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(54) **LOAD SENSOR ASSEMBLY FOR BED LEG AND BED WITH LOAD SENSOR ASSEMBLY**

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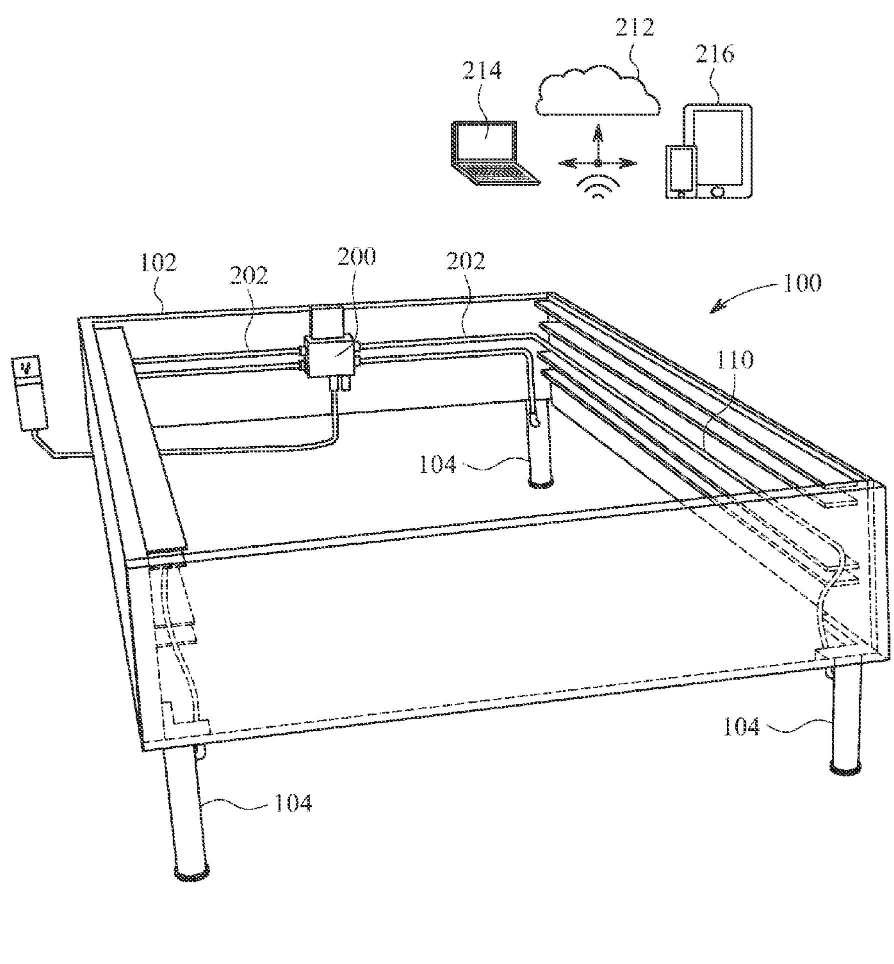
(57) **ABSTRACT**

A bed comprises substrate support members, each including a load bearing and a base configured to provide contact with a floor. The load bearing member is configured to move vertically relative to the base, while the base and the load bearing member are configured to fit together to maintain lateral alignment of the base and the load bearing member. A load sensor is positioned between the base and the load bearing member, the load bearing member configured to transmit a load from the substrate to the load sensor. A printed circuit board is in communication with the load sensor. A controller is in communication with the printed circuit board of each substrate support member and is configured to receive and process data output by the printed circuit boards.



