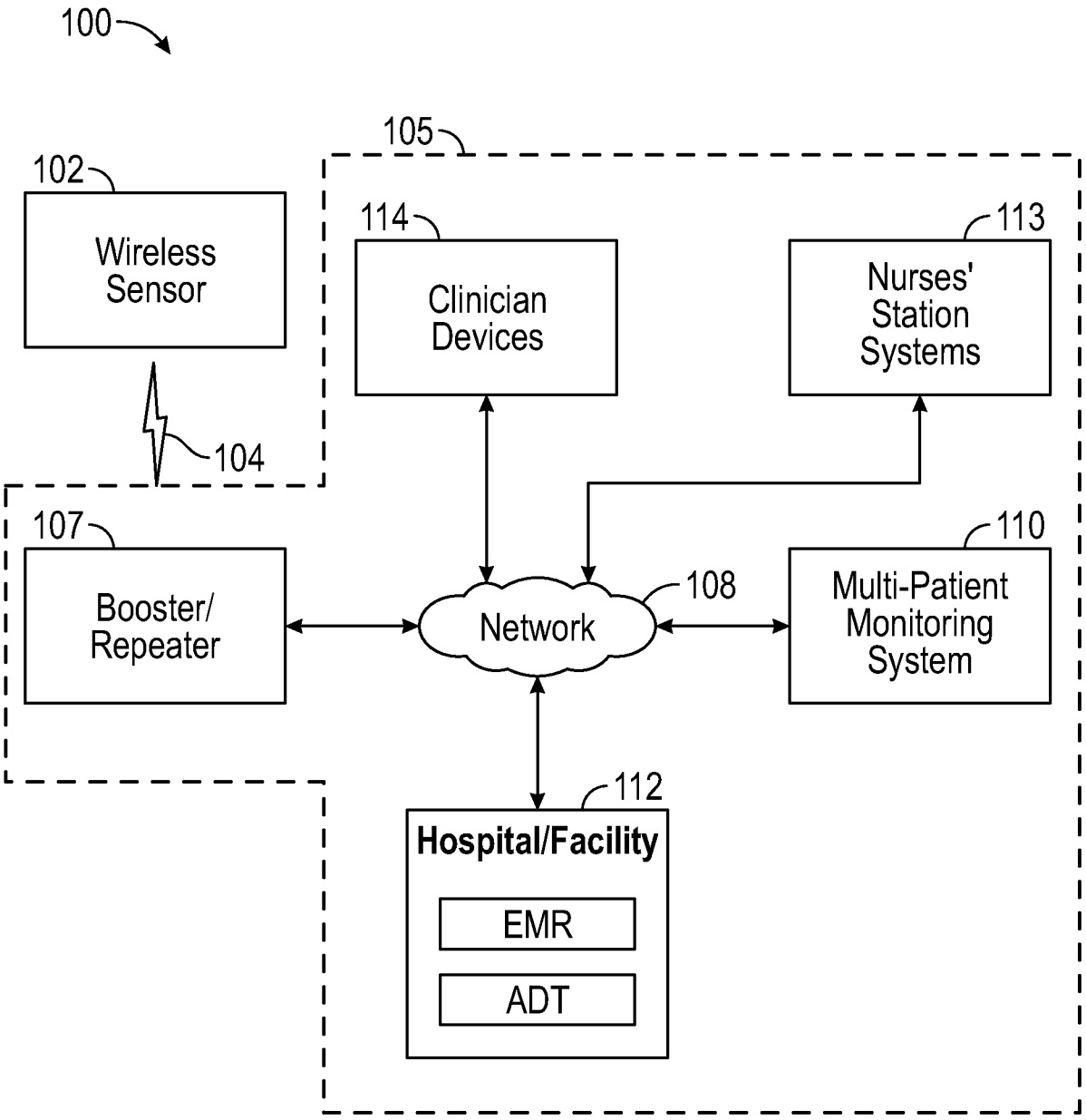

100
105
102
Wireless Sensor
114
Clinician Devices
113
Nurses' Station Systems
104
107
Booster/ Repeater
108
Network
110
Multi-Patient Monitoring System
112
Hospital/Facility
EMR
ADT

FIG. 1E

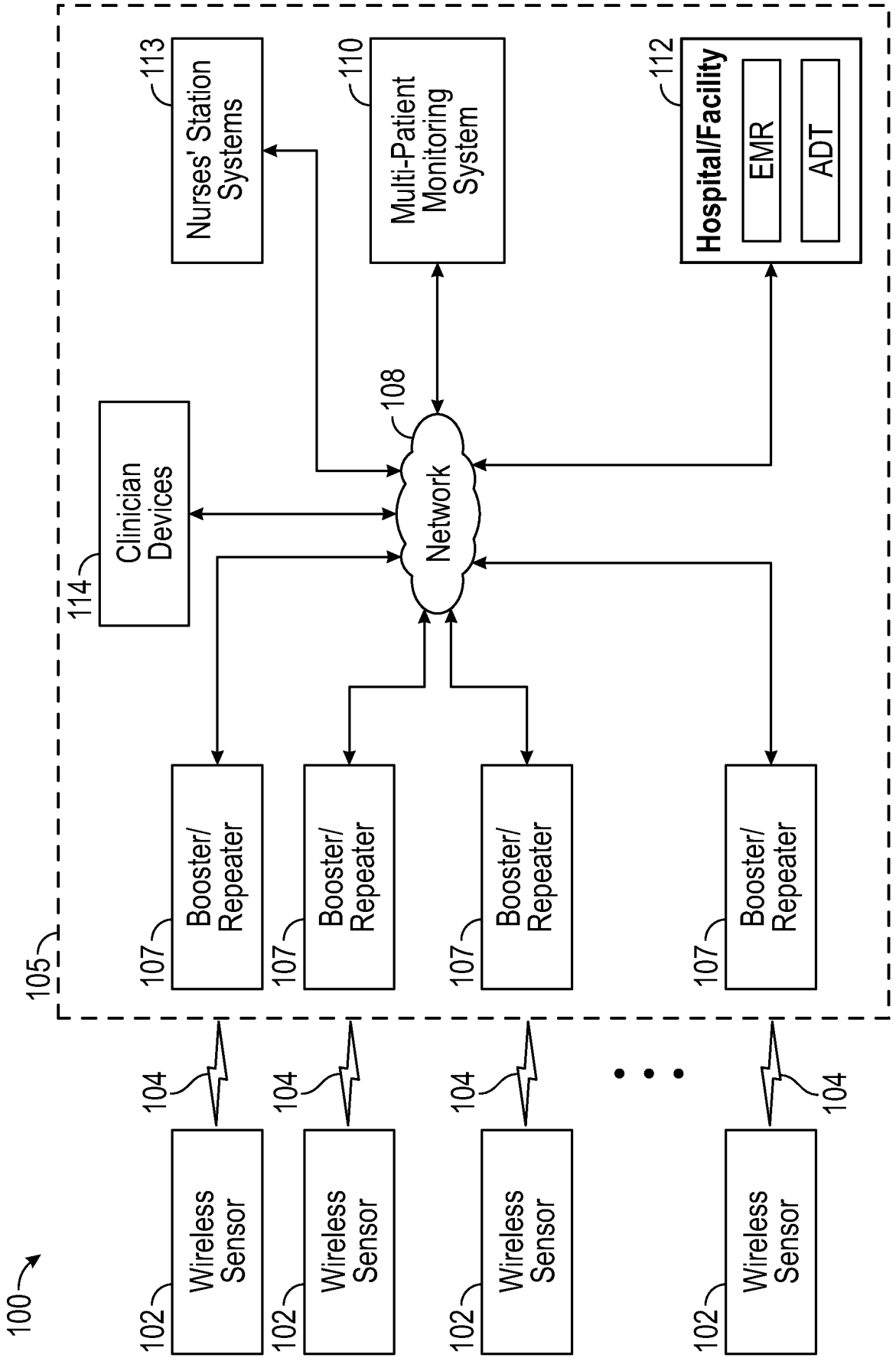

100
105
102
Wireless Sensor
104
107
Booster/ Repeater
108
Network
110
Multi-Patient Monitoring System
112
Hospital/Facility
EMR
ADT
113
Nurses' Station Systems
114
Clinician Devices

FIG. 1F

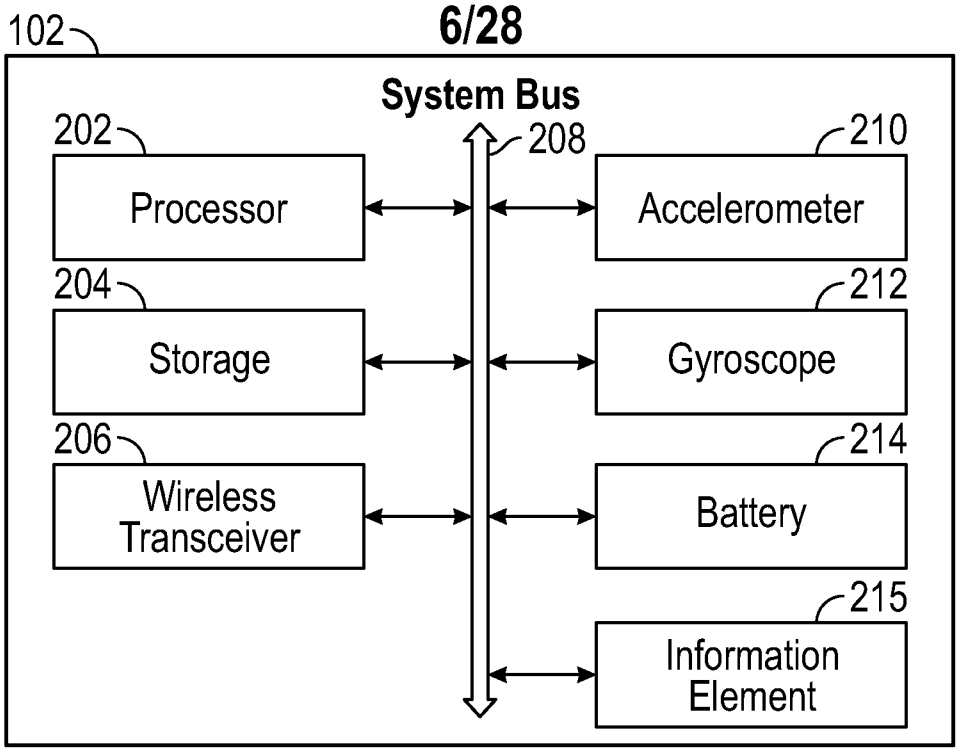

102
System Bus
202
Processor
204
Storage
206
Wireless Transceiver
208
210
Accelerometer
212
Gyroscope
214
Battery
215
Information Element

FIG. 2A

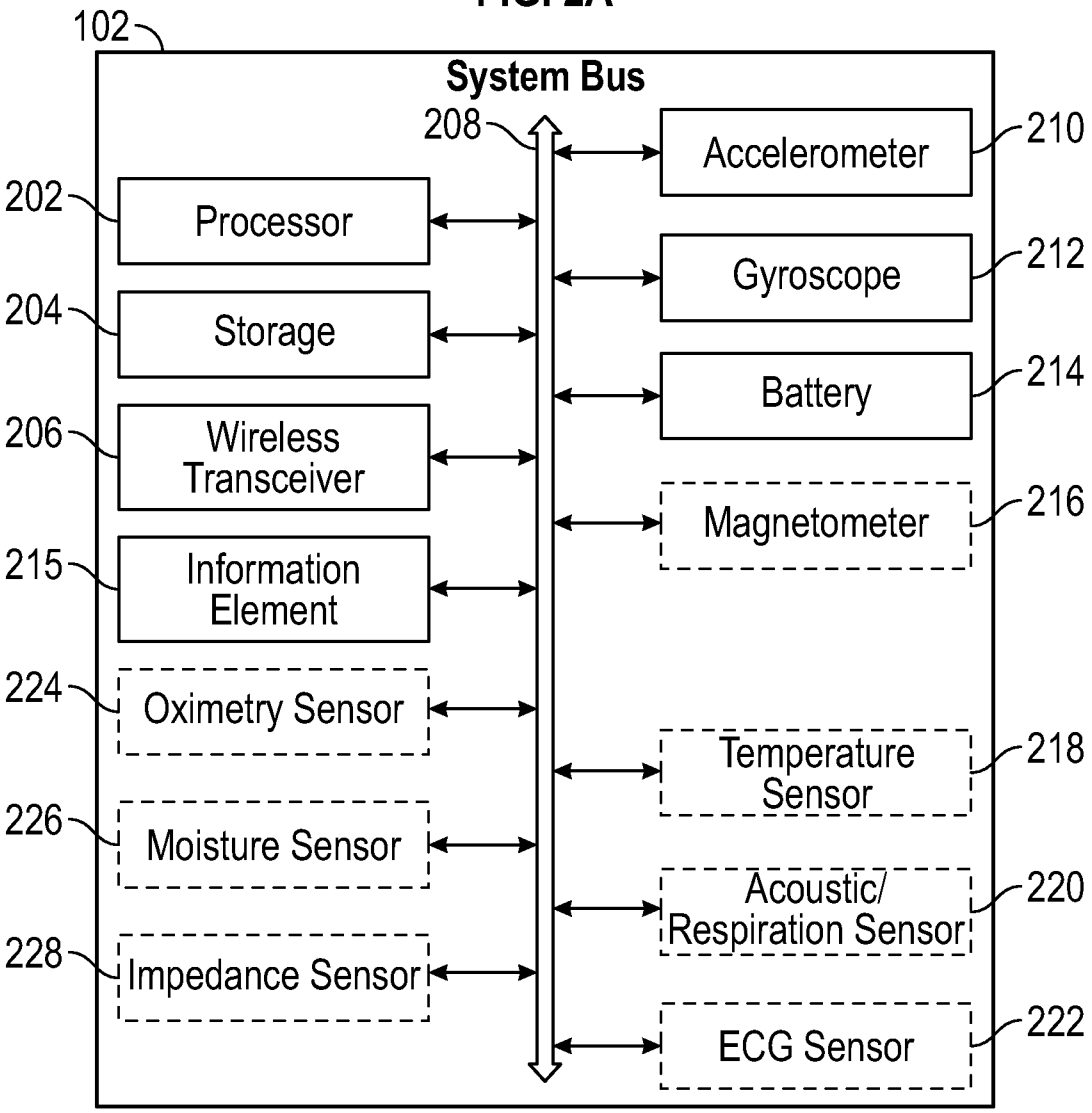

102
System Bus
208
202
Processor
204
Storage
206
Wireless Transceiver
215
Information Element
224
Oximetry Sensor
226
Moisture Sensor
228
Impedance Sensor
210
Accelerometer
212
Gyroscope
214
Battery
216
Magnetometer
218
Temperature Sensor
220
Acoustic/ Respiration Sensor
222
ECG Sensor

