United States Patent	12390379
Kind Code	B2
Date of Patent	August 19, 2025
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Bed having snore detection feature

Abstract

A first bed that includes a first mattress, a first pressure sensor, a first acoustic sensor, and a first controller in data communication with the first pressure sensor and the first acoustic sensor. The first controller is configured to receive first pressure readings and first acoustic readings. The first controller is further configured to transmit the first pressure readings and the first acoustic readings to a remote server. A second controller is configured to receive the one or more snore classifiers. The second controller is further configured to run the received snore classifiers on second pressure readings and on second acoustic readings in order to collect one or more snore votes from the running snore classifiers. The second controller is further configured to determine a snore state of a user on the second bed and operate the bed system according to the determined snore state.

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Appl. No.: **16/233260**

Filed: **December 27, 2018**

Prior Publication Data

Document Identifier	Publication Date
US 20190201268 A1	Jul. 04, 2019

Related U.S. Application Data

us-provisional-application US 62611163 20171228

Publication Classification

Int. Cl.: A61G7/018 (20060101); **A47C21/00** (20060101); **A47C27/08** (20060101); **A47C31/00** (20060101); **A61B5/00** (20060101); **A61B5/11** (20060101); **A61F5/56** (20060101); **A61G7/015** (20060101); **A61G7/057** (20060101); **G06N20/00** (20190101)

U.S. Cl.:

CPC **A61G7/018** (20130101); **A47C21/003** (20130101); **A47C27/082** (20130101); **A61B5/0004** (20130101); **A61B5/4809** (20130101); **A61B5/4812** (20130101); **A61F5/56** (20130101); **A61G7/015** (20130101); **G06N20/00** (20190101); A47C27/083 (20130101); A47C31/008 (20130101); A61B5/11 (20130101); A61B5/4818 (20130101); A61B5/6892 (20130101); A61B5/7267 (20130101); A61G7/05769 (20130101)

Field of Classification Search

CPC: A61G (7/018); A61G (7/015); A61G (7/05769); A61F (5/56); G06N (20/00); A61B (5/0004); A61B (5/4809); A61B (5/4812); A61B (5/11); A61B (5/4818); A61B (5/6892); A61B (5/7267); A47C (27/082); A47C (21/003); A47C (27/083); A47C (31/008)

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Background/Summary

(1) The present document relates to a bed with sensors used for snore detection.
BACKGROUND
(2) In general, a bed is a piece of furniture used as a location to sleep or relax. Many modern beds include a soft mattress on a bed frame. The mattress may include springs, foam material, and/or an air chamber to support the weight of one or more occupants.
SUMMARY
(3) In one aspect, a bed system includes a first bed that includes a first mattress. The system further includes a first pressure sensor in communication with the first mattress to sense pressure applied to the first mattress. The system further includes a first acoustic sensor placed to sense acoustics from a user on the first mattress. The system further includes a first controller in data communication with the first pressure sensor and in data communication with the first acoustic sensor, the first controller configured to: receive, from the first pressure sensor, first pressure readings indicative of the sensed pressure of the first mattress. The first controller is further configured to receive, from the first acoustic sensor, first acoustic readings indicative of the sensed acoustic acoustics from the user. The first controller is further configured to transmit the first pressure readings and the first acoustic readings to a remote server such that the remote server is able to generate one or more snore classifiers that, when run by a controller on incoming pressure readings and on incoming acoustic readings, provide a snore vote. The system further includes a second bed that includes a second mattress. The system further includes a second pressure sensor in communication with the second mattress to sense pressure applied to the second mattress. The system further includes a second acoustic sensor placed to sense acoustics from a user on the second mattress. The system further includes a second controller in data communication with the second pressure sensor and in data communication with the second acoustic sensor, the controller configured to: receive the one or more snore classifiers. The second controller is further configured to run the received snore classifiers on second pressure readings and on second acoustic readings in order to collect one or more snore votes from the running snore classifiers. The second controller is further configured to determine, from the one or more snore votes, a snore state of a user on the second bed. The second controller is further configured to responsive to the determined snore state, operating the bed system according to the determined snore state. Other systems, devices, methods, and computer-readable media can be used.
(4) Implementations can include any, all, or none of the following features. Operating the bed system according to the determined snore state includes one of the list including turning on a light, turning off a light, turning on a warming feature, changing firmness of the second mattress, begin emitting white-noise, and articulating a foundation of the bed system. The bed system including the remote server. The remote server is physically remote from the first controller and the second controller; and wherein the remote server is in data communication with the first controller and the second controller. The remote server is configured to: generate training data from the first pressure data and from the first acoustic data; generate, from the training data, the one or more snore classifiers; and send, to the second controller, the one or more snore classifiers. Generating, from the training data, the one or more snore classifiers includes generating a feature set from the training data; mapping the training data to a kernel space; training a classifier with the feature set so that, based on the training data in kernel space, the classifier is able to classify unseen data.