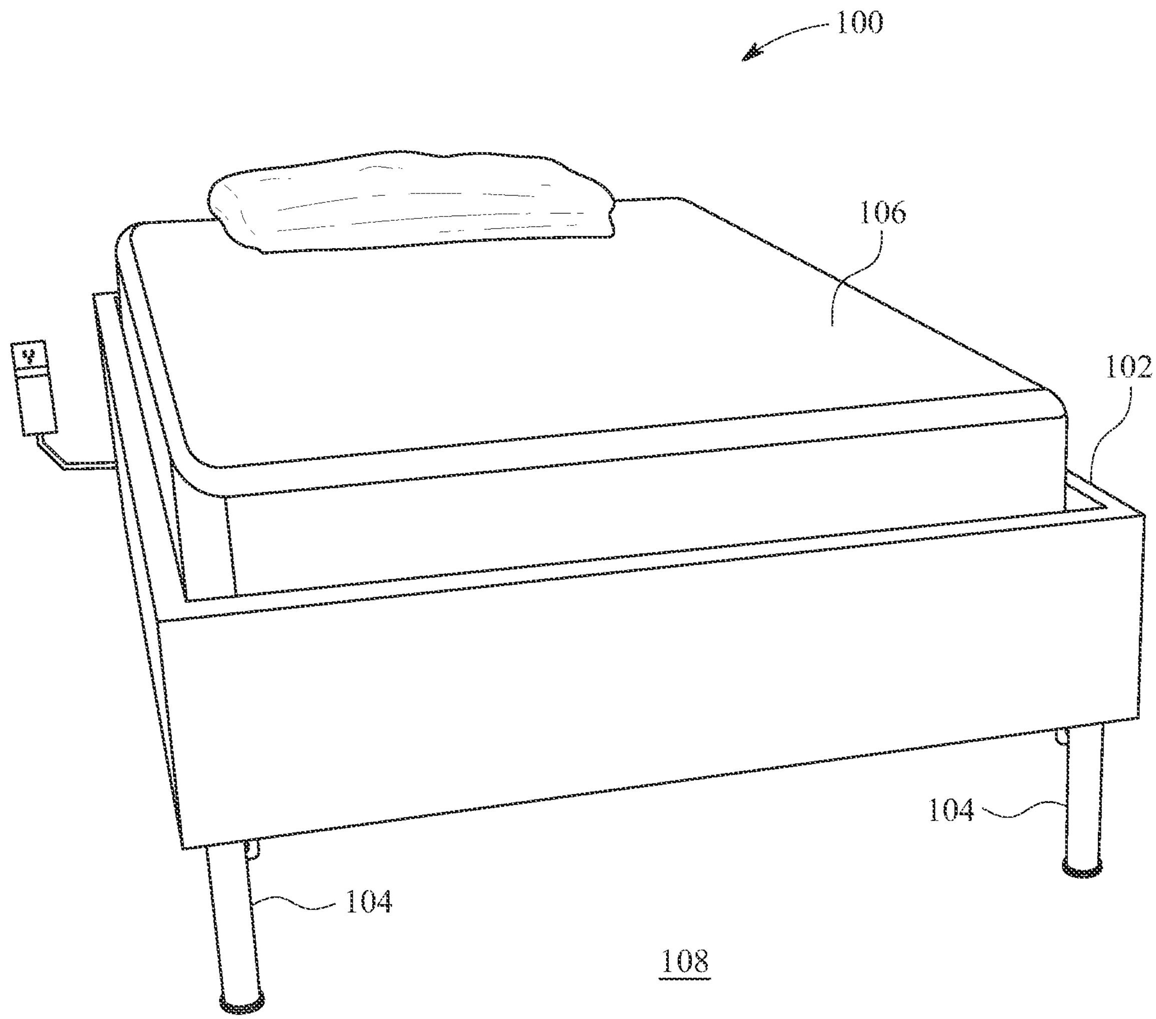


FIG. 1

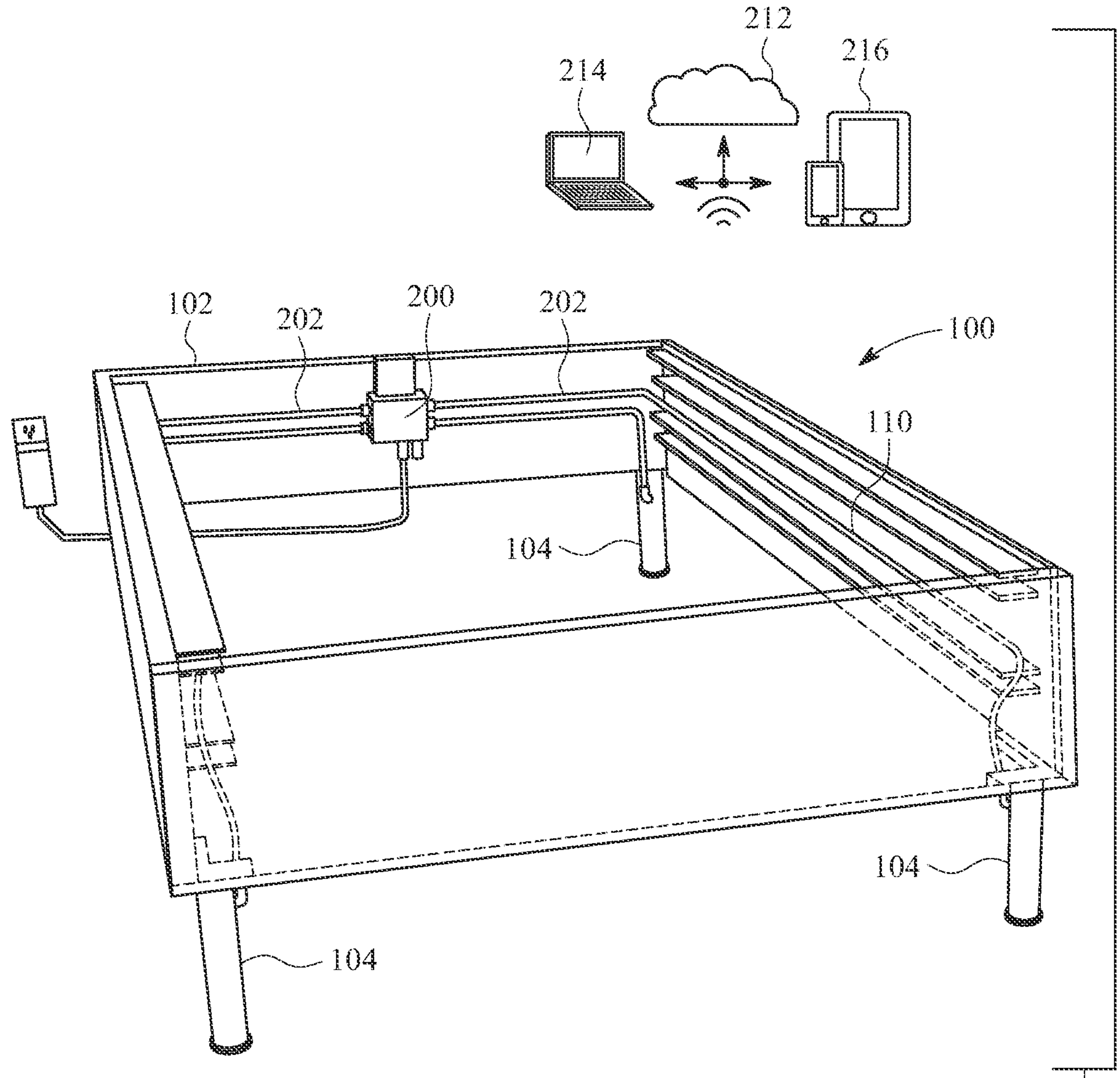


FIG. 2A

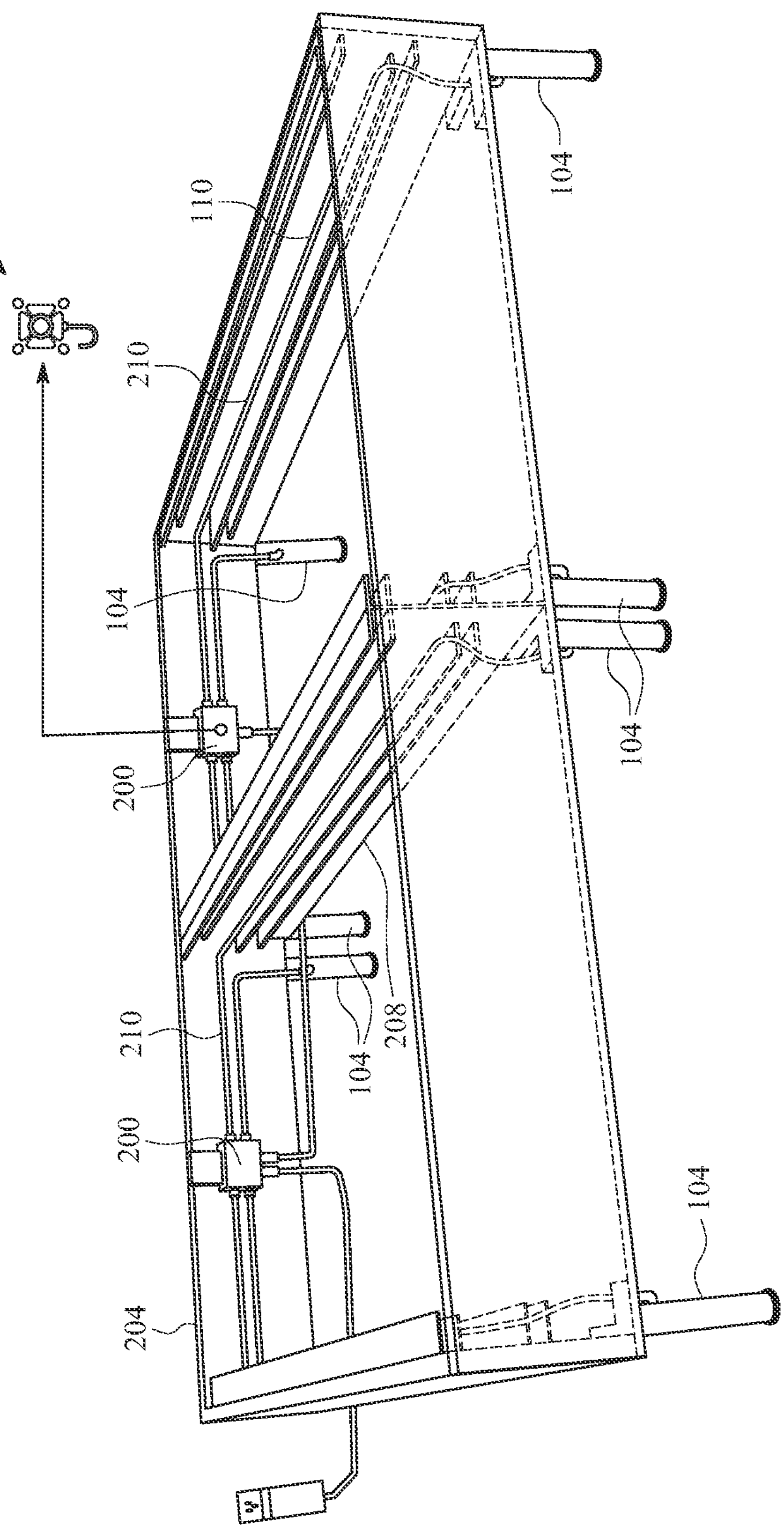


FIG. 2B

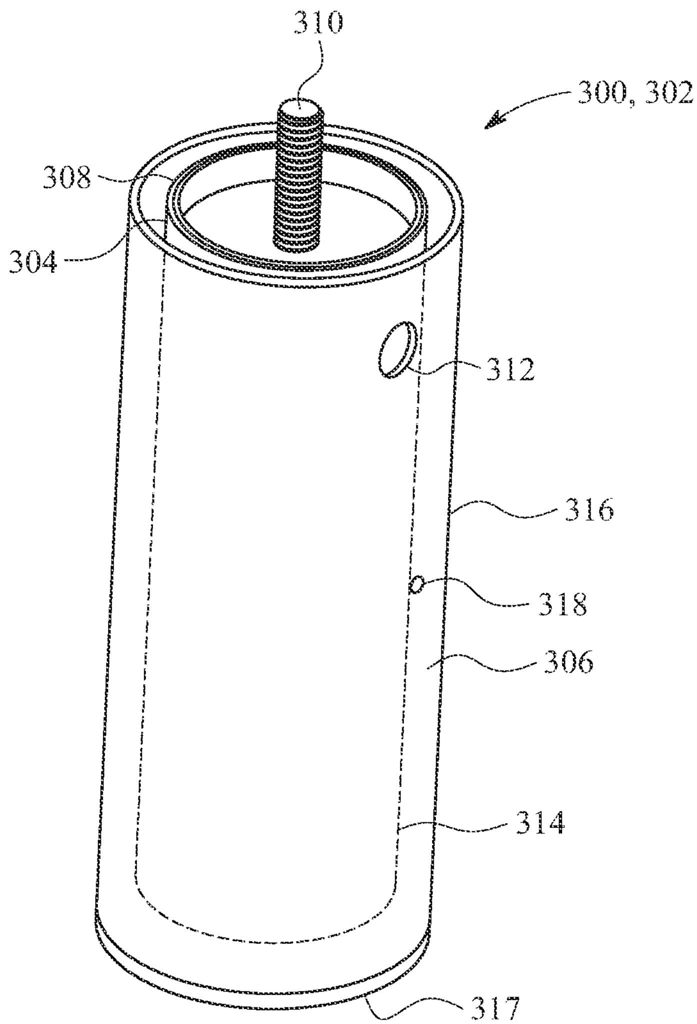


FIG. 3

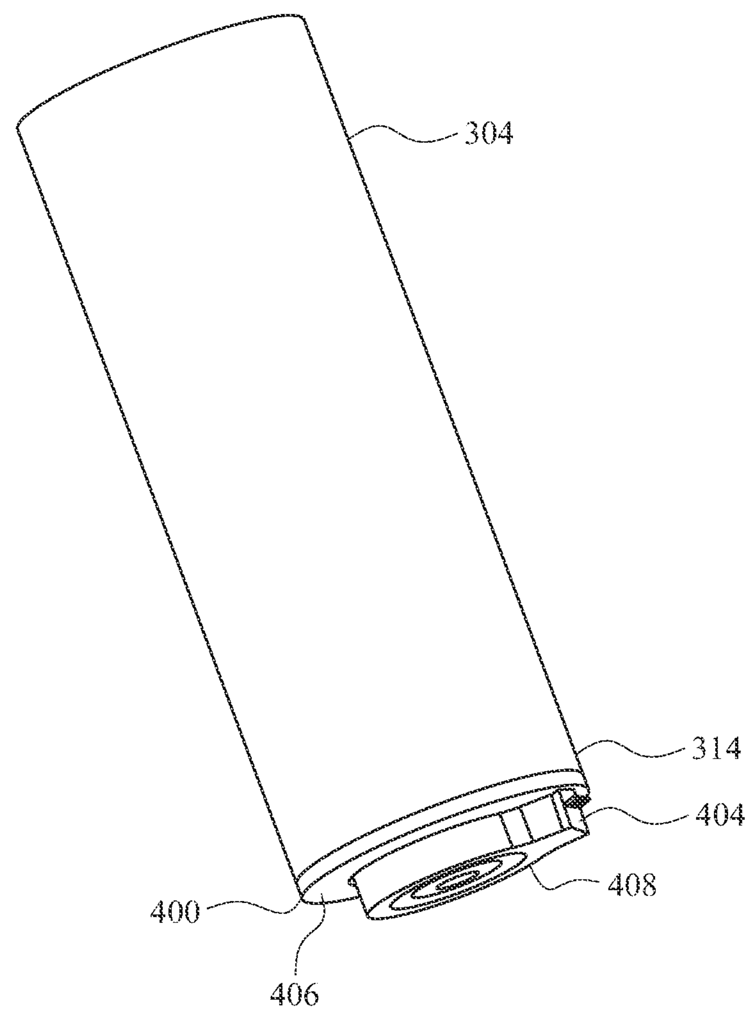


FIG. 4

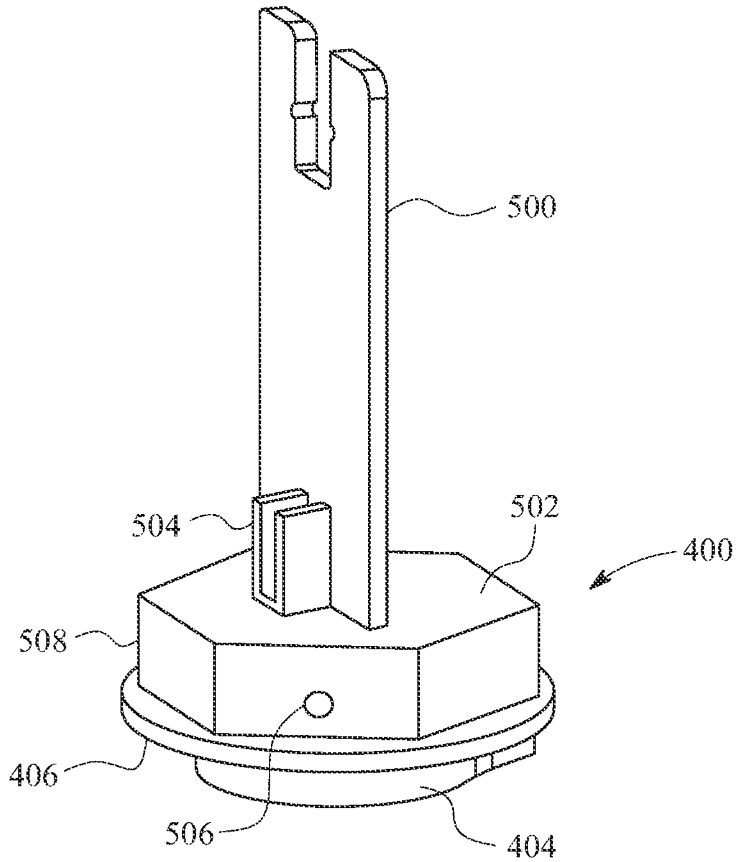


FIG. 5

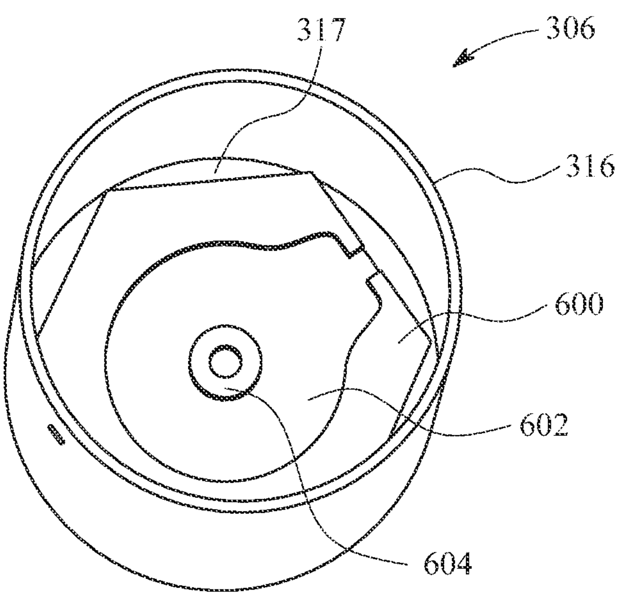


FIG. 6

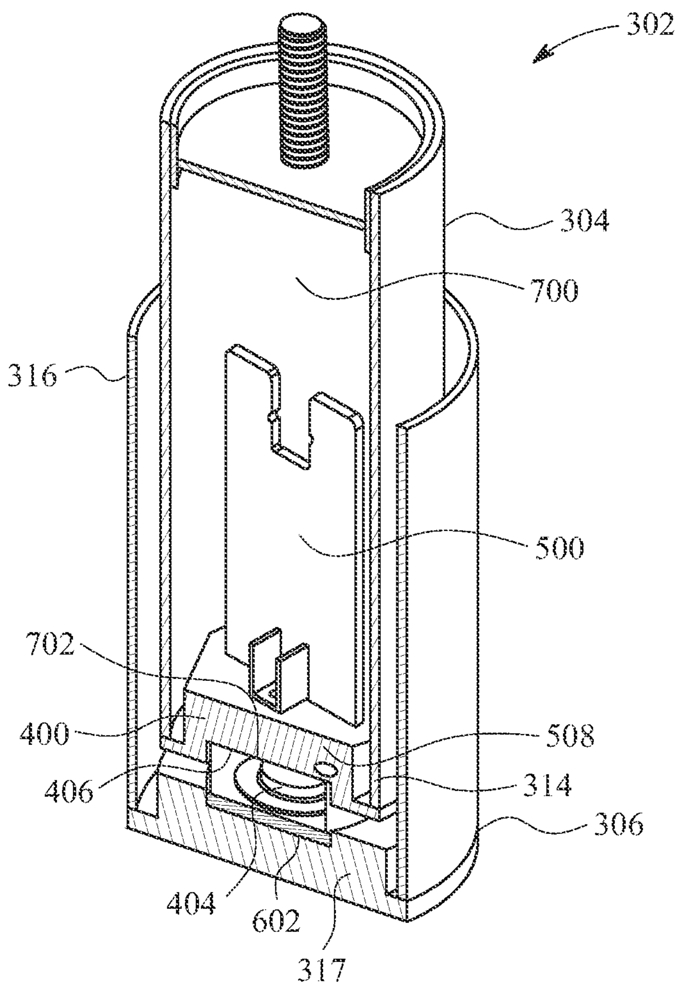


FIG. 7

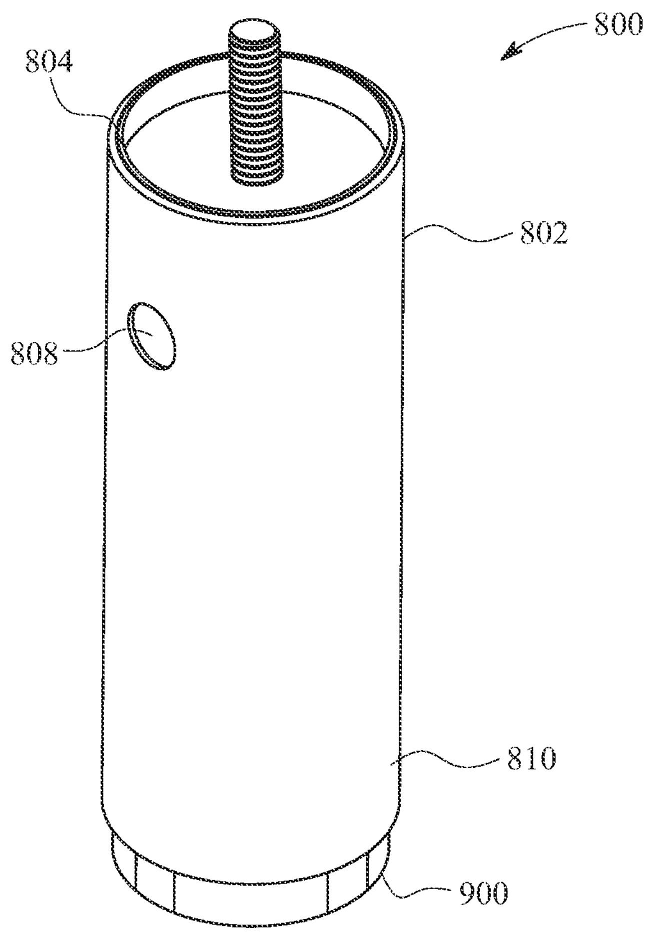


FIG. 8

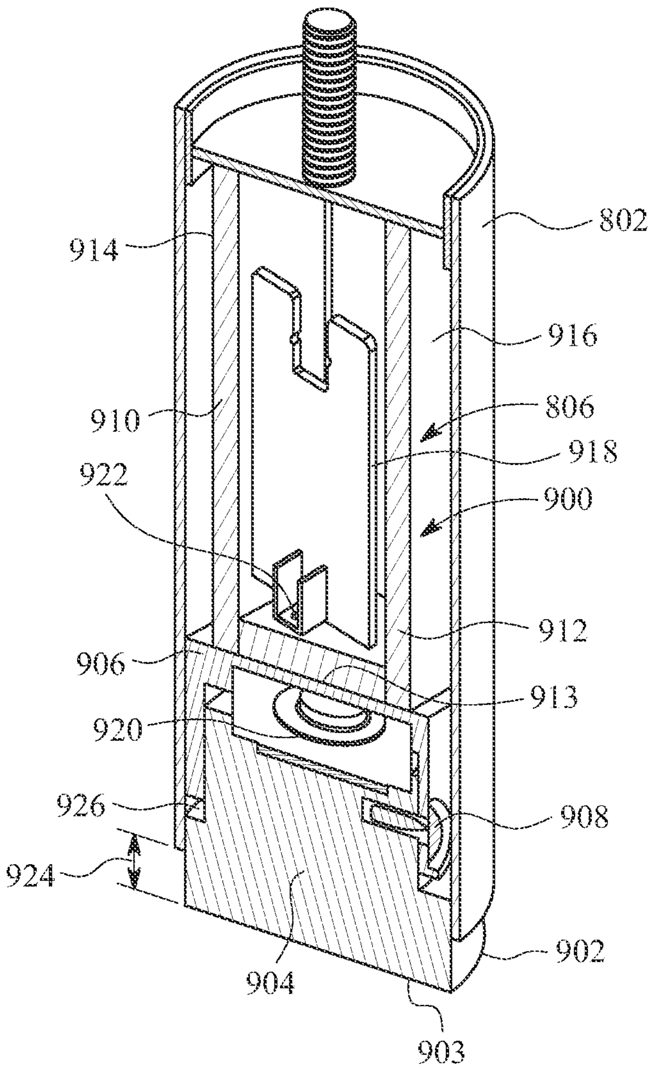

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FIG. 9

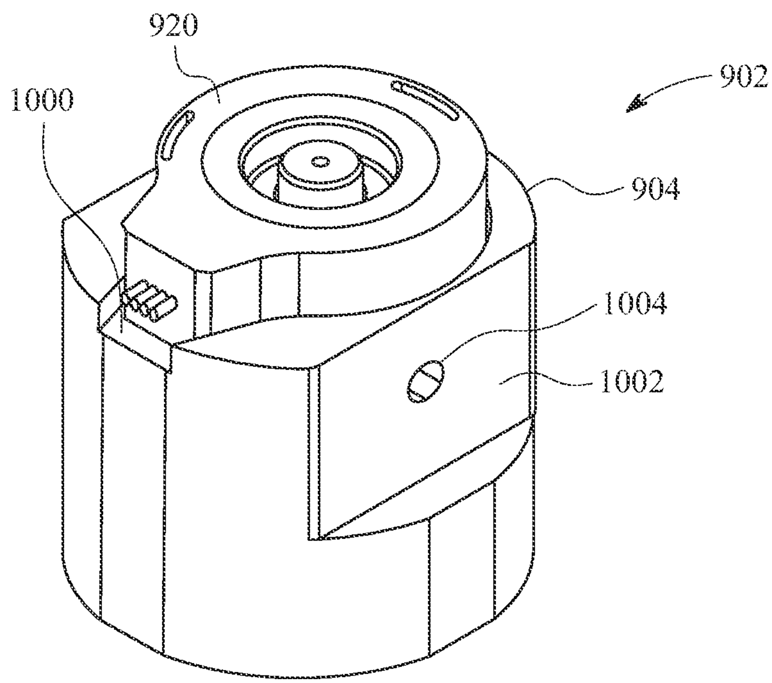

FIG. 10

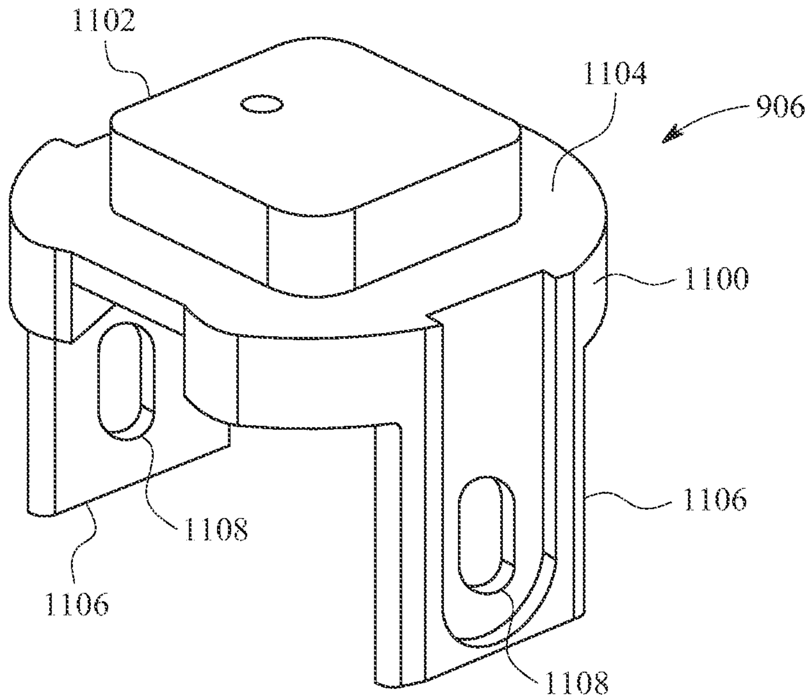

FIG. 11A

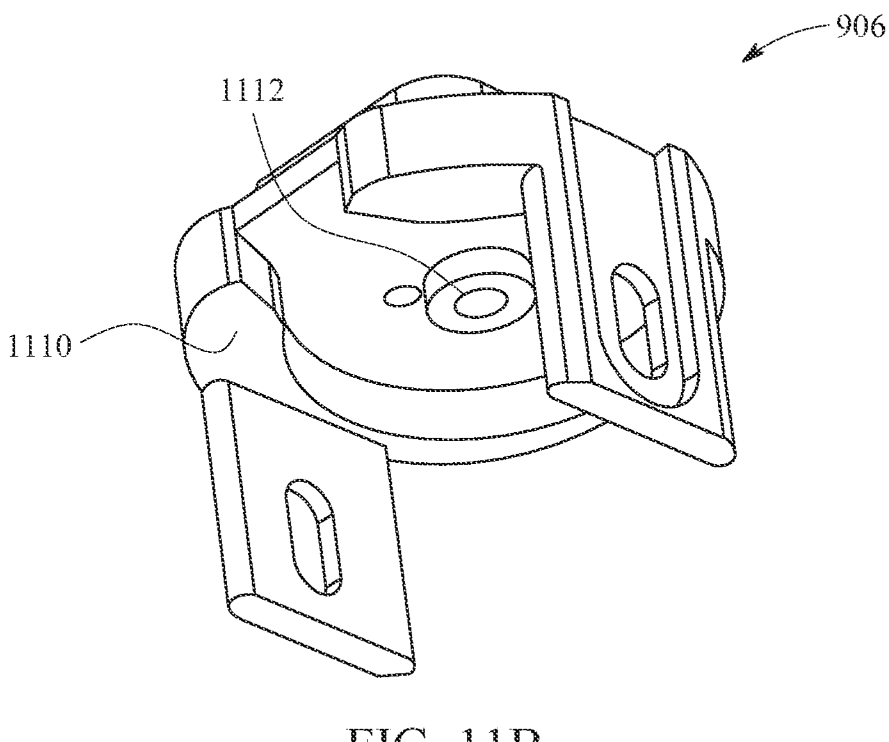

FIG. 11B

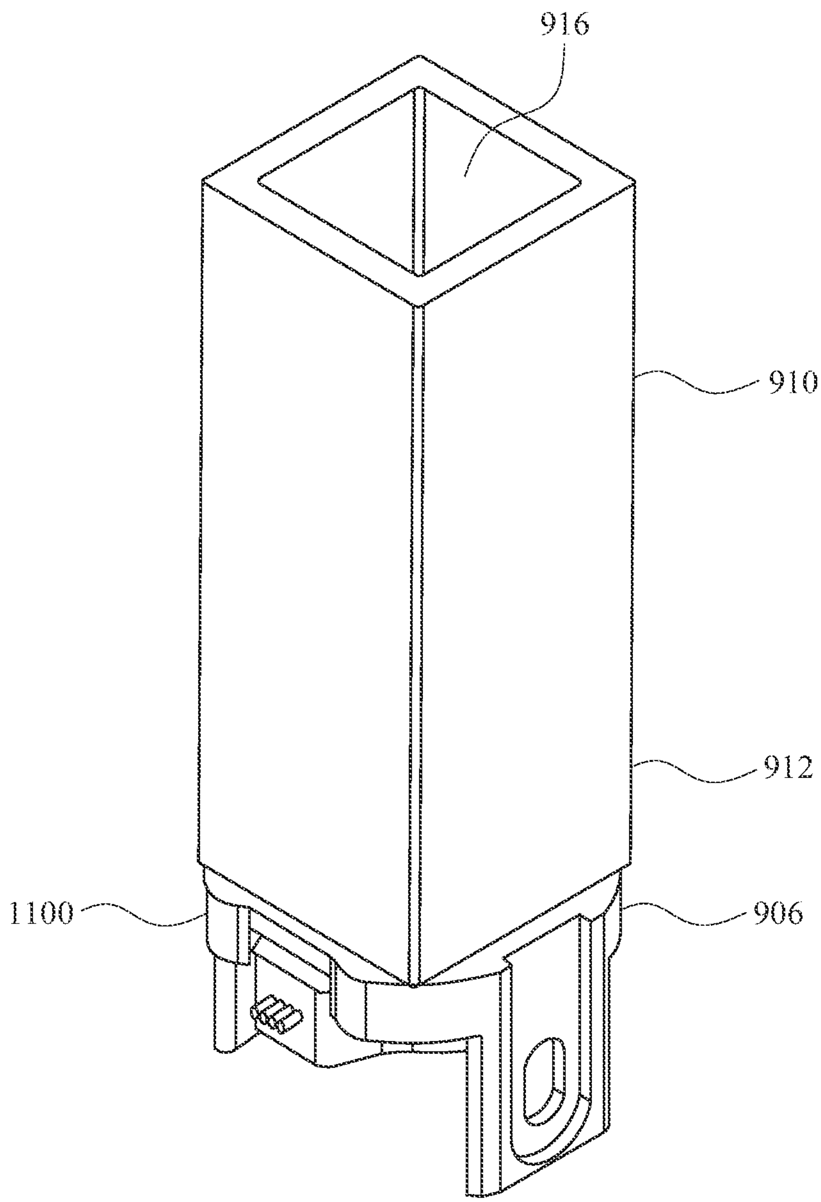

FIG. 12

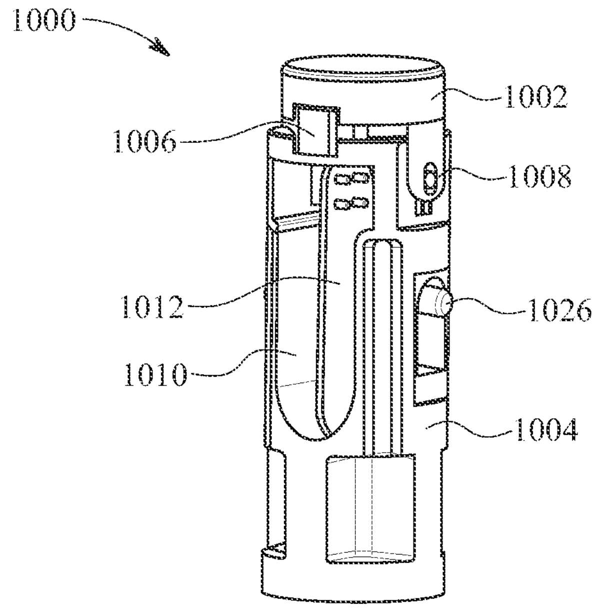

FIG. 13

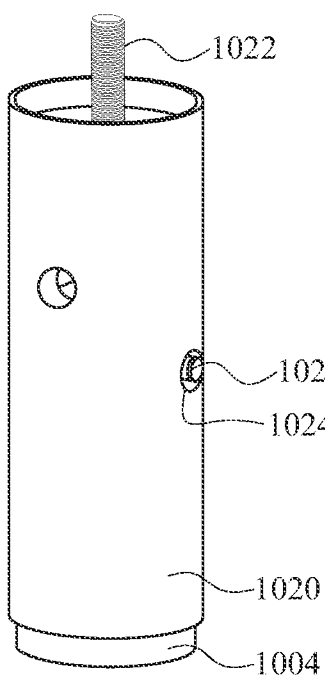

FIG. 14

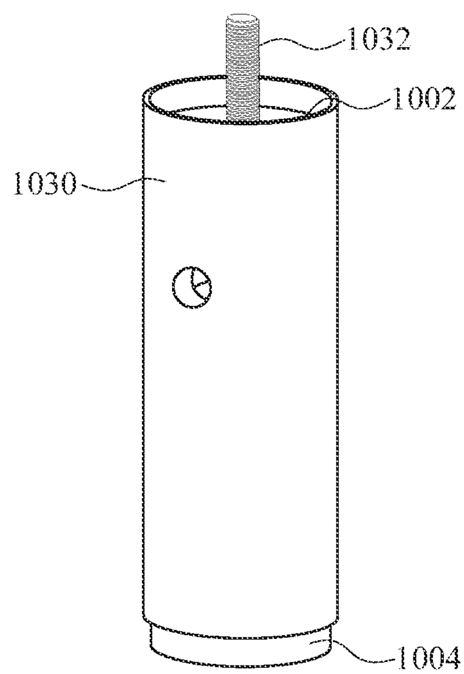

FIG. 15

LOAD SENSOR ASSEMBLY FOR BED LEG AND BED WITH LOAD SENSOR ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application is a continuation application of U.S. Patent Application Ser. No. 16/549,367, filed Aug. 23, 2019, which claims the benefit of U.S. Provisional Patent Application Ser. No. 62/804,623, filed Feb. 12, 2019, the entire disclosure of which is hereby incorporated by reference.

TECHNICAL FIELD

[0002] This disclosure relates to systems and methods for sensing biometrics and other subject-specific information of one or more subjects using multiple sensors that are positioned in or replace a bed leg.

BACKGROUND

[0003] Sensors have been used to detect heart rate, respiration and presence of a single subject using ballistocardiography and the sensing of body movements using noncontact methods, but are often not accurate at least due to their inability to adequately distinguish external sources of vibration and distinguish between multiple subjects. In addition, the nature and limitations of various sensing mechanisms make it difficult or impossible to accurately determine a subject's biometrics, presence, weight, location and position on a bed due to factors such as air pressure variations or the inability to detect static signals.