FIG. 2B

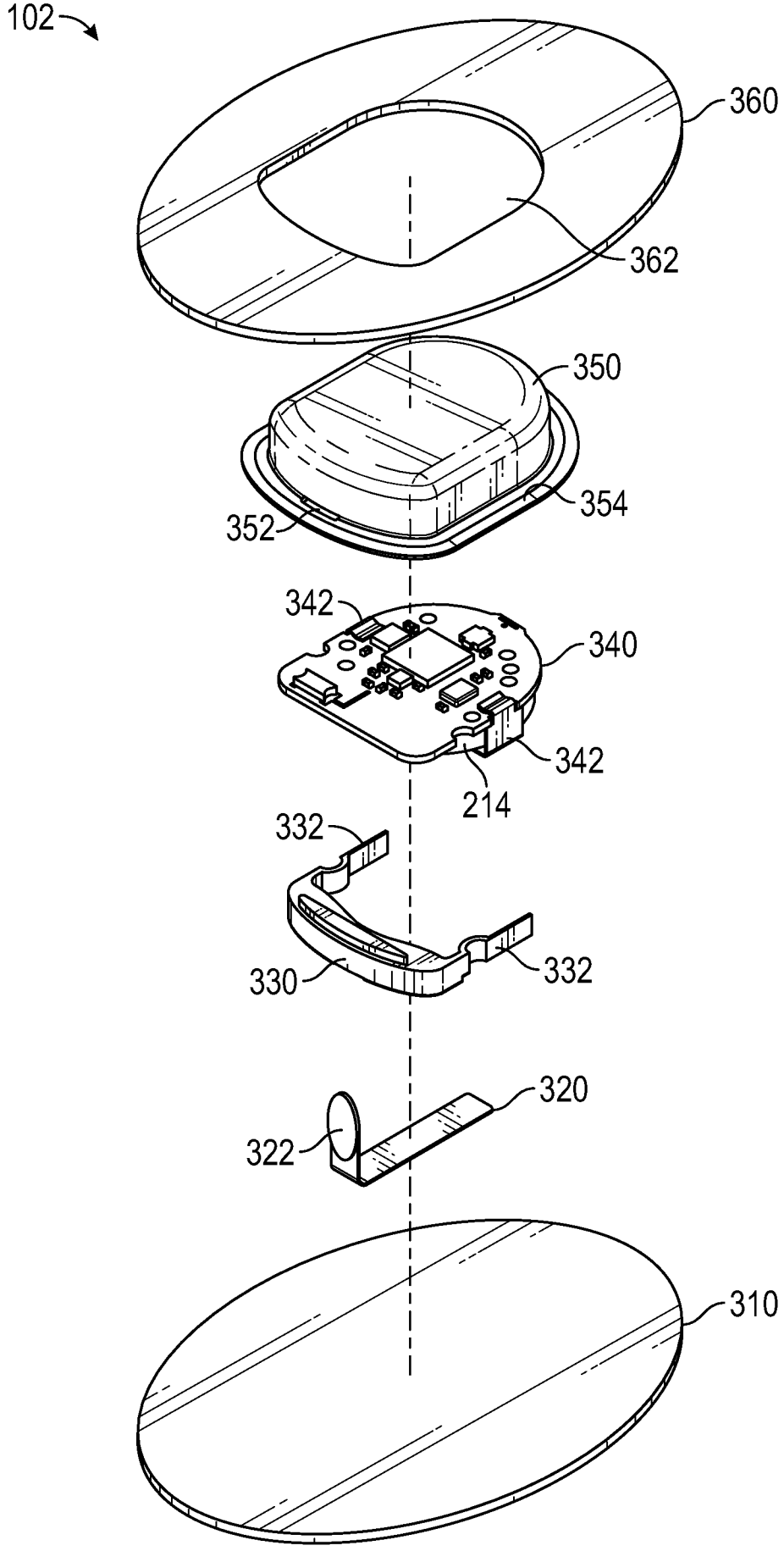


FIG. 3A

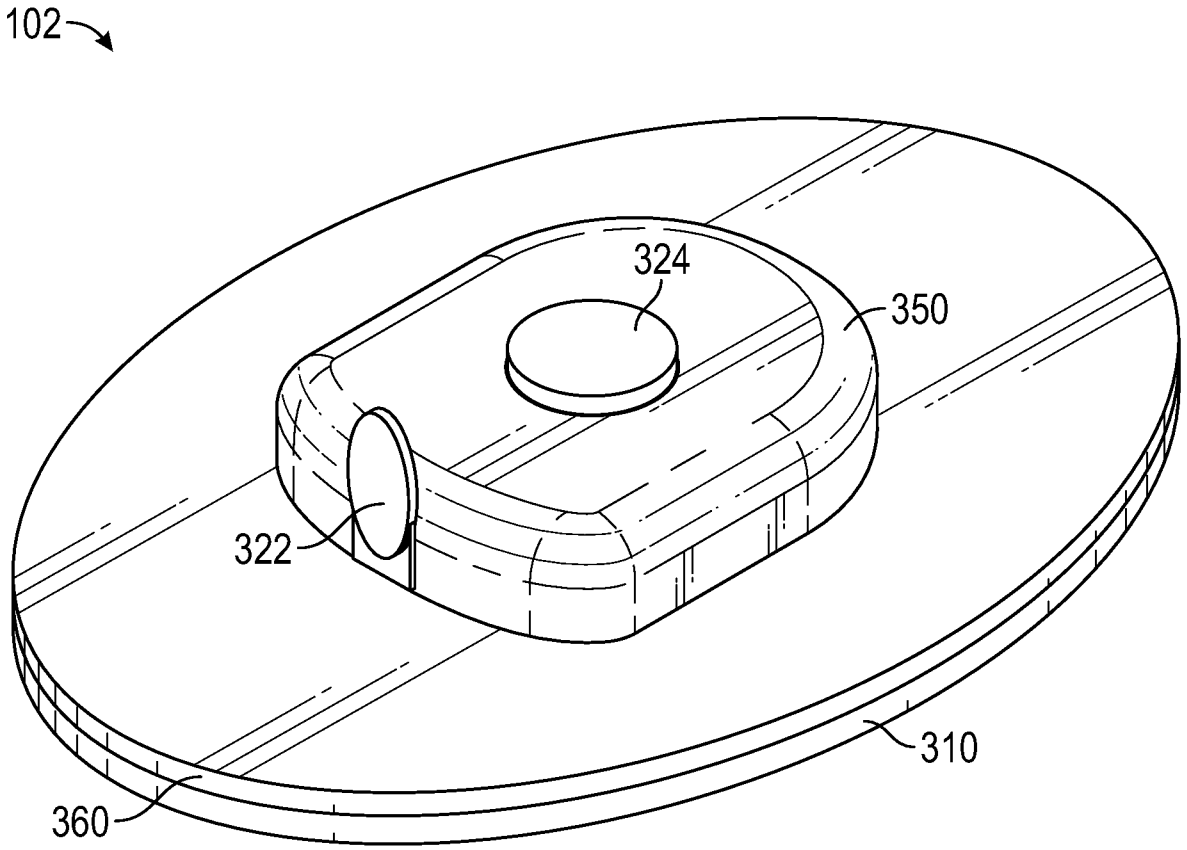


FIG. 3B

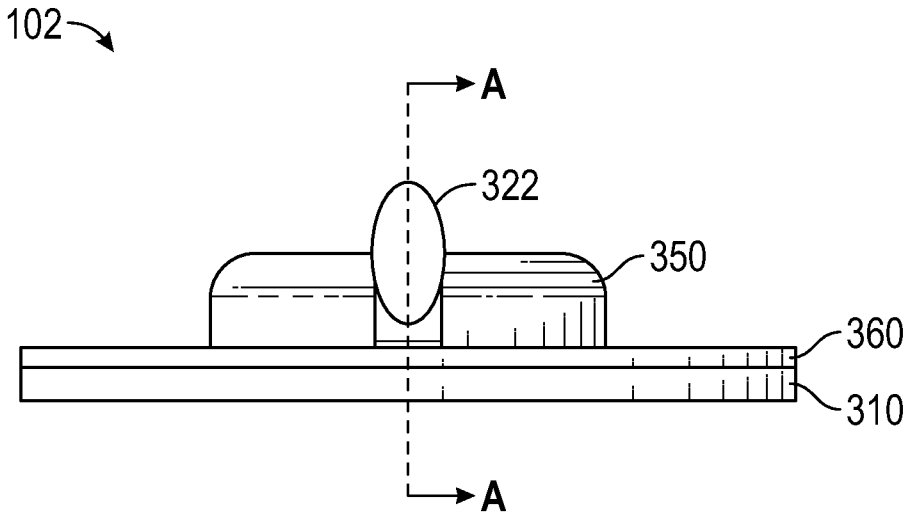


FIG. 3C

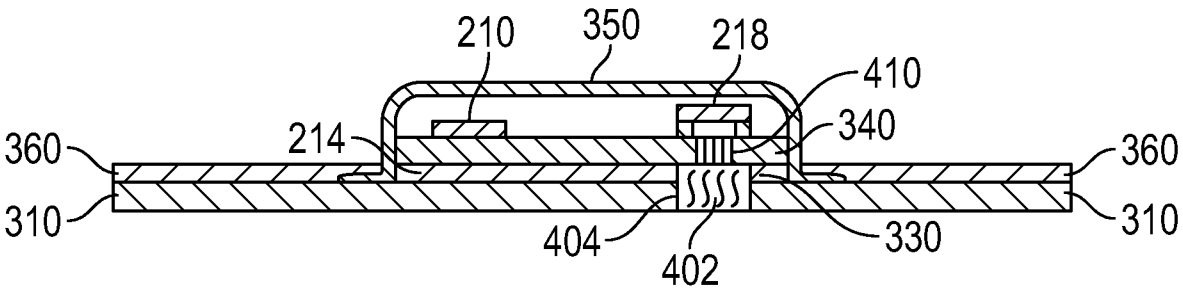

210
350
218
410
214
340
360
360
310
310
404
402
330

FIG. 4A

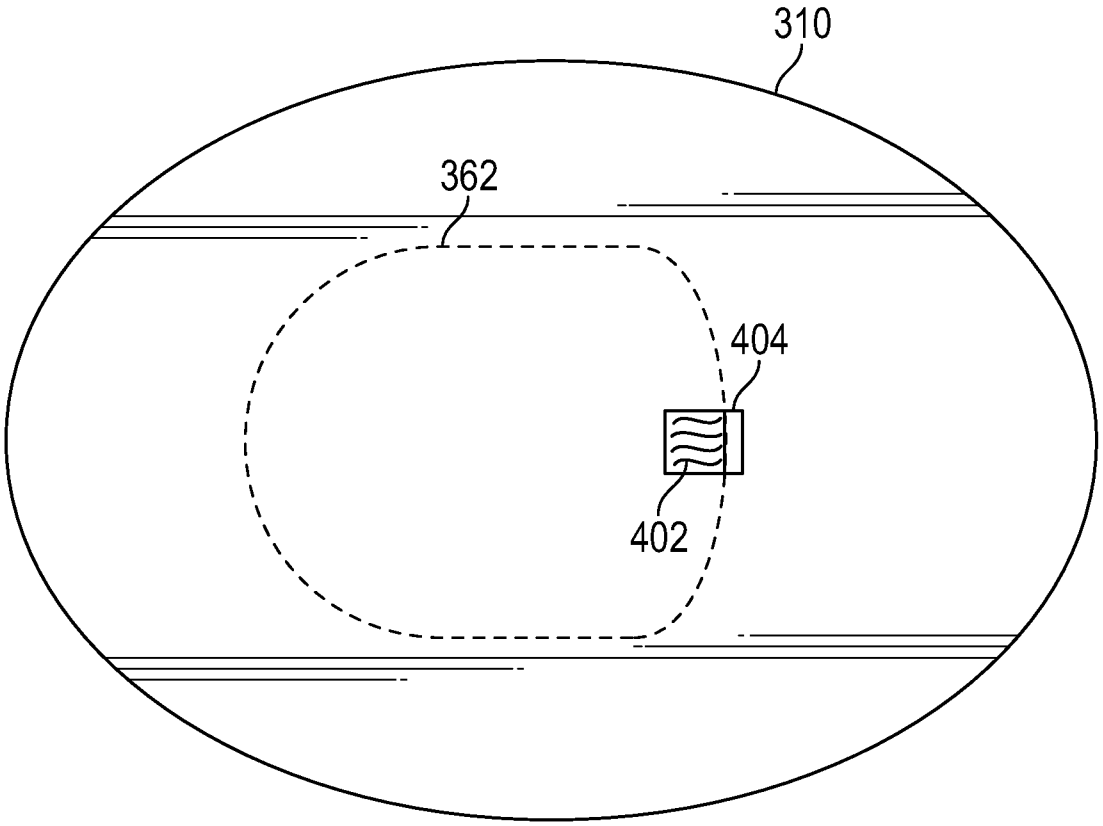

310
362
404
402

FIG. 4B

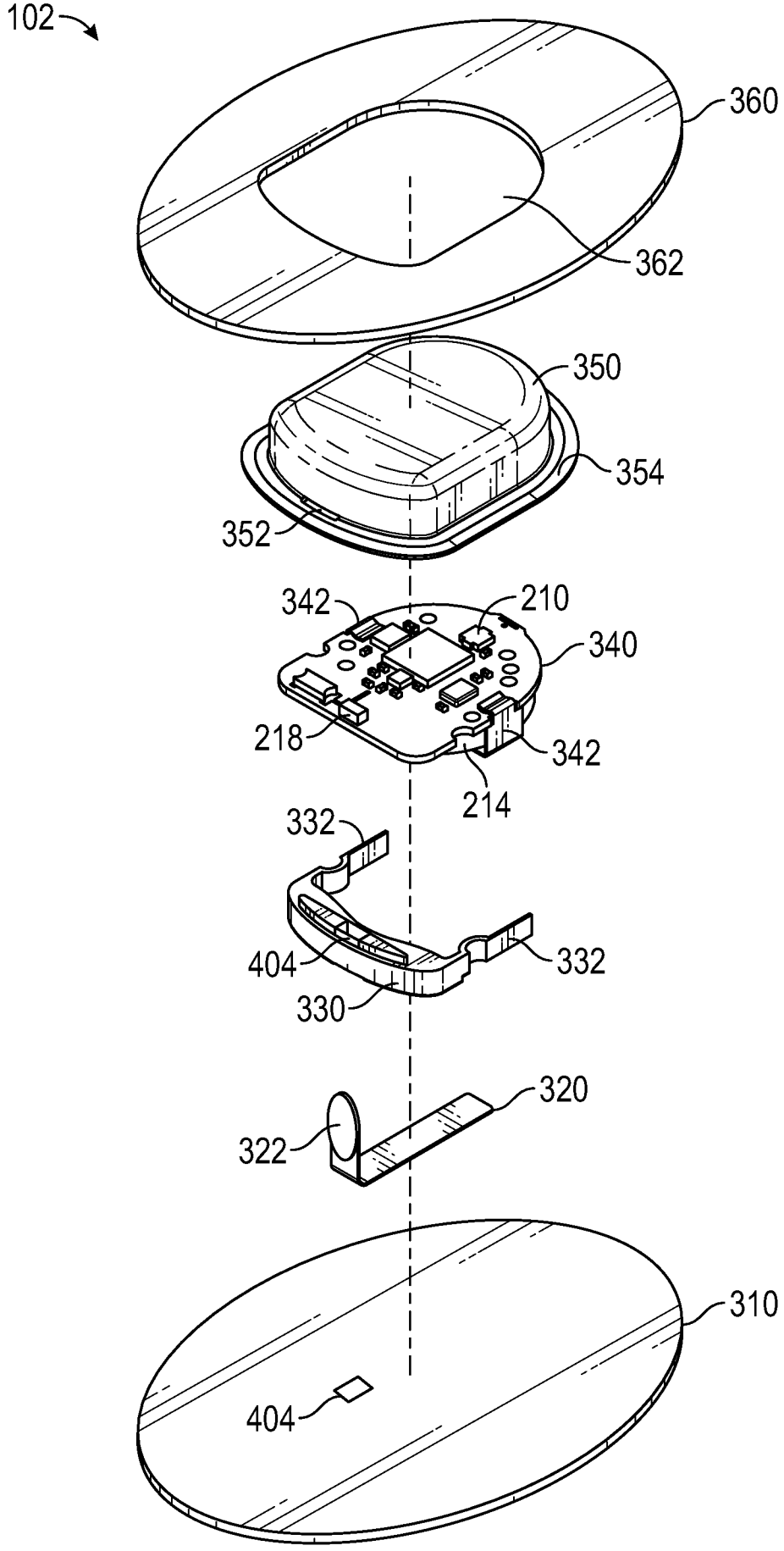

102
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362
350
354
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342