Training a classifier includes unsupervised training. The unsupervised training includes at least one of the group including k-means clustering, mixture modeling, hierarchical clustering, self-organizing mapping, and hidden Markov modelling. Training a classifier includes supervised training. The supervised training includes providing the remote server with a set of annotations for the training data. The annotations for the training data are provided by a human. The annotations for the training data are provided programmatically. Generating the one or more presence classifiers includes training a deep learning model on the training data; Training the deep learning model on the training data includes generating an initial neural network configured to receive pressure data and generate presence votes. The presence vote includes a presence classification and a confidence value. Generating the one or more presence classifiers includes determining a loss value for the initial neural network; and iteratively refining, beginning with the initial neural network, to a final neural network having a lower loss value than the initial neural network. The iterative refining is performed with a gradient descent process until a lower loss value cannot be found with the gradient descent process. A particular snore classifier is used for multiple users in multiple beds. The snore classifiers are personalized for a single user such that the snore classifiers are generated from training data of the single user's use of the bed system and the snore classifiers are used to detect snore of the single user on the second bed. A second set of snore classifiers are personalized for a second user such that the second set of snore classifiers are generated from training data of the second user's use of the bed system and the second set of snore classifiers are used to detect snore of the second user on the second bed. Determining, from the one or more snore votes, a snore state of a user on the second bed is personalized for a single user such that votes from different classifiers are weighted based on the classifiers historical accuracy for that user. The first bed and the second bed are separate beds. The first bed and the second bed are the same beds. To run the received snore classifiers on second pressure readings and on second acoustic readings in order to collect one or more snore votes from the running snore classifiers, the second controller is configured to run the received snore classifiers on a plurality of snore classifiers in order to collect one or more snore votes from the running snore classifiers. Determining a snore state of a user on the second includes snoring a plurality of recent confidence values; aggregating the recent confidence values into an aggregation; and comparing the aggregation to a threshold value. The second controller is configured to operate according to one or more operational-parameters. The operational-parameters are personalized for a particular user of the second bed.
(5) Implementations can include any, all, or none of the following features.
(6) The technology described here may be used to provide a number of potential advantages. Snore detection related to a bed may be improved by the use of machine learning techniques. For example, snore detection may be made faster and/or more accurate. Noisy and complex sensor data may be quickly and efficiently converted into accurate snore detection information. By utilizing user-specific training data, snore categorization may be tailored to specific users and more accurately detect and categorize snore events by the user.
(7) Other features, aspects and potential advantages will be apparent from the accompanying description and figures.

Description

DESCRIPTION OF DRAWINGS
(1) FIG. **1** shows an example air bed system.
(2) FIG. **2** is a block diagram of an example of various components of an air bed system.
(3) FIG. **3** shows an example environment including a bed in communication with devices located in and around a home.
(4) FIGS. **4**A and **4**B are block diagrams of example data processing systems that can be associated

with a bed.

(5) FIGS. **5** and **6** are block diagrams of examples of motherboards that can be used in a data processing system that can be associated with a bed.

(6) FIG. **7** is a block diagram of an example of a daughterboard that can be used in a data processing system that can be associated with a bed.