SUMMARY

[0004] Disclosed herein are implementations of load sensor assemblies for beds.

[0005] One embodiment of a load sensor assembly for a substrate that supports a subject comprises at least four substrate support members, wherein each of the four substrate support members comprises: a load bearing member configured to be attached to the substrate at a first end of the load bearing member; a base configured to support the load bearing member and to provide contact with a floor, wherein the load bearing member is configured to move vertically relative to the base; a load sensor between the cap and the base, wherein the load bearing member is configured to transmit a load from the substrate to the load sensor; and a printed circuit board positioned in a cavity defined by one of the base or the load bearing member and in communication with the load sensor, wherein the printed circuit board is configured to receive and process data from the load sensor.

[0006] Another embodiment of a load sensor assembly is a sensor cartridge for use with a bed having legs to support the bed, the cartridge comprising a base having a first end portion and a second end portion opposite the first end portion, wherein the base is configured to provide contact with a floor at the first end portion; a load bearing member engaged with the second end portion of the base, wherein the base and the load bearing member are configured to fit together to maintain lateral alignment of the cap to the base while allowing vertical movement of the load bearing member with respect to the base; and a load sensor between the load bearing member and the base, wherein the load bearing member is configured to transmit the load from the substrate to the load sensor. A printed circuit board is positioned within a cavity defined by one of the load bearing member or the base, the printed circuit board in communication with the load sensor and configured to receive and process data from the load sensor, wherein the sensor cartridge is configured to insert into a leg of the bed that is at least partially hollow.

[0007] Another embodiment of a load sensor assembly is a bed having a frame supporting a substrate configured to support a subject, the bed comprising substrate support members. Each substrate support member comprises a load bearing member having a first end portion and a second end portion and a base configured to provide contact with a floor. The load bearing member is configured to move vertically relative to the base and the base and the load bearing member are configured to fit together to maintain lateral alignment of the base and the load bearing member. A load sensor is positioned between the load bearing member and the base, wherein the load bearing member is configured to transmit a load from the substrate to the load sensor. A printed circuit board is in communication with the load sensor and is configured to receive and process data from the load sensor. A controller is in communication with the printed circuit board of each substrate support member, wherein the controller is configured to receive and process data output by the printed circuit boards.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The disclosure is best understood from the following detailed description when read in conjunction with the accompanying drawings. It is emphasized that, according to common practice, the various features of the drawings are not to-scale. On the contrary, the dimensions of the various features are arbitrarily expanded or reduced for clarity.

[0009] FIG. **1** is an illustration of a bed incorporating the load sensor assembly as disclosed herein.

[0010] FIG. **2**A is an illustration of the bed frame with the load sensor assembly incorporated, the bed frame configured to support a single subject.