210
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214
332
404
332
330
320
322
310
404

FIG. 4C

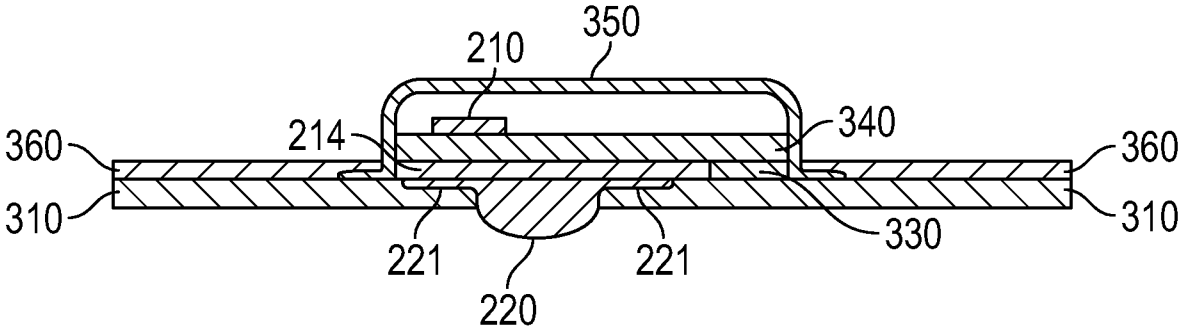


FIG. 5A

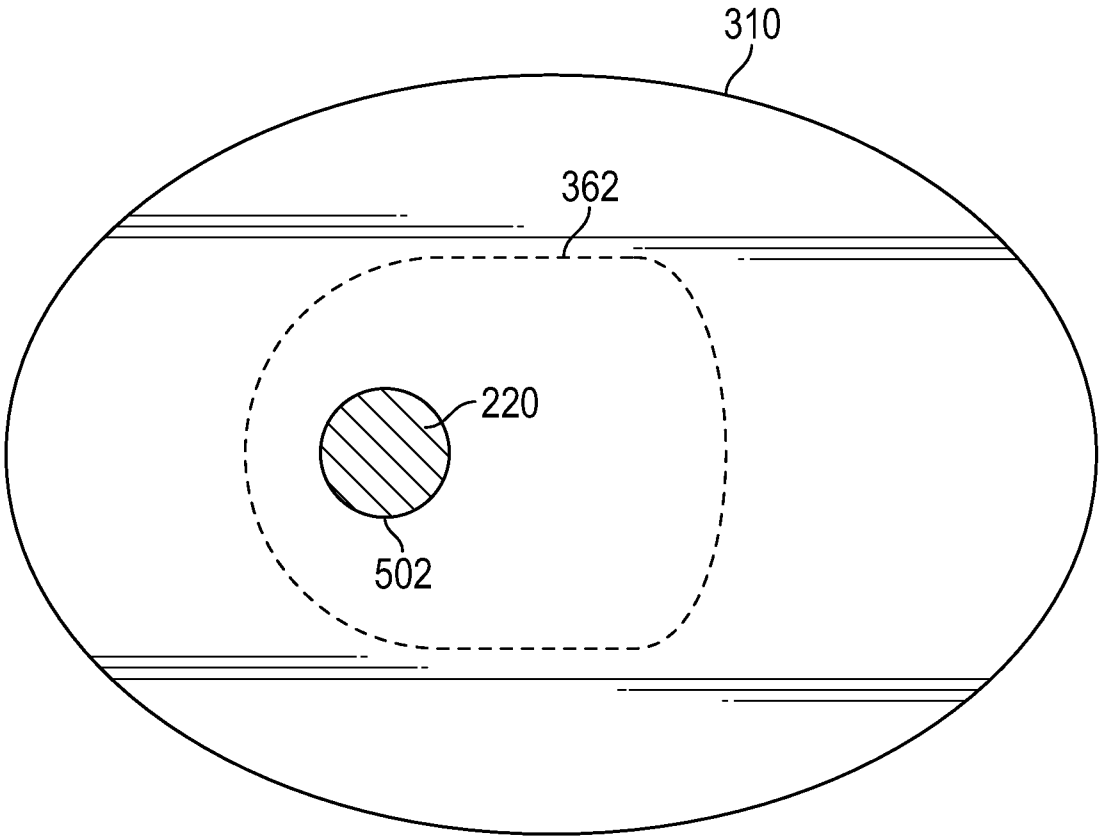


FIG. 5B

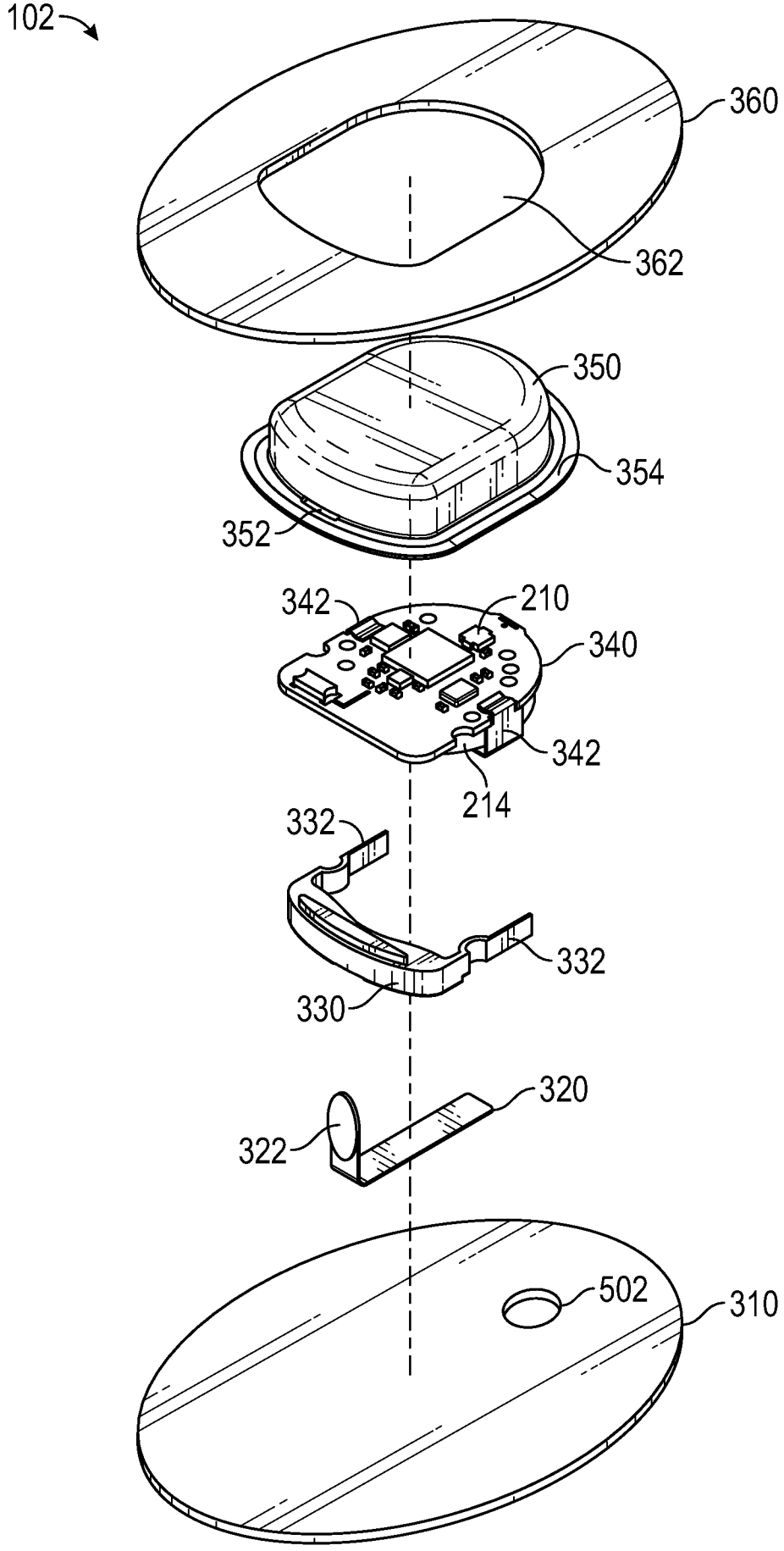

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502
310

FIG. 5C

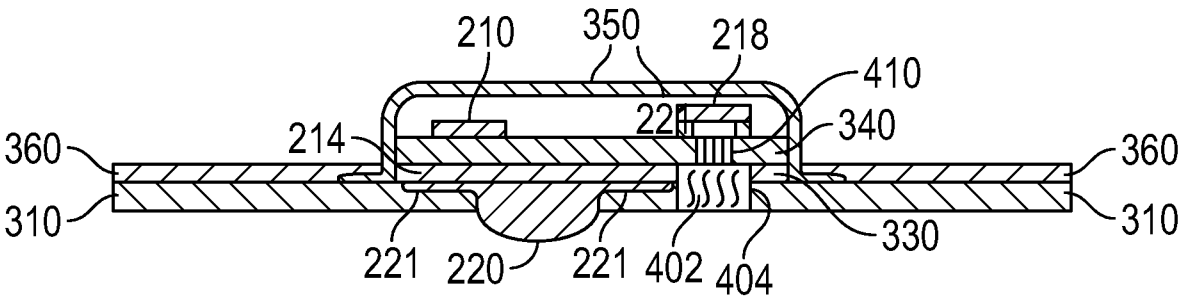

210
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410
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220
221
402
404