(7) FIG. **8** is a block diagram of an example of a motherboard with no daughterboard that can be used in a data processing system that can be associated with a bed.

(8) FIG. **9** is a block diagram of an example of a sensory array that can be used in a data processing system that can be associated with a bed.

(9) FIG. **10** is a block diagram of an example of a control array that can be used in a data processing system that can be associated with a bed

(10) FIG. **11** is a block diagram of an example of a computing device that can be used in a data processing system that can be associated with a bed.

(11) FIGS. **12-16** are block diagrams of example cloud services that can be used in a data processing system that can be associated with a bed.

(12) FIG. **17** is a block diagram of an example of using a data processing system that can be associated with a bed to automate peripherals around the bed.

(13) FIG. **18** is a schematic diagram that shows an example of a computing device and a mobile computing device.

(14) FIG. **19** is a pipeline diagram of an example of a pipeline that can be used to collect acoustic readings and pressure readings for home automation.

(15) FIGS. **20**A and **20**B are swimlane diagrams of example processes for training and using machine-learning classifiers to determine and classify snore events in a bed.

(16) FIG. **21** is a flowchart of an example process for training classifiers on pressure and/or acoustic signals.

(17) FIG. **22** shows an example system for generating new classifiers.

(18) FIG. **23** shows an example system for generating new classifiers.

(19) FIG. **24** is a swimlane diagram of an example process for personalizing machine-learning classifiers based on a particular user's usage history.

(20) Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

(21) A bed that detects snore phenomenon of one or more users may use machine-learning techniques to identify snore-state of a user or users that are on the bed. For example, an airbed may collect pressure and acoustic signals for a particular user over a period of time. These pressure and acoustic signals may be used to train one or more personalized categorizers that are each able to categorize live pressure and/or acoustic signals into a snore state (e.g., no snoring, light snore, mild snore, moderate snore, moderate to loud snore, loud snore). One of these categorizers, or a group of these categorizers, can then be used by the bed on live pressure and/or acoustic readings to determine the snore state of the user on the bed. Based on the snore state, the bed or another device may be actuated or driven (e.g., elevating the head portion of the bed in an attempt to alleviate the snoring).

(22) Example Airbed Hardware

(23) FIG. **1** shows an example air bed system **100** that includes a bed **112**. The bed **112** includes at least one air chamber **114** surrounded by a resilient border **116** and encapsulated by bed ticking **118**. The resilient border **116** can comprise any suitable material, such as foam.

(24) As illustrated in FIG. **1**, the bed **112** can be a two chamber design having first and second fluid chambers, such as a first air chamber **114**A and a second air chamber **114**B. In alternative embodiments, the bed **112** can include chambers for use with fluids other than air that are suitable for the application. In some embodiments, such as single beds or kids' beds, the bed **112** can include a single air chamber **114**A or **114**B or multiple air chambers **114**A and **114**B. First and

second air chambers **114**A and **114**B can be in fluid communication with a pump **120**. The pump **120** can be in electrical communication with a remote control **122** via control box **124**. The control box **124** can include a wired or wireless communications interface for communicating with one or more devices, including the remote control **122**. The control box **124** can be configured to operate the pump **120** to cause increases and decreases in the fluid pressure of the first and second air chambers **114**A and **114**B based upon commands input by a user using the remote control **122**. In some implementations, the control box **124** is integrated into a housing of the pump **120**.

(25) The remote control **122** can include a display **126**, an output selecting mechanism **128**, a pressure increase button **129**, and a pressure decrease button **130**. The output selecting mechanism **128** can allow the user to switch air flow generated by the pump **120** between the first and second air chambers **114**A and **114**B, thus enabling control of multiple air chambers with a single remote control **122** and a single pump **120**. For example, the output selecting mechanism **128** can by a physical control (e.g., switch or button) or an input control displayed on display **126**. Alternatively, separate remote control units can be provided for each air chamber and can each include the ability to control multiple air chambers. Pressure increase and decrease buttons **129** and **130** can allow a user to increase or decrease the pressure, respectively, in the air chamber selected with the output selecting mechanism **128**. Adjusting the pressure within the selected air chamber can cause a corresponding adjustment to the firmness of the respective air chamber. In some embodiments, the remote control **122** can be omitted or modified as appropriate for an application. For example, in some embodiments the bed **112** can be controlled by a computer, tablet, smart phone, or other device in wired or wireless communication with the bed **112**.