[0011] FIG. **2**B is an illustration of a bed frame with the load sensor assembly, the bed frame configured to support two subjects.

[0012] FIG. **3** is a top perspective view of a substrate support member as disclosed herein.

[0013] FIG. **4** is a bottom perspective view of a load bearing member and load sensor of the substrate support member of FIG. **3**.

[0014] FIG. **5** is a top perspective view of a cap and printed circuit board of the substrate support member of FIG. **3**.

[0015] FIG. **6** is a top perspective view of a base of the substrate support member of FIG. **3**.

[0016] FIG. **7** is a cross-sectional view of the substrate support member of FIG. **3**.

[0017] FIG. **8** is a top perspective view of a bed leg incorporating a sensor cartridge as disclosed herein.

[0018] FIG. **9** is a cross-sectional view of the bed leg incorporating the sensor cartridge of FIG. **8**.

[0019] FIG. **10** is a top perspective view of a base of the sensor cartridge of FIG. **8**.

[0020] FIG. **11**A is a top perspective view of a cap of the sensor cartridge of FIG. **8**.

[0021] FIG. **11**B is a bottom perspective view of the cap of the sensor cartridge of FIG. **11**A.

[0022] FIG. **12** is a top perspective view of a load bearing member and cap of the sensor cartridge of FIG. **8**.

[0023] FIG. **13** is a perspective view of another sensor assembly as disclosed herein.

[0024] FIG. **14** is a perspective view of the sensor assembly of FIG. **13** used as a cartridge.

[0025] FIG. **15** is a perspective view of the sensor assembly of FIG. **13** used as the bed leg itself.

DETAILED DESCRIPTION

[0026] Disclosed herein are implementations of systems and methods employing gravity and motion to determine biometric parameters and other person-specific information for single or multiple subjects at rest and in motion on one or multiple substrates. The systems and methods use multiple sensors to sense a single subject's or multiple subjects' body motions against the force of gravity on a substrate, including beds, furniture or other objects, and transforms those motions into macro and micro signals. Those signals are further processed and uniquely combined to generate the person-specific data, including information that can be used to further enhance the ability of the sensors to obtain accurate readings. The sensors are connected either with a wire, wirelessly or optically to a host computer or processor which may be on the internet and running artificial intelligence software. The signals from the sensors can be analyzed locally with a locally present processor or the data can be networked by wire or other means to another computer and remote storage that can process and analyze the real-time and/or historical data.

[0027] The sensors are designed to be placed under, or be built into a substrate, such as a bed, couch, chair, exam table, floor, etc. The sensors can be configured for any type of surface depending on the application. Additional sensors can be added to augment the system, including light sensors, temperature sensors, vibration sensors, motion sensors, infrared sensors and sound sensors as non-limiting examples. Each of these sensors can be used to improve accuracy of the overall data as well as provide actions that can be taken based on the data collected. Example actions might be: turning on a light when a subject exits a bed, adjusting the room temperature based on a biometric status, alerting emergency responders based on a biometric status, sending an alert to another alert based system such as: Alexa, Google Home or Siri for further action.

[0028] The data collected by the sensors can be collected for a particular subject for a period of time, or indefinitely, and can be collected in any location, such as at home, at work, in a hospital, nursing home or other medical facility. A limited period of time may be a doctor's visit to assess weight and biometric data or can be for a hospital stay, to determine when a patient needs to be rolled to avoid bed sores, to monitor if the patient might exit the bed without assistance, and to monitor cardiac signals for atrial fibrillation patterns. Messages can be sent to family and caregivers and/or reports can be generated for doctors.

[0029] The data collected by the sensors can be collected and analyzed for much longer periods of time, such as years or decades, when the sensors are incorporated into a subject's personal or animal's residential bed. The sensors and associated systems and methods can be transferred from one substrate to another to continue to collect data from a particular subject, such as when a new bed frame is purchased for a residence or retrofitted into an existing bed or furniture.

[0030] The highly sensitive, custom designed sensors detect wave patterns of vibration, pressure, force, weight, presence and motion. These signals are then processed using proprietary algorithms which can separate out and track individual source measurements from multiple people, animals or other mobile or immobile objects while on the same substrate.

[0031] These measurements are returned in real-time as well as tracked over time. Nothing is attached to the subject. The sensors can be electrically or optically wired to a power source or operate on batteries or use wireless power transfer mechanisms. The sensors and the local processor can power down to zero or a low power state to save battery life when the substrate is not supporting a subject. In addition, the system may power up or turn on after subject presence is detected automatically.

[0032] The system is configured based on the number of sensors. Because the system relies on the force of gravity to determine weight, sensors are required at each point where an object bears weight on the ground. For other biometric signals fewer sensors may be sufficient. For example, a bed with four wheels or legs may require a minimum of four sensors, a larger bed with five or six legs may require five for six sensors, a chair with four legs would may require sensors on each leg, etc. The number of sensors is determined by the needed application. The unique advantage of multiple sensors provides the ability to map and correlate a subject's weight, position and bio signals. This is a clear advantage in separating out a patient's individual signals from any other signals as well as combining signals uniquely to augment the signals for a specific biosignal.

[0033] The system can be designed to configure itself automatically based on the number of sensors determined on a periodic or event-based procedure. A standard configuration would be four sensors per single bed with four legs to eight leg sensors for a multiple person bed. The system would automatically reconfigure for more or less sensors. Multiple sensors provide the ability to map and correlate a subject's weight, position and bio signals. This is necessary to separate multiple subjects' individual signals.

[0034] Some examples of the types of information that the disclosed systems and methods provide are dynamic center of mass and center of signal locations, accurate bed exit prediction (timing and location of bed exit), the ability to differentiate between two or more bodies on a bed, supine/side analysis, movement vectors for multiple subjects and other objects or animals on the bed, presence, motion, position, direction and rate of movement, respiration rate, respiration condition, heart rate, heart condition, beat to beat variation, instantaneous weight and weight trends, and medical conditions such as heart arrhythmia, sleep apnea, snoring, restless leg, etc. By leveraging multiple sensors that detect the z-axis and other axes of the force vector of gravity, and by discriminating and tracking the center of mass or center of signal of multiple people as they enter and move on a substrate, not only can the disclosed systems and methods determine presence, motion and cardiac and respiratory signals for multiple people, but they can enhance the signals of a single person or multiple people on the substrate by applying the knowledge of location to the signal received. Secondary processing can also be used to identify multiple people on the same substrate, to provide individual sets of metrics for them, and to enhance the accuracy and strength of signals for a single person or multiple people. For example, the system can discriminate between signals from an animal jumping on a bed, another person sitting on the bed, or another person lying in bed, situations that would otherwise render the signal data mixed. Accuracy is increased by processing signals differently by evaluating how to combine or subtract signal components from each sensor for a particular subject.

[0035] Additional sensor types can be used to augment the signal, such as light sensors, temperature sensors, accelerometers, vibration sensors, motion sensors and sound sensors. While the disclosure has been described in connection with certain embodiments, it is to be understood that the disclosure is not to be limited to the disclosed embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.

[0036] FIG. **1** is a top perspective view of a bed **100** having a substrate **106** on which the subject can lie. The bed **100** includes a frame **102** which supports the substrate **106** (e.g. bedding, a mattress or a box-spring mattress foundation). The frame **102** may include internal or external channels configured to receive wiring. The bed **100** may include four sensor assemblies **104** attached to the frame **102**. More or fewer sensor assemblies **104** may be attached to bed frames of varying shapes, sizes and configurations. Any point in which a load is transferred from the bed **100** to the floor may have an intervening sensor assembly **104**. In other embodiments, the sensor assemblies **104** may be attached to and/or inserted into existing legs supporting the bed **100**. In the illustrated, non-limiting example, one sensor assembly **104** is attached to each corner of the frame **102**. The sensor assemblies **104** may extend from the frame **102** or an existing bed leg to a floor **108** used to support the bed **100**. The floor can include the ground or any surface suitable to support the bed **100**.

[0037] FIG. **2**A is a top perspective view of the frame **102** and sensor assemblies **104**. A controller **200** can be wired or wirelessly connected to the sensor assemblies **104**. Wiring **202** may electrically connect the sensor assemblies **104** to the controller **200**. The wiring **202** may be attached to an interior of the frame **102** and/or may be routed through the interior channels **110** of the frame **102**. The controller **200** can collect and process signals from the sensor assemblies **104**. The controller **200** may also be configured to output power to the sensors and/or to printed circuit boards disposed in the sensor assemblies **104**. The controller **200** can be attached to the frame **102** so that it is hidden from view, can be under the bed, or can be positioned anywhere a wire reaches the sensor assemblies **104** if transmission is hard wired. The controller **200** can be positioned anywhere a wireless transmission can be received from the sensor assemblies **104** if transmission is wireless. The controller **200** can be programmed to control other devices based on the processed data as discussed below, the control of other devices also being wired or wireless. Alternatively or in addition to, a cloud based computer **212** or off-site controller **214** can collect the signals directly from the sensor assemblies **104** for processing or can collect raw or processed data from the controller **200**. For example, the controller **200** may process the data in real time and control other local devices as disclosed herein, while the data is also sent to the off-site controller **214** that collects and stores the data over time. The controller **200** or the off-site controller **214** may transmit the processed data off-site for use by downstream third parties such a medical professionals, fitness trainers, family members, etc. The controller **200** or the off-site controller **214** can be tied to infrastructure that assists in collecting, analyzing, publishing, distributing, storing, machine learning, etc. Design of real-time data stream processing has been developed in an event-based form using an actor model of programming. This enables a producer/consumer model for algorithm components that provides a number of advantages over more traditional architectures. For example, it enables reuse and rapid prototyping of processing and algorithm modules. As another example, it enables computation to be location-independent (i.e., on a single device, combined with one or more additional devices or servers, on a server only, etc.)

[0038] The long-term collected data can be used in both a medical and home setting to learn and predict patterns of sleep, illness, etc. for a subject. As algorithms are continually developed, the long-term data can be reevaluated to learn more about the subject. Sleep patterns, weight gains and losses, changes in heart beat and respiration can together or individually indicate many different ailments. Alternatively, patterns of subjects who develop a particular ailment can be studied to see if there is a potential link between any of the specific patterns and the ailment.

[0039] The data can also be sent live from the controller **200** or the off-site controller **214** to a connected device **216**, which can be wirelessly connected for wired. The connected device **216** can be, as examples, a mobile phone or home computer. Devices can subscribe to the signal, thereby becoming a connected device **216**.

[0040] FIG. **2**B is a top perspective view of a frame **204** for a bed **206** used with a substrate on which two or more subjects can lie. The bed **206** may include features similar to those of the bed **100** except as otherwise described. The bed **206** includes a frame **204** configured to support two or more subjects. The bed **206** may include eight sensor assemblies **104**, including one sensor assembly **104** disposed at each corner of the frame **204** and four sensor assemblies **104** disposed at opposing ends of a central frame member **208**. In other embodiments, the bed may include nine sensor assemblies **104**, including an additional sensor assembly **104** disposed at the middle of the central frame member **208**. In other embodiments, the bed **206** may include any arrangement of sensor assemblies **104**. Two controllers **200** can be attached to the frame **204**. The controllers **200** may be in wired or wireless communication with its respective sensors and optionally with each other. Each of the controllers **200** collects and processes signals from a subset of sensor assemblies **104**. For example, one controller **200** can collect and process signals from sensor assemblies **104** (e.g. four sensor assemblies) configured to support one subject lying on the bed **206**. Another controller **200** can collect and process signals from the other sensor assemblies **104** (e.g. four sensor assemblies) configured to support the other subject lying on the bed **206**. Wiring **210** may connect the sensor assemblies **104** to either or both of the controllers **200** attached to the frame **204**. The wiring **210** may also connect the controllers **200**. In other embodiments, the controllers may be in wireless communication with each other.