FIG. 6A

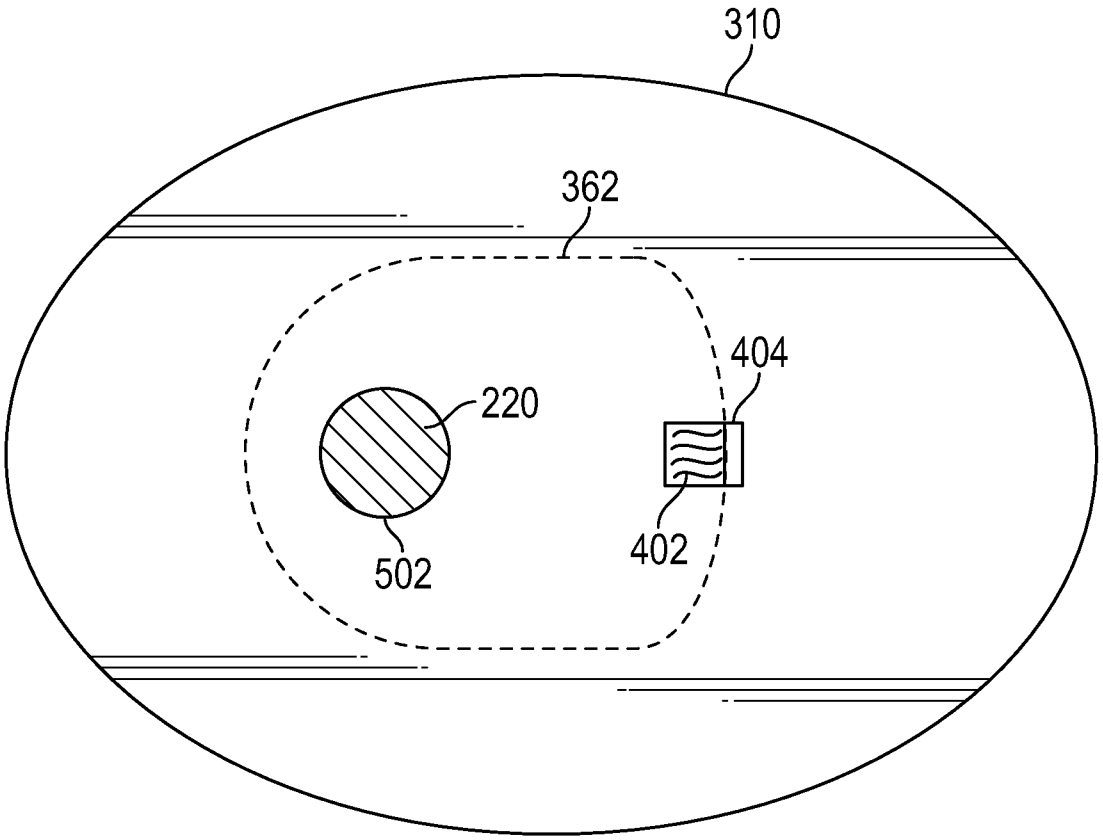

310
362
404
220
502
402

FIG. 6B

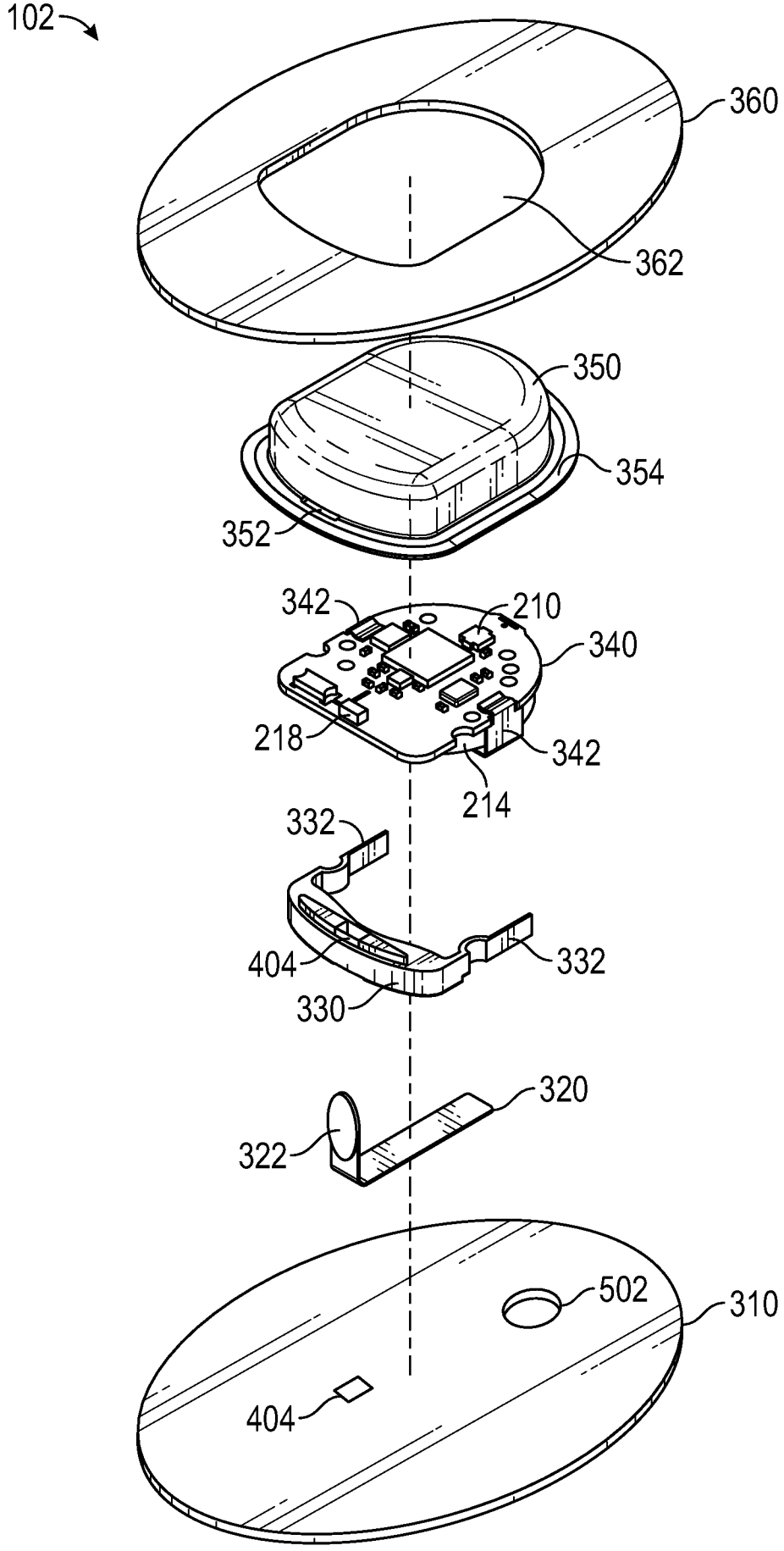

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404

FIG. 6C

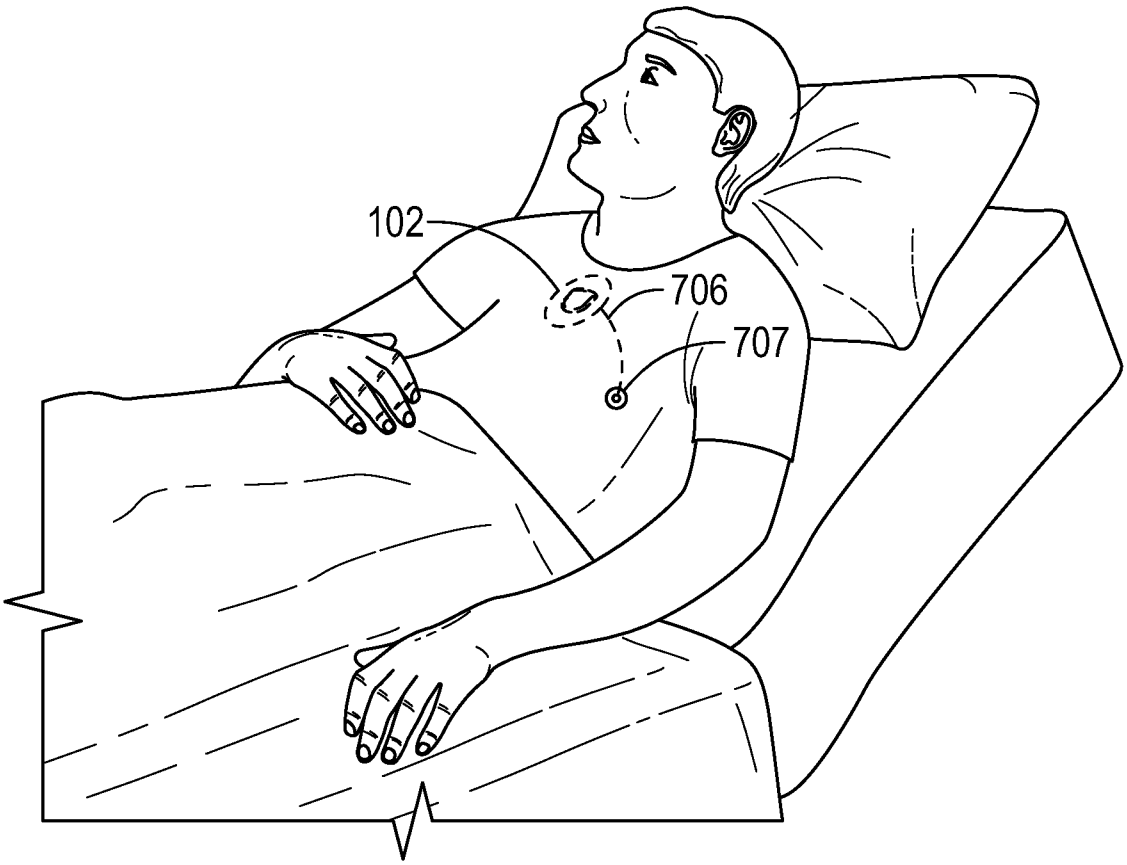


FIG. 7A

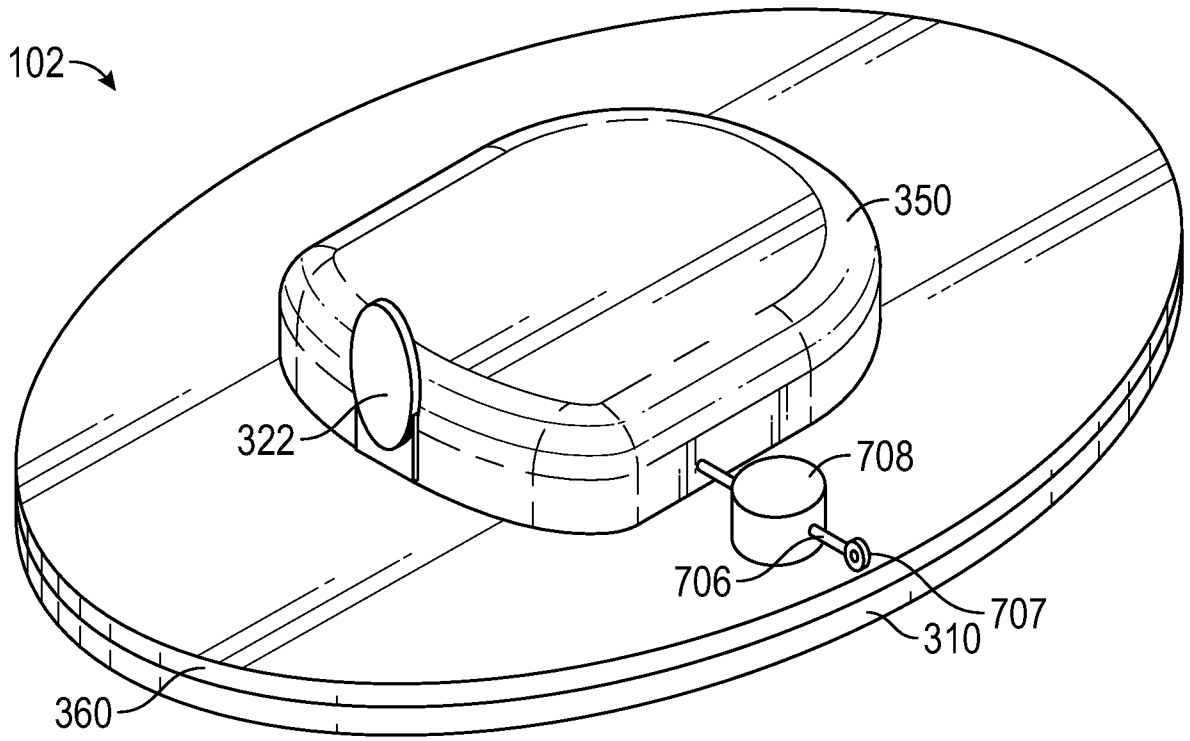


FIG. 7B

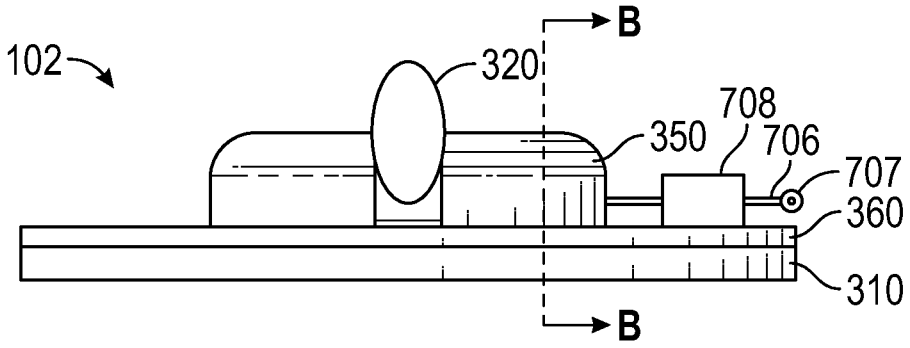


FIG. 7C

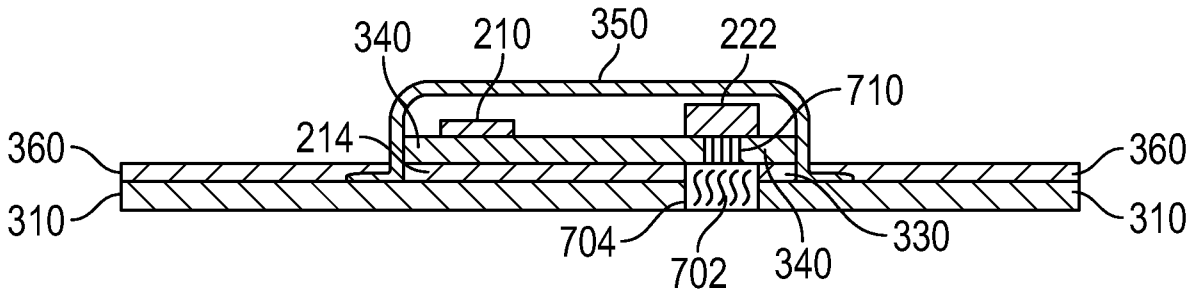


FIG. 7D

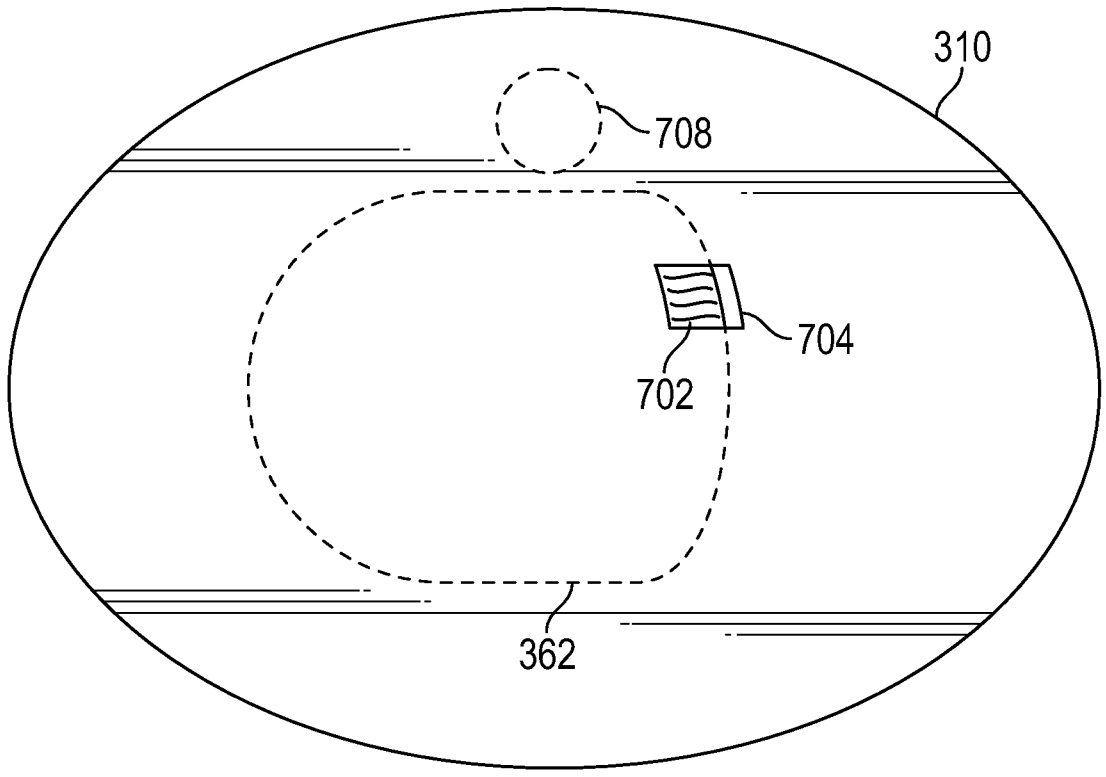


FIG. 7E

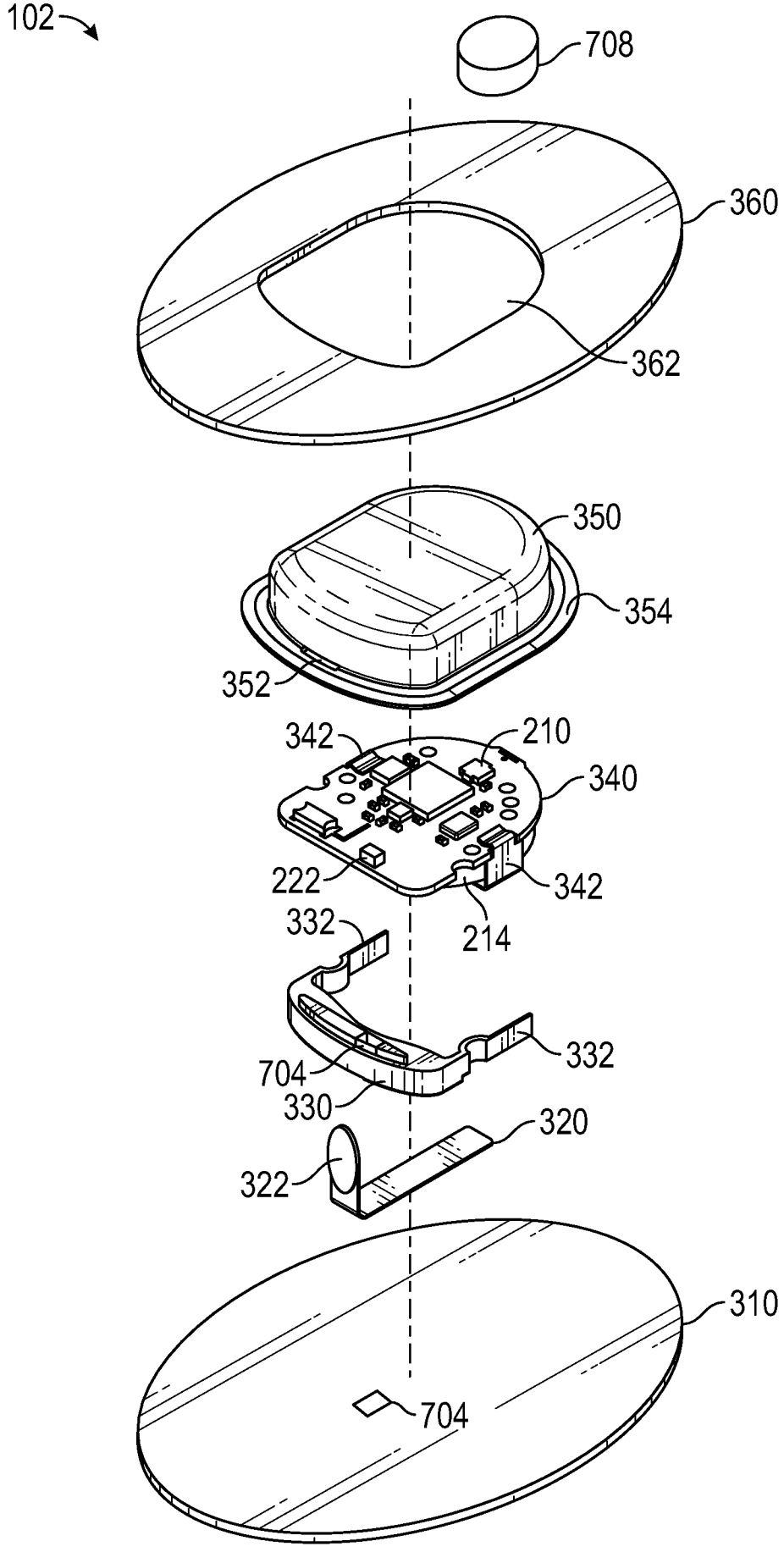

102
708
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362
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704

FIG. 7F

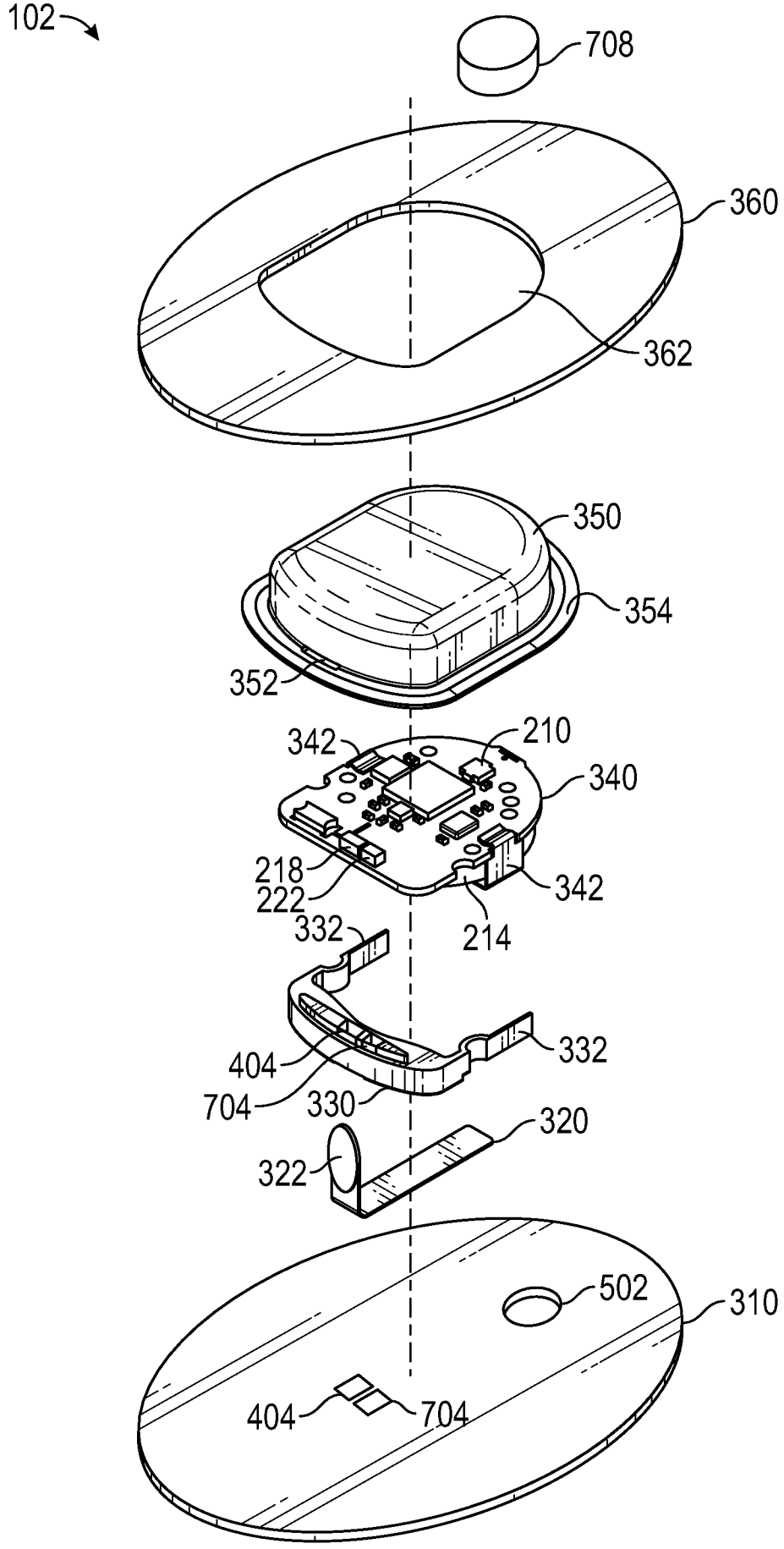

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222
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502
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404
704