[0041] FIG. **3** is a top perspective view of a sensor assembly **300** according to one embodiment. The sensor assembly **300** includes multiple substrate support members **302** (one of which is shown in FIG. **3**) configured to support a bed frame and/or substrate. The substrate support member **302** includes a load bearing member **304** engaging a base **306**. The load bearing member **304** extends between the frame **102** and/or substrate **106** and the base **306**. A sensor (e.g. load sensor **404** in FIG. **4**) is disposed between the load bearing member **304** and the base **306**. A first end **308** of the load bearing member **304** may include an attachment member **310** configured to be attached to the frame **102** and/or substrate **106**. In the illustrated, non-limiting example, the attachment member **310** is a threaded member configured to be screwed into a bed frame. In other embodiments, the attachment member **310** may include a screw, bolt, or any other fastener. The load bearing member **304** may be a substantially cylindrical tube, but may be any other shape or configuration. For example, the load bearing member **304** may be a rectangular tube with two or more walls, may be two or more columns, or any may be any other structure that adequately supports and evenly distributes the load from the frame and/or substrate to the sensor. The load bearing member **304** may be made of any wood, plastic, metal, any other suitable material, or any combination thereof. The load bearing member **304** may include an aperture **312** configured to allow wiring (not shown) to extend from an interior of the load bearing member **304** to an exterior of the load bearing member **304**.

[0042] The base **306** supports the load bearing member **304** and is configured to provide contact with the floor (or ground) at an end of the base **306**. A second end **314** of the load bearing member **304** is engaged with the base **306** such that vertical movement is allowed. The load bearing member **304** is configured to move vertically with respect to the base **306**. This movement can be very slight but allows for transfer of various loads onto the sensor. The base **306** may be a sleeve **316** disposed around the load bearing member **304**. The base **306** may also include a bottom portion **317** integral with or attached to the sleeve **316**. The bottom portion **317** may be disposed between the sleeve **316** and the floor. The sleeve **316** may have an exterior profile shaped to represent a leg of the bed **100**. The sleeve **316** may extend partially along a length of the load bearing member **304** or may extend along nearly an entire length of the load bearing member **304**. The base **306** or sleeve **316** does not contact the frame and/or the substrate to ensure all load is transferred to the load bearing member **304**. For example, the sleeve **316** may extend along a length of the load bearing member **304** sufficient to conceal the load bearing member **304** and to look to a subject proximate the bed that the sleeve **316** is a leg of the bed **100**. The sleeve **316** may include a substantially cylindrical shape or any other shape. The base **306**, the sleeve **316**, and/or the bottom portion **317** may be made of any wood, plastic, metal, any other suitable material, or any combination thereof. The base **306** may include an aperture **318** configured to allow wiring (not shown) to extend from an interior of the base to an exterior of the base **306**. The sleeve **316** can be separate from the base **306** and may be used to provide the aesthetics of a bed leg without being actually a part of the base **306** or load bearing member **304**.

[0043] FIG. **4** is a bottom perspective view of the load bearing member **304**. A cap **400** may be disposed proximate to the second end **314** of the load bearing member **304**. For example, a portion of the cap **400** may be disposed inside the load bearing member **304**. The cap **400** may be attached to the second end **314** of the load bearing member **304** via interference fit, adhesive, or any other means of attachment. The cap **400** can be integral with the load bearing member **304**, such that it is simply an end of the load bearing member **304**.

[0044] A load sensor **404** may be attached to a bottom surface **406** of the cap **400**. In other embodiments, the load sensor **404** may be attached to an interior surface of the base **306** (e.g. to a top surface of the bottom portion **317**). The load sensor **404** may be attached to the cap **400** and/or the base **306** via interference fit, adhesive, plastic welding, or any other means of attachment. The cap **400** may include a recess defined by the bottom surface of the cap **400**. The recess may be configured to receive the load sensor **404**. For example, an interior profile of the recess in the cap **400** may be shaped to correspond with an exterior profile of a portion of the load sensor **404**. In this configuration, the load bearing member **304**, the cap **400**, and the load sensor **404** may be configured to fit together to maintain lateral, or radial, alignment of the load bearing member **304**, the cap **400**, and the load sensor **404** to maintain accurate transmission of the load to the load sensor **404**.

[0045] In FIGS. **4** and **5**, a bottom surface **408** of the load sensor **404** is configured to contact the bottom portion **317** of the base **306**. As described later with respect to FIG. **6**, the bottom portion **317** of the base **306** includes a contact member **604** that contacts the load sensor **404**. Load from the subject on the substrate is transmitted through the load bearing member **304** with the contact member **604** providing the resistance, allowing the load sensor **404** to read the load. In this configuration, the base **306**, the cap **400**, the load bearing member **304**, and the load sensor **404** are configured to fit together to maintain lateral alignment of the base **306**, the cap **400**, the load bearing member **304**, and the load sensor **404**. In other embodiments, the load sensor **404** may be attached to the bottom portion **317** with the contact member **604** provided on the bottom surface **406** of the cap **400**.

[0046] FIG. **5** is a top perspective view of the cap **400** attached to a printed circuit board **500**. The printed circuit board **500** may be attached to a top surface **502** of the cap **400** via a mount **504**. The printed circuit board **500** may be attached to the cap **400** and/or the mount **504** using plastic welding, adhesive, or any other means of attachment. The printed circuit board **500** may be located inside the load bearing member **304** when the cap **400** is attached to the second end **314** of the load bearing member **304**. The printed circuit board **500** may be in communication with the load sensor **404** and/or the controller **200** (e.g. via wired or wireless communication). The printed circuit board **500** may be configured to receive and process data from the load sensor **404**. The cap **400** may include an aperture **506** through a portion of the cap **400**. Wiring (not shown) may be routed through the aperture **506** from the load sensor **404** to the printed circuit board **500**.

[0047] The cap **400** may optionally include a portion **508** configured to be disposed inside the load bearing member **304**. The portion **508** may be shaped and sized to fit inside a cavity defined by the load bearing member **304** such that the cap **400** and the load bearing member **304** may be attached via interference fit between the portion **508** and the load bearing member **304**. The printed circuit board **500** may be attached to the portion **508** of the cap **400**.

[0048] FIG. **6** is a top perspective view of the base **306**. In the illustrated, non-limiting example, the sleeve **316** is attached to the bottom portion **317**. The bottom portion **317** may include a supporting member **600**. The bottom portion **317** (e.g. the supporting member **600**) may include a recess **602** shaped to receive the load sensor **404**. The bottom portion **317** includes the contact member **604** configured to contact the load sensor **404**. In other embodiments, the supporting member **600** may have be of a different shape and size.

[0049] FIG. **7** is a cross sectional view of the substrate support member **302**. The load bearing member **304** defines a cavity **700**. The cap **400** is attached to the second end **314** of the load bearing member **304**. The printed circuit board **500** attached to the cap **400** may be positioned in the cavity **700** of the load bearing member **304**. The load sensor **404** is disposed between the cap **400** and the base **306**. For example, the load sensor **404** may be disposed in the recess **602** of the bottom portion **317** of the base **306** and in a recess **702** defined by the cap **400**. A bottom surface of the bottom portion **317** of the base **306** may contact the floor. One end of the sleeve **316** may contact a top surface of the bottom portion **317**.

[0050] When the subject sits, lies, or moves on the substrate, a load is placed on the substrate. The load is transferred from the substrate to each load bearing member **304**. The load bearing member **304** transfers the load to the load sensor **404**. The load bearing member **304** and the cap **400** attached to the second end **314** of the load bearing member **304** may be configured to move vertically relative to the base **306** as the magnitude of the load on the substrate changes.

[0051] FIG. **8** illustrates an assembly **800** that has another embodiment of a sensor assembly **900** inserted into a leg **802** of the bed **100**. The leg **802** is on an existing bed or may be purchased with a bed, already on the bed or a separate component that is selected with a frame. The leg shown is provided as an example only. A first end **804** of the leg **802** is configured to attached to the frame and/or substrate.

[0052] The sensor assembly **900** may be packaged as a cartridge that is configured to fit into the bottom of the leg **802**. The sensor assembly may be disposed inside a cavity **806** that is defined by the leg **802**. The cavity **806** may be existing in the leg **802** at the time of original manufacture of the leg or may be formed into a leg that does not have a cavity; i.e., the cavity **806** and the sensor assembly **900** can be retrofit to existing legs after the time of original manufacture. The sensor assembly **900** may be configured to support the leg **802** such that a distal end **810** of the leg **802** does not contact the floor. The leg **802** may have an aperture **808** anywhere in its side or top to surfaces to accommodate wiring if necessary.

[0053] FIG. **9** is cross-sectional view of FIG. **8**. The sensor assembly **900** includes a base **902** having a first end portion **903** and a second end portion **904** opposite the first end portion **903**. The base **902** is configured to provide contact with the floor at the first end portion **903**. A cap **906** slides over the second end portion **904** of the base **902**. The cap **906** may be attached to the base **902** using a screw **908**, for example, to maintain radial alignment of the cap **906** and the base **902**, so long as vertical movement is allowed between the cap **906** and the base **902**. The sensor assembly **900** includes a load bearing member **910** having a third end portion **912** and a fourth end portion **914** opposite the third end portion **912**. The load bearing member **910** defines a cavity **916**. The third end portion **912** is in contact with the cap **906**. The fourth end portion **914** is in contact with an interior portion of the leg **802** to transmit a load from the leg **802** to the sensor assembly **900**. The cap **906** and the load bearing member **910** can be a single, integral piece.

[0054] The sensor assembly **900** includes a load sensor **920** between the cap **906** and the base **902**. The load sensor **920** may include features similar to those of the load sensor **404** unless otherwise described. The load sensor **920** may be attached to the cap **906** and/or the base **902** via interference fit, adhesive, plastic welding, or any other means of attachment. The cap **906** may be configured to transmit the load from the leg **802** through the load bearing member **910** to the load sensor **920**. The sensor assembly **900** includes a printed circuit board **918** disposed inside the cavity **916** defined by the load bearing member **910**. The printed circuit board may have features similar to those of printed circuit board **500**. The printed circuit board may be in wired or wireless communication with the load sensor **920**. The cap **906** may include an aperture **922** through a portion of the cap **906** such that wiring may be routed through the aperture **922** from the load sensor **920** to the printed circuit board **918**. If the cap **906** and load bearing member **910** are integral, i.e., no separate cap **906**, a wall **913** may be configured in the load bearing member **910** to translate the force to the load sensor **920** as well as have means to retain the printed circuit board **918**.