FIG. 8A

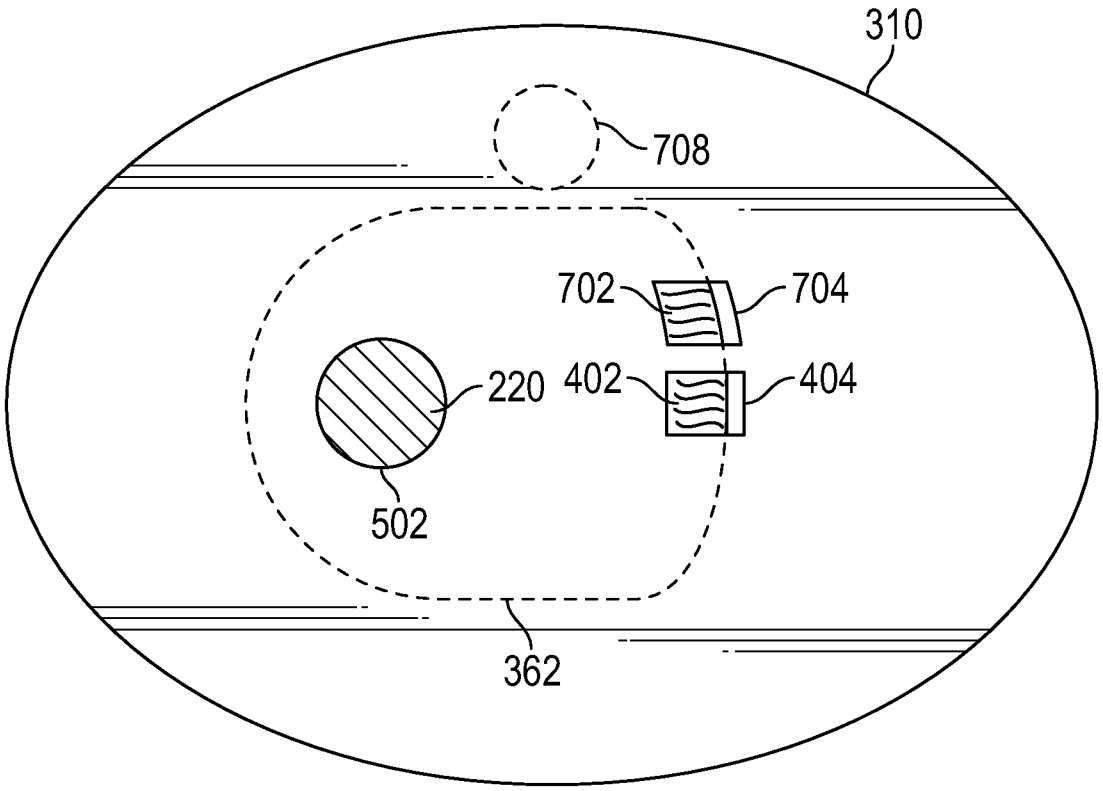


FIG. 8B

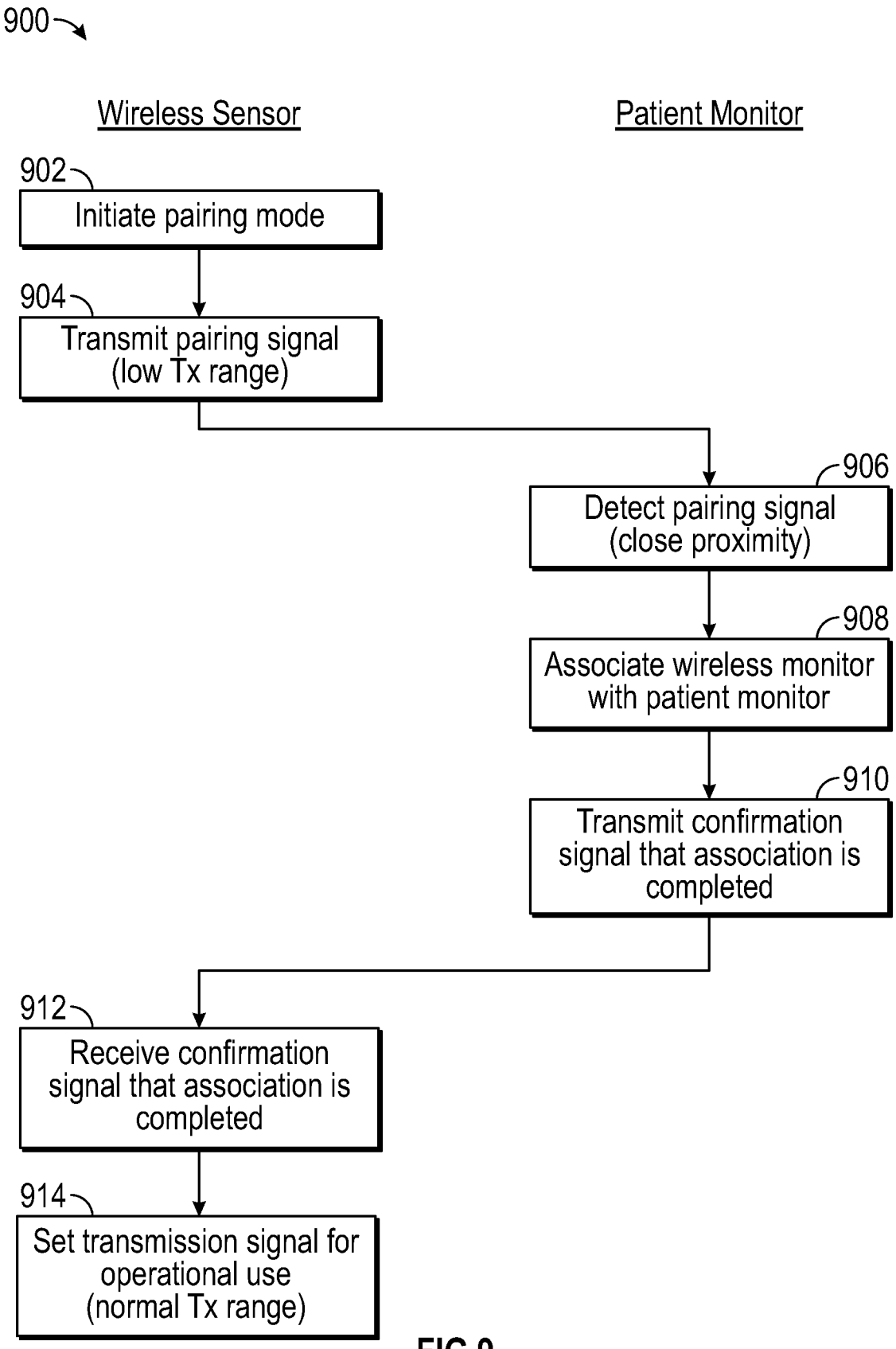

900
Wireless Sensor
Patient Monitor
902
Initiate pairing mode
904
Transmit pairing signal (low Tx range)
906
Detect pairing signal (close proximity)
908
Associate wireless monitor with patient monitor
910
Transmit confirmation signal that association is completed
912
Receive confirmation signal that association is completed
914
Set transmission signal for operational use (normal Tx range)

FIG.9

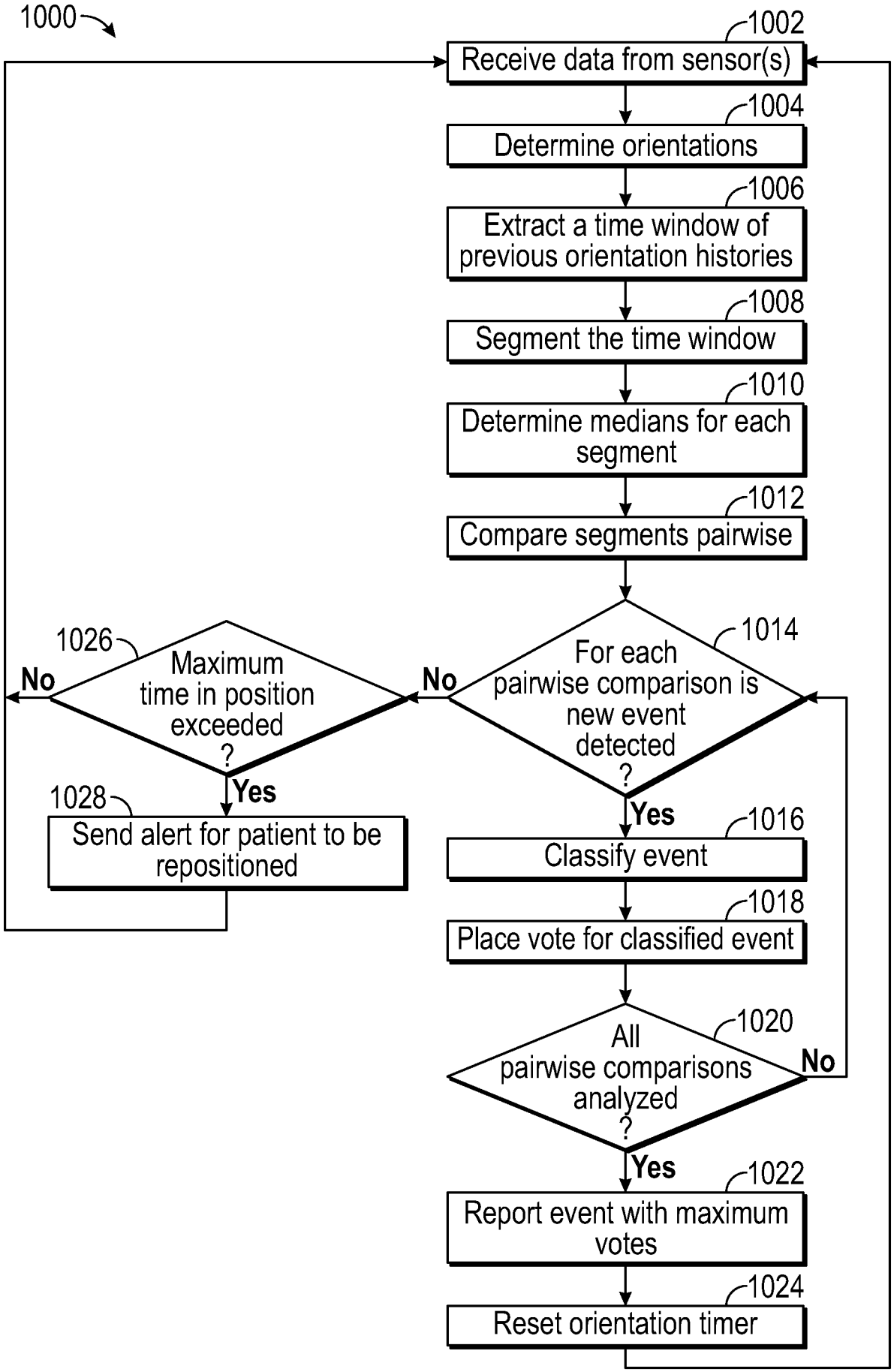

1000
1002
Receive data from sensor(s)
1004
Determine orientations
1006
Extract a time window of previous orientation histories
1008
Segment the time window
1010
Determine medians for each segment
1012
Compare segments pairwise
1014
For each pairwise comparison is new event detected ?
No
Yes
1016
Classify event
1018
Place vote for classified event
1020
All pairwise comparisons analyzed ?
No
Yes
1022
Report event with maximum votes
1024
Reset orientation timer
1026
Maximum time in position exceeded ?
No
Yes
1028
Send alert for patient to be repositioned

FIG. 10

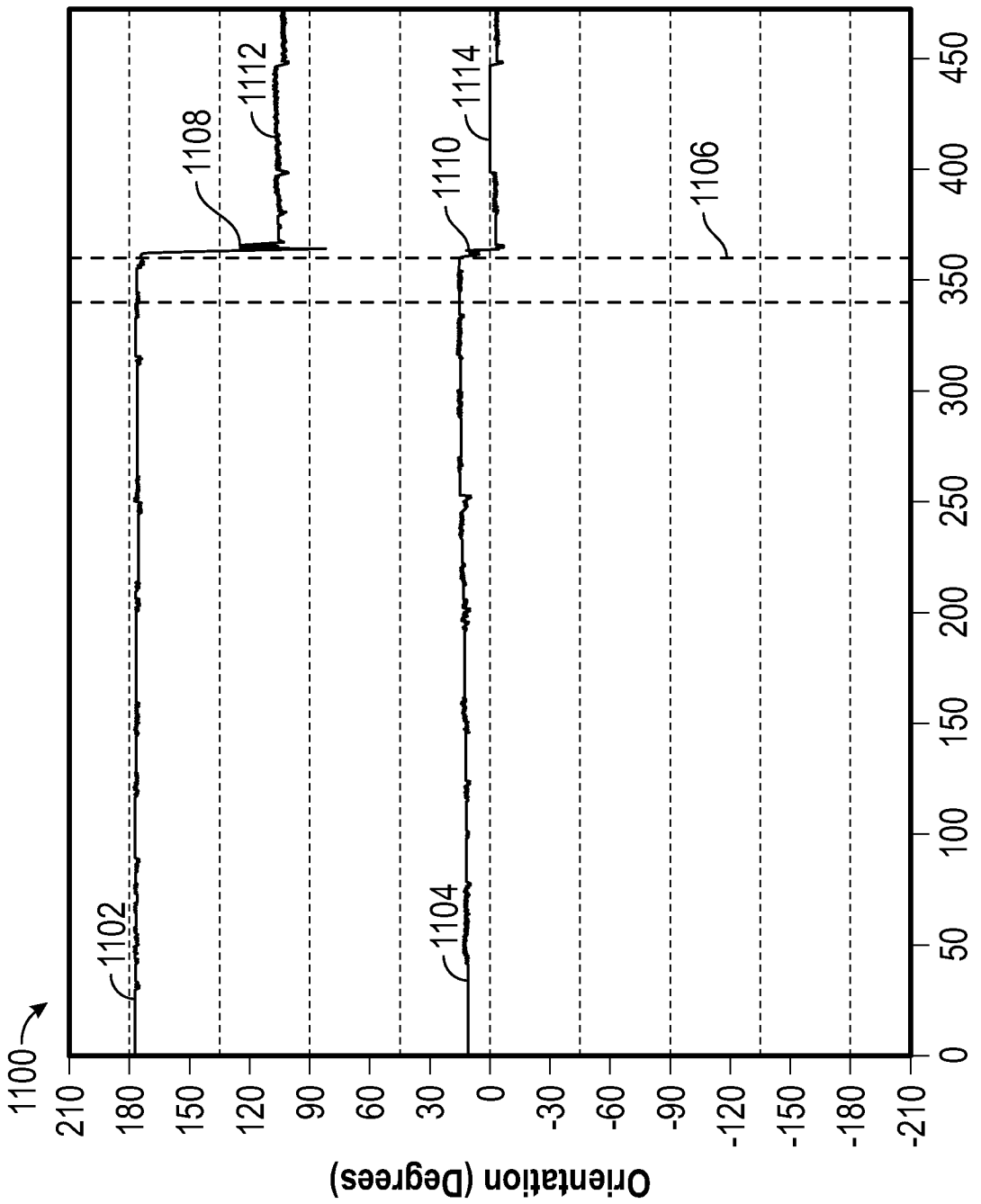

1100
1102
1104
1106
1108
1110
1112
1114
210
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
-210
Orientation (Degrees)
0
50
100
150
200
250
300
350
400
450
Time (Seconds)

FIG.11A

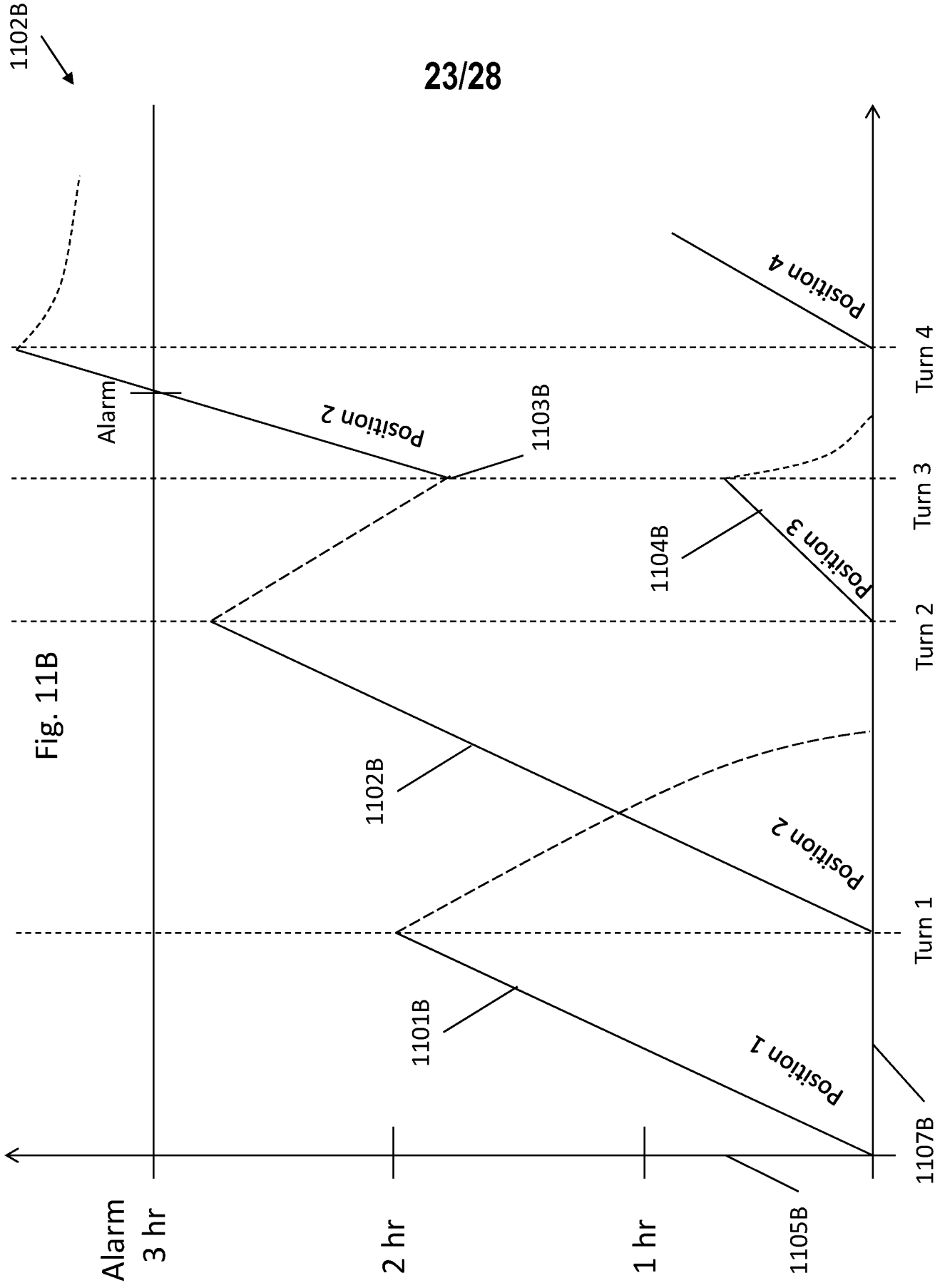

1102B
Alarm
Position 2
1103B
Position 4
Turn 4
Turn 3
1104B
Position 3
Turn 2
1102B
Position 2
Turn 1
1101B
Position 1
1107B
Alarm
3 hr
2 hr
1 hr
1105B

Fig. 11B

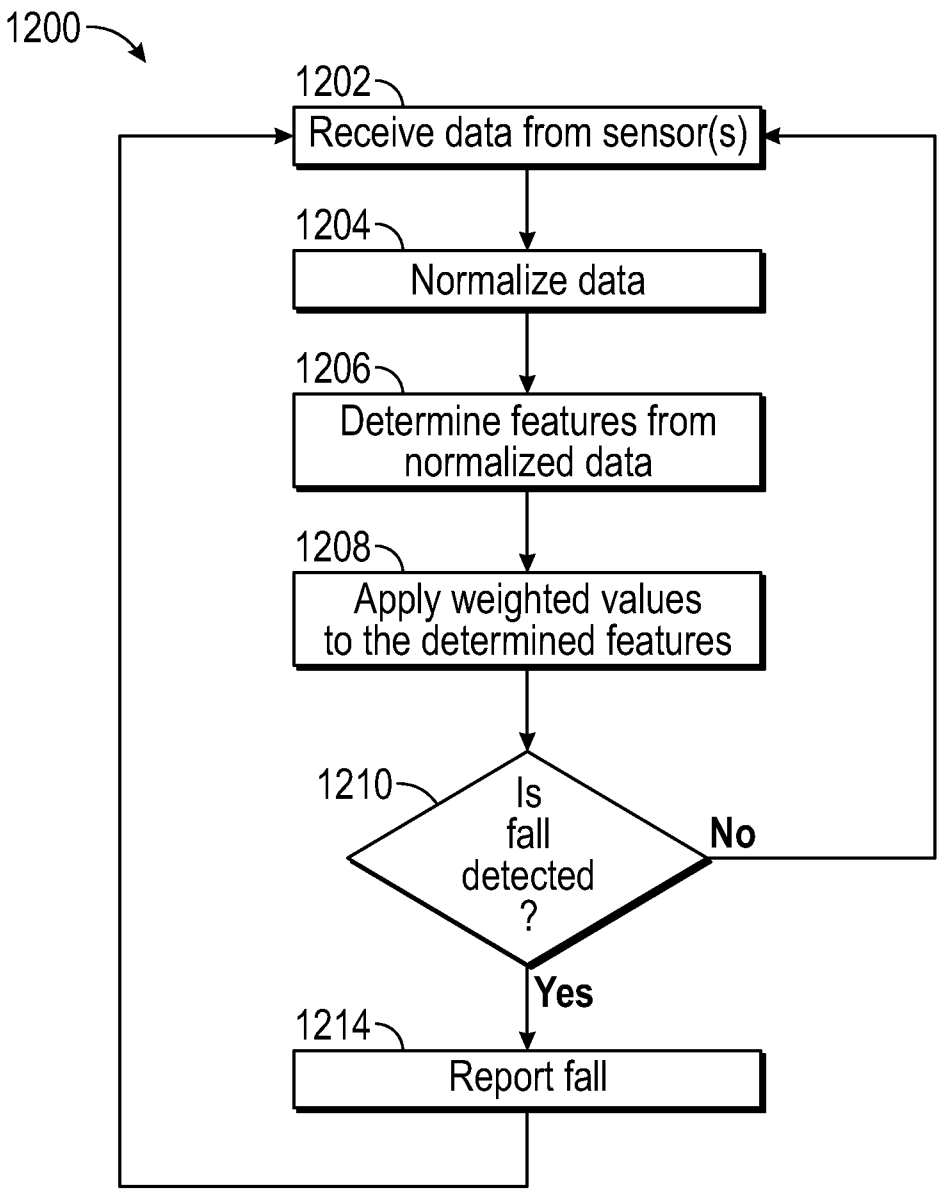

1200
1202
Receive data from sensor(s)
1204
Normalize data
1206
Determine features from normalized data
1208
Apply weighted values to the determined features
1210
Is fall detected ?
No
Yes
1214
Report fall