[0055] When the subject sits, lies, or moves on the substrate, the load from the subject is transferred through each contact with the floor (i.e., ground). The load is transferred from the leg **802** to the sensor assembly **900**. Specifically, the load may be transferred from the leg **802** to the load bearing member **910** via contact between the leg **802** and the fourth end portion **914** of the load bearing member **910**. The load bearing member **910** transfers the load to the cap **906**. The cap **906** transfers the load to the load sensor **920**. The substrate leg **802** is configured to move vertically relative to the base **902** as the magnitude of the load on the substrate changes. A gap **924** between the leg **802** and the floor facilitates the vertical movement of the leg **802** relative to the base **902**. A gap **926** between the cap **906** and the base **902** allows for vertical movement between the cap **906** and the base **902**.

[0056] FIG. **10** is a top perspective view of the base **902**. The base **902** may have a shape profile that cooperates with the shape of the leg **802**. As illustrated, the base **902** has a substantially cylindrical shape as does the leg **802**. However, the base **902** may be a square, rectangular, or any other shape so long as it fits into the leg **802**. The second end portion **904** of the base **902** may include a recess **1000** defined in the second end portion **904** of the base **902**. The recess **1000** may be configured to receive the load sensor **920**. For example, an interior profile of the recess **1000** in the base **902** may be shaped to correspond with an exterior profile of a portion of the load sensor **920**. In this configuration, the load sensor **920** and the base **902** may be configured to fit together to maintain alignment of the load sensor **920** and the base **902**. The base **902** is configured to receive the cap **906** over at least a portion of the base **902**, and may include one or more cut outs shaped to receive the cap **906**. In the illustrated, non-limiting example, the base **902** includes two opposing flat portions **1002** located on a periphery of the base **902**. The opposing flat portions **1002** may be shaped to receive flanges of the cap **906**. The base **902** may also include one or more aperture **1004** configured to receive a fastener (e.g. screw) to attach the cap **906** to the base **902**. In other embodiments, any portion of the base **902** may be shaped in any way to receive the cap **906**.

[0057] FIGS. **11**A and **11**B illustrate the cap **906**. The cap **906** may include a bottom portion **1100** and a top portion **1102**. The top portion **1102** is configured to hold the printed circuit board **918** in the cavity **916** of the load bearing member **910**. The top portion **1102** may have an exterior profile shaped to correspond with an interior profile of the load bearing member **910**. In the illustrated, non-limiting example, the top portion **1102** includes a rectangular shape such that the top portion **1102** may be received inside a load bearing member **910** having a rectangular and tubular shape. In other embodiments, the top portion **1102** and the load bearing member **910** may include any other shape. The third end portion **912** of the load bearing member **910** may contact a top surface **1104** of the bottom portion **1100**. The bottom portion **1100** is configured to slide over the base **902**. For example, the cap **906** may include two flanges **1106** disposed on opposing sides of the bottom portion **1100** configured to slide over a portion of the base **902** (e.g. the flat portions **1002** of the base **902**). The flanges **1106** may each include an aperture **1108** configured to receive a fastener (e.g. a screw) such that the cap **906** may be attached to the base **902**. For example, the apertures **1108** may be aligned with the apertures **1004** so that a fastener can extend through the flanges **1106** and through a portion of the base **902**. The apertures **1108** are shaped to allow for vertical movement of the cap **906** relative to the base **902**. In other embodiments, the cap **906** may not include the flanges **1106** and the cap **906** may attach to the base **902** in any other suitable manner.

[0058] A bottom surface **1110** of the cap **906** has a contact member **1112** configured to contact the load sensor **920** of the base **902**. In this configuration, the base **902**, the cap **906**, the load bearing member **910**, and the load sensor **920** are configured to fit together to maintain radial alignment of the base **902**, the cap **906**, the load bearing member **910**, and the load sensor **920**. In other embodiments, load sensor **920** may be attached to the cap **906** with the contact member **1112** located on the base **902**.

[0059] FIG. **12** is a top perspective view of the load bearing member **910** attached to the cap **906**. In the illustrated, non-limiting example, the load bearing member **910** includes a rectangular tube that defines the cavity **916**. The cavity **916** may be shaped to receive a portion of the cap **906** and the printed circuit board **918**. The load bearing member **910** can be any alternative shape so long is it provides contact with the leg **802** and evenly distributes the load. For example, the load bearing member **910** may a cylindrical tube, a cylinder having a portion that is solid, two or more walls, two or more columns or any other shape, configuration, and orientation.

[0060] FIG. **13** is another example of a sensor assembly **1000** that can be used as either a cartridge that is slid into an existing leg of a bed or can include a sleeve and means of attachment to the frame/substrate. The sensor assembly includes a load bearing member **1002** and a base **1004** configured to contact a floor. A load sensor **1006** is positioned between the load bearing member **1002** and the base **1004**. The load bearing member **1002** is attached to the base **1004** in such a way that vertical movement is allowed of the load bearing member **1002** but lateral or radial movement is restrained. As shown, one means of this attachment **1008** is a fastener that threads both the load bearing member **1002** and the base **1004**, while the base **1004** has an aperture that allows vertical movement of the fastener and the load bearing member **1002** has an aperture that is sized to tightly fit the aperture. A cavity **1010** is provided in the base **1002** to hold a printed circuit board **1012**. However, the printed circuit board **1012** can be held within a cavity of the load bearing member **1002** as well.

[0061] The load sensor **1006** will be attached to one of the load bearing member **1002** and the base **1004**, with the other of the load bearing member or the base having a sensor contact that is configured to contact the load sensor **106** and transfer the load to the load sensor **1006**.

[0062] The base **1004** and load bearing member **1002** have exterior profiles that will slide into an existing leg of a bed. However, this exterior profile is not necessary and can be of any exterior profile so long as the base **1004** is in contact with the floor and the load is properly transferred from the load bearing member **1002** to the load sensor **1006**. As illustrated in FIG. **14**, the sensor assembly **1000** can slide into an existing leg **1020** having an existing attachment **1022** for attachment to the frame or substrate. The existing leg **1020** can have an aperture **1024** that is configured to receive a peg **1026** in the sensor assembly **100** that can be retracted while the sensor assembly **1000** is slide into the existing leg **1020** and pop out when aligned with the aperture **1024** to hold the sensor assembly **1000** in place within the leg **1020**. Note that the existing leg **1020** does not contact the floor. Only the base **1004** of the sensor assembly **1000** contacts the floor.

[0063] Alternatively, as illustrated in FIG. **15**, the sensor assembly **1000** can be the bed leg and can include a sleeve **1030** that is integral with the base **1004** or that covers the base **1004** and the load bearing member **1002** for aesthetic purposes. The load bearing member **1002** can include an attachment member **1032** that attaches to the frame or substrate.

[0064] Examples of data determinations that can be made using the systems herein are described. The algorithms are dependent on the number of sensors and each sensor's angle and distance with respect to the other sensors. This information is predetermined. Software algorithms will automatically and continuously maintain "empty weight" calibration with the sensors so that any changing in weight due to changes in a mattress or bedding is accounted for.

[0065] The load sensor assemblies herein utilize macro signals and micro signals and process those signals to determine a variety of data, described herein. Macro signals are low frequency signals and are used to determine weight and center of mass, for example. The strength of the macro signal is directly influence by the subject's proximity to each sensor.

[0066] Micro signals are also detected due to the heartbeat, respiration and to movement of blood throughout the body. Micro signals are higher frequency and can be more than 1000 times smaller than macro signals. The sensors detect the heart beating and can use this amplitude data to determine where on the substrate the heart is located, thereby assisting in determining in what direction and position the subject is laying. In addition, the heart pumps blood in such a way that it causes top to bottom changes in weight. There is approximately seven pounds of blood in a human subject, and the movement of the blood causes small changes in weight that can be detected by the sensors. These directional changes are detected by the sensors. The strength of the signal is directly influenced by the subject's proximity to the sensor. Respiration is also detected by the sensors. Respiration will be a different frequency than the heart beat and has different directional changes than those that occur with the flow of blood. Respiration can also be used to assist in determining the exact position and location of a subject on the substrate. These bio-signals of heart beat, respiration and directional movement of blood are used in combination with the macro signals to calculate a large amount of data about a subject, including the relative strength of the signal components from each of the sensors, enabling better isolation of a subject's bio-signal from noise and other subjects.

[0067] As a non-limiting example, the cardiac bio-signals in the torso area are out of phase with the signals in the leg regions. This allows the signals to be subtracted which almost eliminates common mode noise while allowing the bio-signals to be combined, increasing the signal to noise by as much as a factor of 3 db or 2× and lowering the common or external noise by a significant amount. By analyzing the phase differences in the 1 hz to 10 hz range (typically the heart beat range) the angular position of a person laying on the bed can be determined. By analyzing the phase differences in the 0 to 0.5 hz range, it can be determined if the person is supine or laying on their side, as non-limiting examples.

[0068] Because signal strength is still quite small, the signal strength can be increased to a level more conducive to analysis by adding or subtracting signals, resulting in larger signals. The signal deltas are combined in signal to increase the signal strength for higher resolution algorithmic analysis.

[0069] The controller can be programmed to cancel out external noise that is not associated with the subject laying on the bed. External noise, such as the beat of a bass or the vibrations caused by an air conditioner, register as the same type of signal on all sensor assemblies and is therefore canceled out when deltas are combined during processing.

[0070] Using superposition analysis, two subjects can be distinguished on one substrate. Superposition simplifies the analysis of the signal with multiple inputs. The usable signal equals the algebraic sum of the responses caused by each independent sensor acting alone. To ascertain the contribution of each individual source, all of the other sources first must be turned off, or set to zero. This procedure is followed for each source in turn, then the resultant responses are added to determine the true result. The resultant operation is the superposition of the various sources. By using signal strength and out-of-phase heart rates, individuals can be distinguished on the same substrate.

[0071] The controller can be programmed to provide provide dynamic center of mass location and movement vectors for the subject, while eliminating those from other subjects and inanimate objects or animals on the substrate. By leveraging multiple sensor assemblies that detect the z-axis of the force vector of gravity, and by discriminating and tracking the center of mass of multiple subjects as they enter and move on a substrate, not only can presence, motion and cardiac and respiratory signals for the subject be determined, but the signals of a single or multiple subjects on the substrate can be enhanced by applying the knowledge of location to the signal received. By analyzing the bio-signal's amplitude and phase in different frequency bands, the center of mass for a subject can be obtained using multiple methods, examples of which include:

[0072] DC weight;

[0073] AC low band analysis of signal, center of mass and back supine respiratory identification of subject;

[0074] AC mid band analysis of signal center of mass and cardiac identification of subject; and

[0075] AC upper mid band identification of snorer or apnea events.

[0076] The data from the load sensor assemblies can be used to determine presence and location X, Y, theta, back and supine positions of a subject on a substrate. Such information is useful for calculating in/out statistics for a subject such as: period of time spent in bed, time when subject fell asleep, time when subject woke up, time spent on back, time spent on side, period of time spent out of bed. The sensor assemblies can be in sleep mode until the presence of a subject is detected on the substrate, waking up the system.

[0077] Macro weight measurements can be used to measure the actual static weight of the subject as well as determine changes in weight over time. Weight loss or weight gain can be closely tracked as weight and changes in weight can be measured the entire time a subject is in bed every night. This information may be used to track how different activities or foods affect a person's weight. For example, excessive water retention could be tied to a particular food. In a medical setting, for example, a two-pound weight gain in one night or a five-pound weight gain in one week could raise an alarm that the patient is experiencing congestive heart failure. Unexplained weight loss or weight gain can indicate many medical conditions. The tracking of such unexplained change in weight can alert professionals that something is wrong.