FIG.12

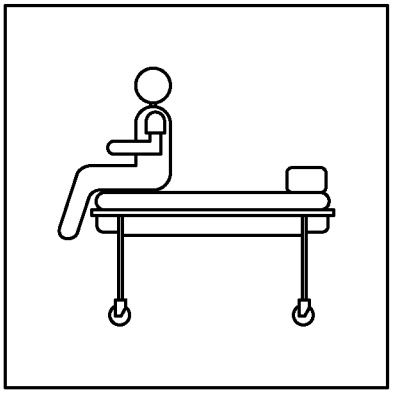


FIG. 13A



FIG. 13B

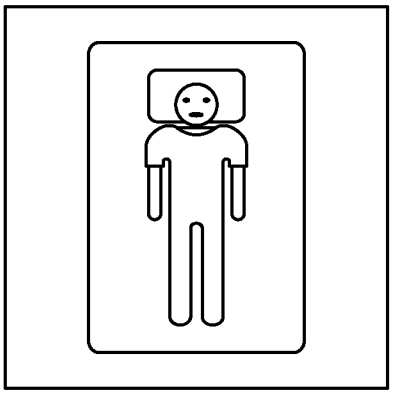


FIG. 13C

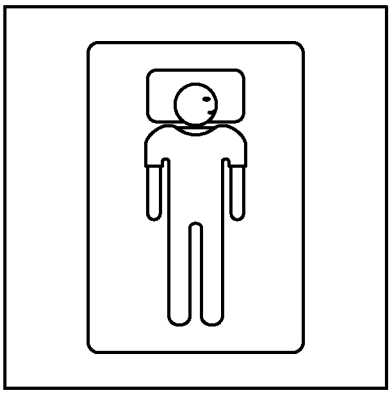


FIG. 13D

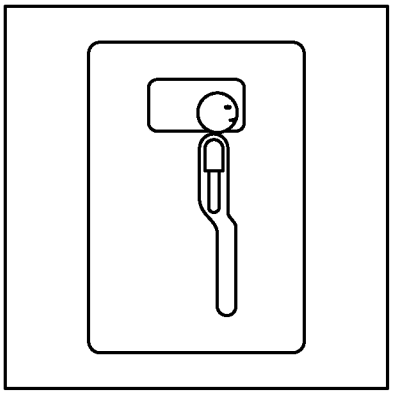


FIG. 13E

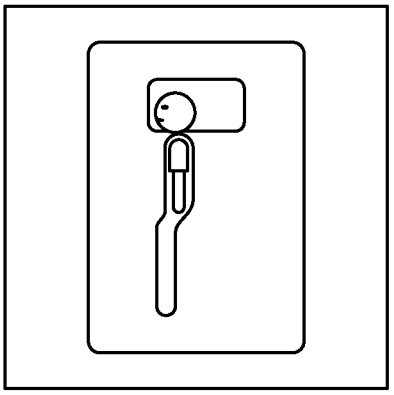


FIG. 13F

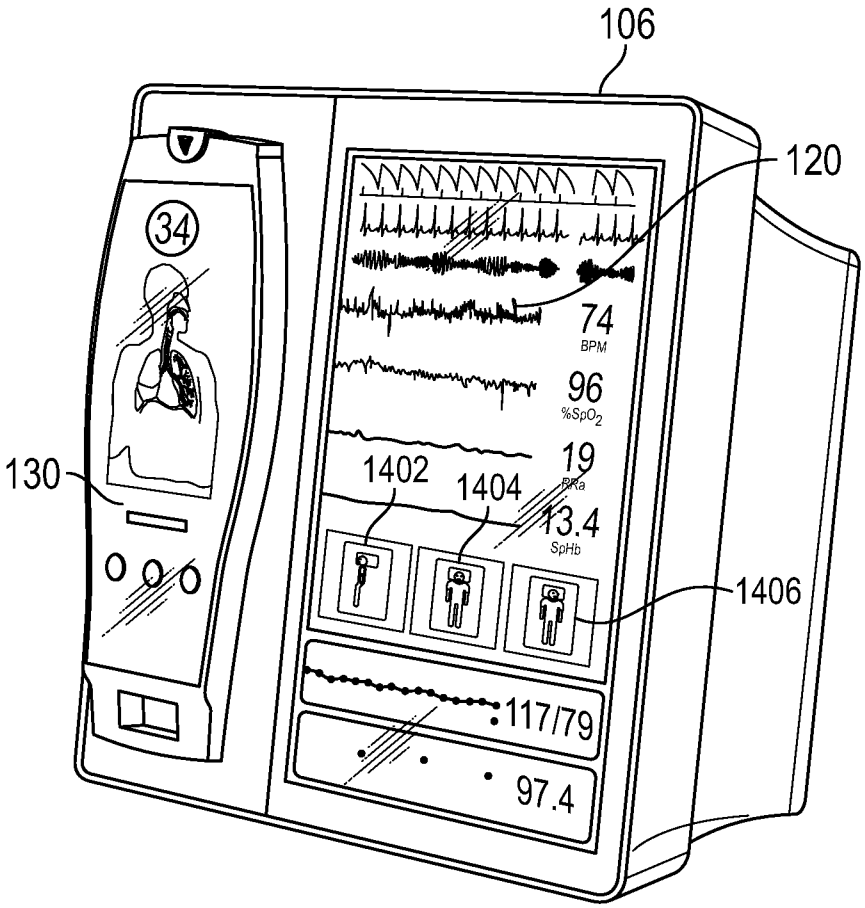

106
120
34
74
BPM
96
%SpO2
19
RRa
1402
1404
13.4
SpHb
130
1406
117/79
97.4

FIG. 14

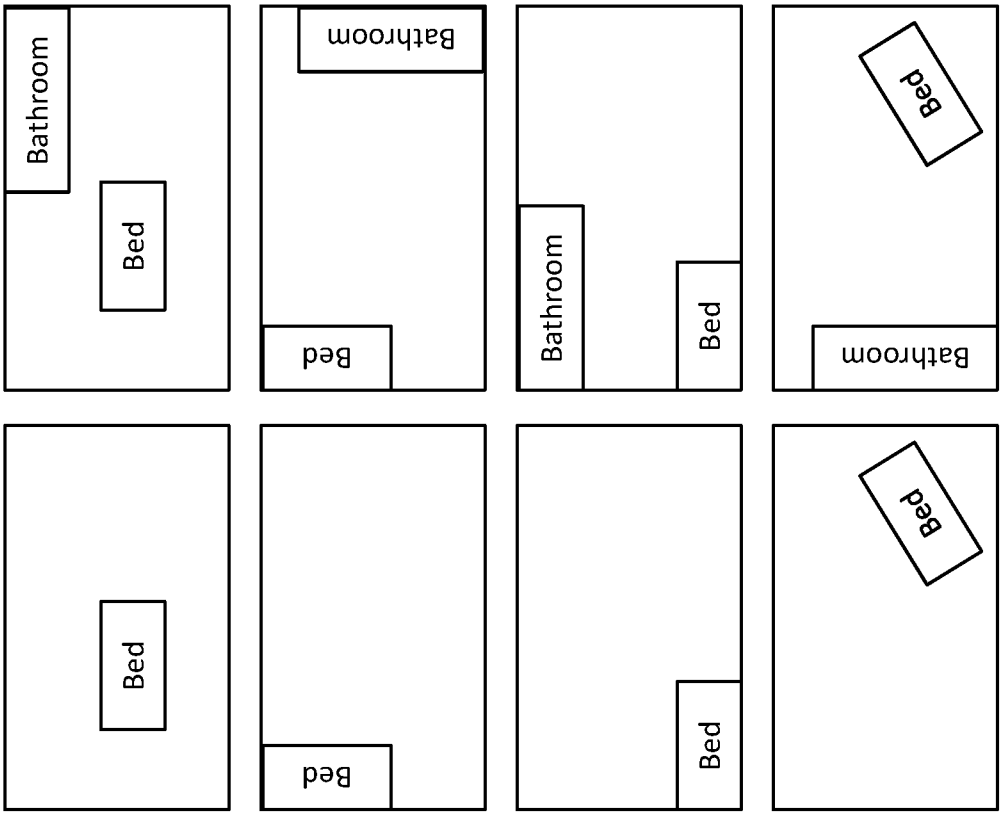


Fig. 15A Fig. 15B Fig. 15C Fig. 15D

Fig. 15E Fig. 15F Fig. 15G Fig. 15H

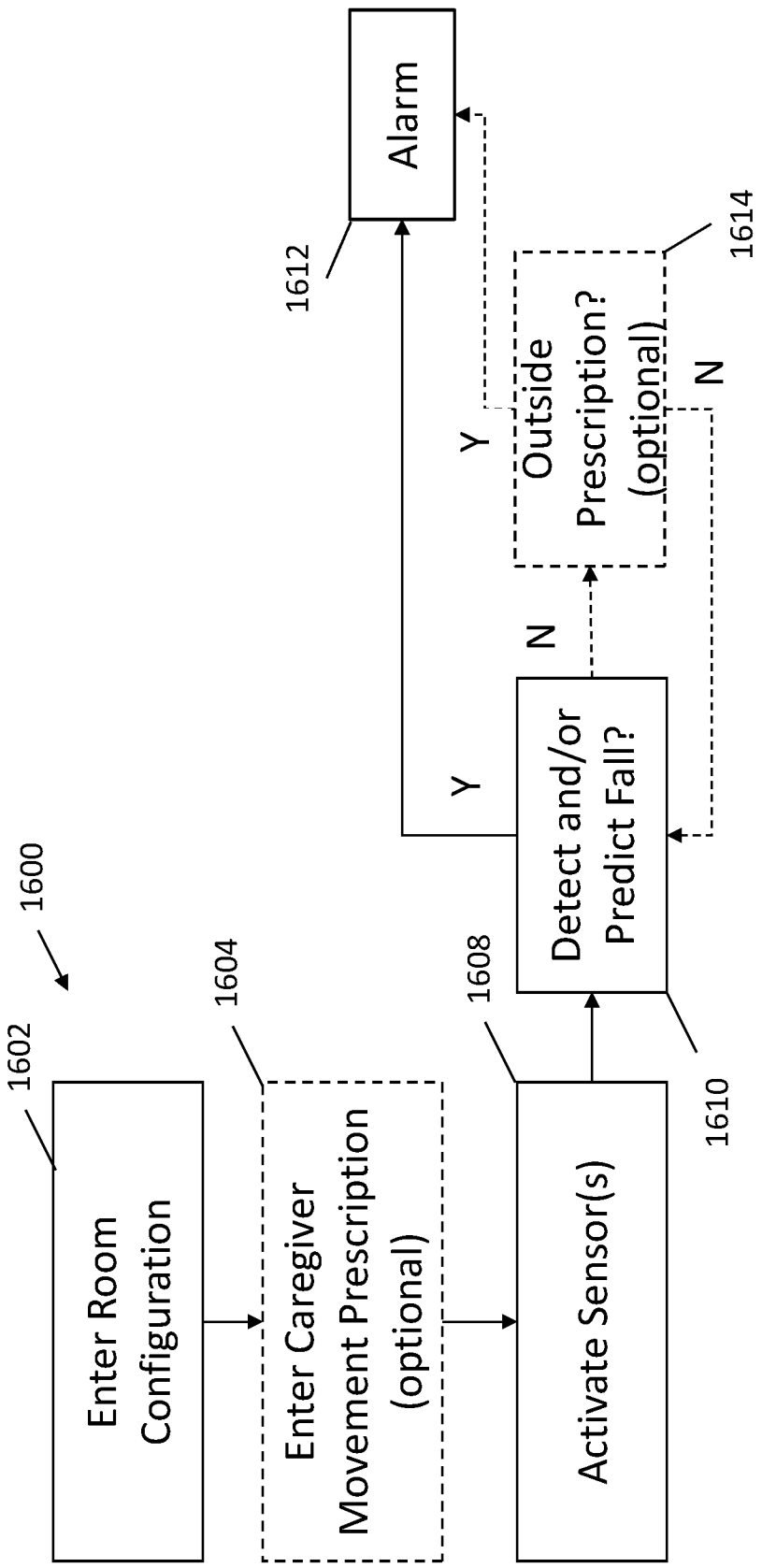
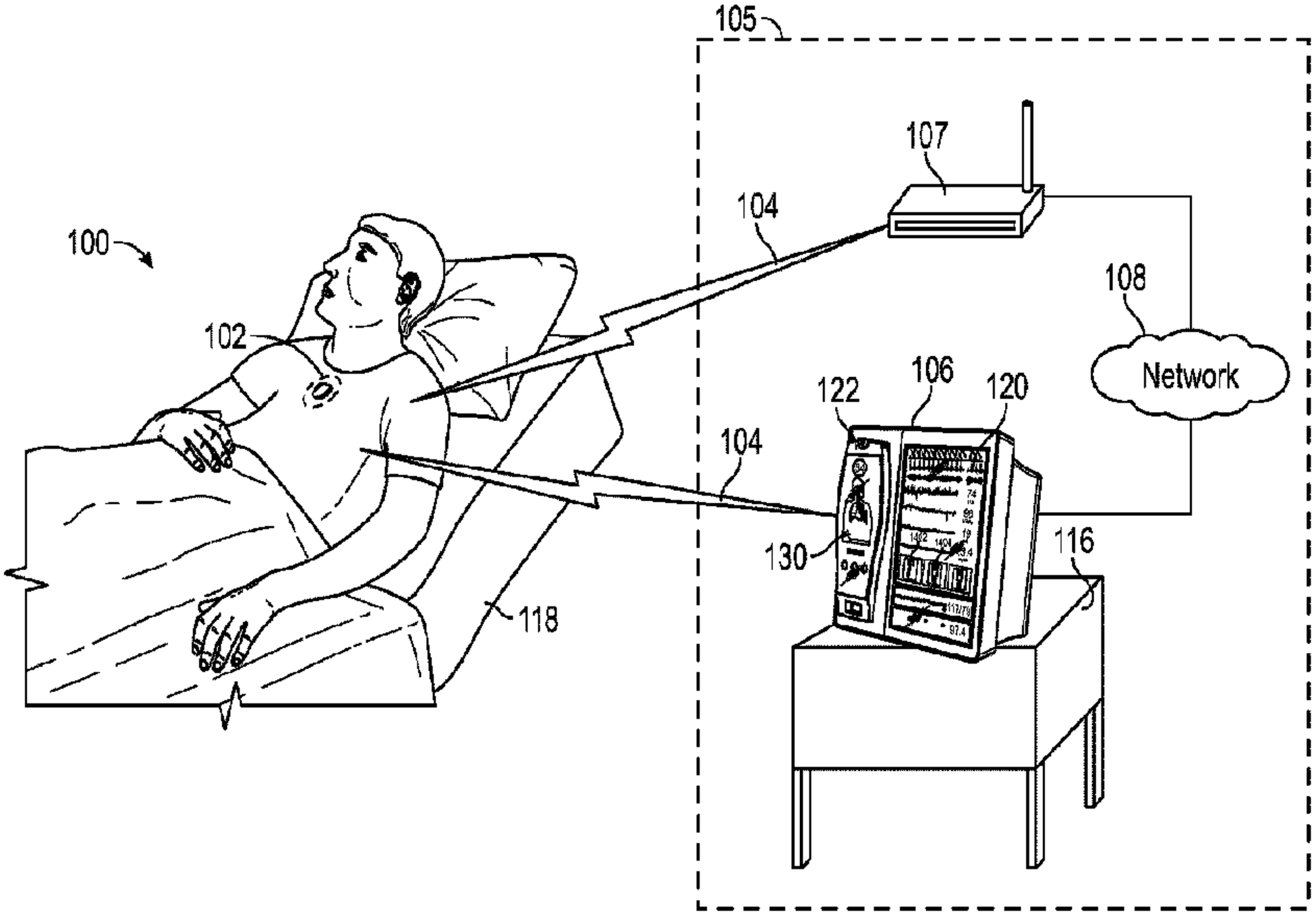

1600
1602
Enter Room Configuration
1604
Enter Caregiver Movement Prescription (optional)
1608
Activate Sensor(s)
1610
Detect and/or Predict Fall?
N
Y
1612
Alarm
Y
Outside Prescription? (optional)
N
1614

Fig. 16


105
107
104
100
108
102
Network
106
122
120
104
130
116
118