[0078] Center of mass can be used to accurately heat and cool particular and limited space in a substrate such as a mattress, with the desired temperature tuned to the specific subject associated with the center of mass, without affecting other subjects on the substrate. Certain mattresses are known to provide heating and/or cooling. As non-limiting examples, a subject can set the controller to actuate the substrate to heat the portion of the substrate under the center of mass when the temperature of the room is below a certain temperature. The subject can set the controller to instruct the substrate to cool the portion of the substrate under the center of mass when the temperature of the room is above a certain temperature.

[0079] These macro weight measurements can also be used to determine a movement vector of the subject. Subject motion can be determined and recorded as a trend to determine amount and type of motion during a sleep session. This can determine a general restlessness level as well as other medical conditions such as "restless leg syndrome" or seizures.

[0080] Motion detection can also be used to report in real time a subject exiting from the substrate. Predictive bed exit is also possible as the position on the substrate as the subject moves is accurately detected, so movement toward the edge of a substrate is detected in real time. In a hospital or elder care setting, predictive bed exit can be used to prevent falls during bed exit, for example. An alarm might sound so that a staff member can assist the subject exit the substrate safely.

[0081] Data from the load sensor assemblies can be used to detect actual positions of the subject on the substrate, such as whether the subject is on its back, side, or stomach, and whether the subject is aligned on the substrate vertically, horizontally, with his or her head at the foot of the substrate or head of the substrate, or at an angle across the substrate. The sensors can also detect changes in the positions, or lack thereof. In a medical setting, this can be useful to determine if a subject should be turned to avoid bed sores. In a home or medical setting, firmness of the substrate can be adjusted based on the position of the subject. For example, sleeping angle can be determined from center of mass, position of heart beat and/or respiration, and directional changes due to blood flow.

[0082] Controlling external devices such as lights, ambient temperature, music players, televisions, alarms, coffee makers, door locks and shades can be tied to presence, motion and time, for example. As one example, the controller can collect signals from each load sensor assembly, determine if the subject is asleep or awake and control at least one external device based on whether the subject is asleep or awake. The determination of whether a subject is asleep or awake is made based on changes in respiration, heart rate and frequency and/or force of movement. As another example, the controller can collect signals from each load sensor assembly, determine that the subject previously on the substrate has exited the substrate and change a status of the at least one external device in response to the determination. As another example, the controller can collect signals from each load sensor assembly, determine that the subject has laid down on the substrate and change a status of the at least one external device in response to the determination.

[0083] A light can be automatically dimmed or turned off by instructions from the controller to a controlled lighting device when presence on the substrate is detected. Electronic shades can be automatically closed when presence on the substrate is detected. A light can automatically be turned on when bed exit motion is detected or no presence is detected. A particular light, such as the light on a right side night stand, can be turned on when a subject on the right side of the substrate is detected as exiting the substrate on the right side. Electronic shades can be opened when motion indicating bed exit or no presence is detected. If a subject wants to wake up to natural light, shades can be programmed to open when movement is sensed indicating the subject has woken up. Sleep music can automatically be turned on when presence is detected on the substrate. Predetermined wait times can be programmed into the controller, such that the lights are not turned off or the sleep music is not started for ten minutes after presence is detected, as non-limiting examples.

[0084] The controller can be programmed to recognize patterns detected by the load sensor assemblies. The patterned signals may be in a certain frequency range that falls between the macro and the micro signals. For example, a subject may tap the substrate three times with his or her hand, creating a pattern. This pattern may indicate that the substrate would like the lights turned out. A pattern of four taps may indicate that the subject would like the shades closed, as non-limiting examples. Different patterns may result in different actions. The patterns may be associated with a location on the substrate. For example, three taps near the top right corner of the substrate can turn off lights while three taps near the base of the substrate may result in a portion of the substrate near the feet to be cooled. Patterns can be developed for medical facilities, in which a detected pattern may call a nurse.

[0085] While the figures all illustrate the use of the sensor assemblies with a bed as a substrate, it is contemplated that the sensor assemblies can be used with chairs such as desks, where a subject spends extended periods of time. A wheel chair can be equipped with the sensors to collect signals and provide valuable information about a patient. The sensors may be used in an automobile seat and may help to detect when a driver is falling asleep or his or her leg might go numb. Furthermore, the bed can be a baby's crib, a hospital bed, or any other kind of bed.

[0086] Implementations of controller **200** and/or controller **214** (and the algorithms, methods, instructions, etc., stored thereon and/or executed thereby) can be realized in hardware, software, or any combination thereof. The hardware can include, for example, computers, intellectual property (IP) cores, application-specific integrated circuits (ASICs), programmable logic arrays, optical processors, programmable logic controllers, microcode, microcontrollers, servers, microprocessors, digital signal processors or any other suitable circuit. In the claims, the term "controller" should be understood as encompassing any of the foregoing hardware, either singly or in combination.

[0087] Further, in one aspect, for example, controller **200** and/or controller **214** can be implemented using a general purpose computer or general purpose processor with a computer program that, when executed, carries out any of the respective methods, algorithms and/or instructions described herein. In addition or alternatively, for example, a special purpose computer/processor can be utilized which can contain other hardware for carrying out any of the methods, algorithms, or instructions described herein.

[0088] The word "example," "aspect," or "embodiment" is used herein to mean serving as an example, instance, or illustration. Any aspect or design described herein as using one or more of these words is not necessarily to be construed as preferred or advantageous over other aspects or designs. Rather, use of the word "example," "aspect," or "embodiment" is intended to present concepts in a concrete fashion. As used in this application, the term "or" is intended to mean an inclusive "or" rather than an exclusive "or". That is, unless specified otherwise, or clear from context, "X includes A or B" is intended to mean any of the natural inclusive permutations. That is, if X includes A; X includes B; or X includes both A and B, then "X includes A or B" is satisfied under any of the foregoing instances. In addition, the articles "a" and "an" as used in this application and the appended claims should generally be construed to mean "one or more" unless specified otherwise or clear from context to be directed to a singular form.

[0089] While the disclosure has been described in connection with certain embodiments, it is to be understood that the disclosure is not to be limited to the disclosed embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.

What is claimed is:

1. A load sensor assembly for a substrate that supports a subject, the load sensor assembly comprising:

at least four substrate support members, wherein each of the four substrate support members comprises:

a load bearing member configured to be attached to the substrate at a first end of the load bearing member;

a base configured to support the load bearing member and to provide contact with a floor, wherein the base and the load bearing member are configured to fit together to maintain lateral alignment of the base and the load bearing member while the load bearing member is configured to move vertically relative to the base;

a load sensor between the load bearing member and the base, wherein the load bearing member is configured to transmit a load from the substrate to the load sensor; and

a printed circuit board positioned in a cavity defined by one of the load bearing member or the base, the printed circuit board in communication with the load sensor, wherein the printed circuit board is configured to receive and process data from the load sensor.

2. The load sensor assembly of claim **1**, wherein the load sensor is attached to at least one of the load bearing member or the base, and wherein at least one of the load bearing member or the base includes a recess configured to receive the load sensor.

3. The load sensor assembly of claim **1**, wherein the load bearing member defines the cavity and includes a cap at the second end of the load bearing member, and wherein the cap is configured to hold the printed circuit board within the cavity.

4. The load sensor assembly of claim **1**, wherein the base includes a sleeve disposed around the load bearing member, the sleeve having an exterior profile shaped to represent a leg of the substrate.

5. The load sensor assembly of claim **1**, comprising a controller in communication with the printed circuit board, wherein the controller is configured to output power to the printed circuit board and the load sensor, to process data output by the printed circuit board, and to transmit the processed data to an external device.

6. The load sensor assembly of claim **1**, comprising eight support members, wherein the substrate is configured to support two subjects.

7. The load sensor assembly of claim **1**, comprising nine support members, wherein the substrate is configured to support two subjects.

8. A sensor cartridge for use with a bed having legs to support the bed, the cartridge comprising:

a base having a first end portion and a second end portion opposite the first end portion, wherein the base is configured to provide contact with a floor at the first end portion;

a load bearing member engaged with the second end portion of the base, wherein the base and the load bearing member are configured to fit together to maintain lateral alignment of the cap to the base while allowing vertical movement of the load bearing member with respect to the base;

a load sensor between the load bearing member and the base, wherein the load bearing member is configured to transmit the load from the substrate to the load sensor; and

a printed circuit board positioned within a cavity defined by one of the load bearing member or the base, the printed circuit board in communication with the load sensor and configured to receive and process data from the load sensor, wherein the sensor cartridge is configured to insert into a leg of the bed that is at least partially hollow.

9. The cartridge of claim **8**, wherein the load sensor is attached to at least one of the load bearing member or the base, and wherein at least one of the second end portion of the base or a bottom surface of the load bearing member includes a recess to receive the load sensor.

10. The cartridge of claim **8**, wherein the printed circuit board is in communication with a controller configured to do one or more of output power to the printed circuit board and the load sensor, receive and process data output by the printed circuit board, and transmit the processed data to an external device.

11. The cartridge of claim **8**, wherein the load bearing member defines the cavity in which the printed circuit board is positioned, the load bearing member comprising a wall positioned between the load sensor and the cavity and having a means of retaining the printed circuit board opposite the load sensor.

12. The cartridge of claim **8**, wherein the base defines the cavity in which the printed circuit board is positioned.

13. The cartridge of claim **8**, wherein the first end portion of the base is configured to be in contact with the floor while the leg is not in contact with the floor.

14. A bed having a frame supporting a substrate configured to support a subject, the bed comprising:

substrate support members, each substrate support member comprising:

a load bearing member having a first end portion and a second end portion;

a base configured to provide contact with a floor, wherein the load bearing member is configured to move vertically relative to the base

and the base and the load bearing member are configured to fit together to maintain lateral alignment of the base and the load bearing member;

a load sensor between the load bearing member and the base, wherein the load bearing member is configured to transmit a load from the substrate to the load sensor; and

a printed circuit board in communication with the load sensor, wherein the printed circuit board is configured to receive and process data from the load sensor; and

a controller in communication with the printed circuit board of each substrate support member, wherein the controller is configured to receive and process data output by the printed circuit boards.

15. The bed of claim **14**, comprising four substrate support members, wherein:

each substrate support member is a leg of the bed; and

the load bearing member contacts the frame at the first end portion of the load bearing member.

16. The bed of claim **14**, wherein the base includes a sleeve disposed around the load bearing member, the sleeve having an exterior profile shaped to represent the leg of the bed.

17. The bed of claim **14**, comprising at least eight substrate support members, wherein the bed is configured to support two subjects.

18. The bed of claim **14**, further comprising at least four legs, wherein:

each substrate support member is a cartridge configured to be inserted into a leg that is at least partially hollow such that a first end portion of the load bearing member contacts a horizontal surface of the leg.

19. The bed of claim **18**, wherein the cartridge is configured to be inserted into the leg such that the base is in contact with the floor while the leg is not in contact with the floor.

20. The bed of claim **14**, wherein the controller is attached internally to the frame and the frame is configured to conceal wiring that extends between each substrate support member and the controller.

21. The bed of claim **14**, wherein the controller is configured to control external devices that are configured to wirelessly communicate with the controller, the control based on the data output by the printed circuit boards.

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