(26) FIG. **2** is a block diagram of an example of various components of an air bed system. For example, these components can be used in the example air bed system **100**. As shown in FIG. **2**, the control box **124** can include a power supply **134**, a processor **136**, a memory **137**, a switching mechanism **138**, and an analog to digital (A/D) converter **140**. The switching mechanism **138** can be, for example, a relay or a solid state switch. In some implementations, the switching mechanism **138** can be located in the pump **120** rather than the control box **124**.

(27) The pump **120** and the remote control **122** are in two-way communication with the control box **124**. The pump **120** includes a motor **142**, a pump manifold **143**, a relief valve **144**, a first control valve **145**A, a second control valve **145**B, and a pressure transducer **146**. The pump **120** is fluidly connected with the first air chamber **114**A and the second air chamber **114**B via a first tube **148**A and a second tube **148**B, respectively. The first and second control valves **145**A and **145**B can be controlled by switching mechanism **138**, and are operable to regulate the flow of fluid between the pump **120** and first and second air chambers **114**A and **114**B, respectively.

(28) In some implementations, the pump **120** and the control box **124** can be provided and packaged as a single unit. In some alternative implementations, the pump **120** and the control box **124** can be provided as physically separate units. In some implementations, the control box **124**, the pump **120**, or both are integrated within or otherwise contained within a bed frame or bed support structure that supports the bed **112**. In some implementations, the control box **124**, the pump **120**, or both are located outside of a bed frame or bed support structure (as shown in the example in FIG. **1**).

(29) The example air bed system **100** depicted in FIG. **2** includes the two air chambers **114**A and **114**B and the single pump **120**. However, other implementations can include an air bed system having two or more air chambers and one or more pumps incorporated into the air bed system to control the air chambers. For example, a separate pump can be associated with each air chamber of the air bed system or a pump can be associated with multiple chambers of the air bed system. Separate pumps can allow each air chamber to be inflated or deflated independently and simultaneously. Furthermore, additional pressure transducers can also be incorporated into the air bed system such that, for example, a separate pressure transducer can be associated with each air chamber.

(30) In use, the processor **136** can, for example, send a decrease pressure command to one of air chambers **114**A or **114**B, and the switching mechanism **138** can be used to convert the low voltage command signals sent by the processor **136** to higher operating voltages sufficient to operate the relief valve **144** of the pump **120** and open the control valve **145**A or **145**B. Opening the relief valve **144** can allow air to escape from the air chamber **114**A or **114**B through the respective air tube **148**A or **148**B. During deflation, the pressure transducer **146** can send pressure readings to the processor **136** via the A/D converter **140**. The A/D converter **140** can receive analog information from pressure transducer **146** and can convert the analog information to digital information useable by the processor **136**. The processor **136** can send the digital signal to the remote control **122** to update the display **126** in order to convey the pressure information to the user.

(31) As another example, the processor **136** can send an increase pressure command. The pump motor **142** can be energized in response to the increase pressure command and send air to the designated one of the air chambers **114**A or **114**B through the air tube **148**A or **148**B via electronically operating the corresponding valve **145**A or **145**B. While air is being delivered to the designated air chamber **114**A or **114**B in order to increase the firmness of the chamber, the pressure transducer **146** can sense pressure within the pump manifold **143**. Again, the pressure transducer **146** can send pressure readings to the processor **136** via the A/D converter **140**. The processor **136** can use the information received from the A/D converter **140** to determine the difference between the actual pressure in air chamber **114**A or **114**B and the desired pressure. The processor **136** can send the digital signal to the remote control **122** to update display **126** in order to convey the pressure information to the user.

(32) Generally speaking, during an inflation or deflation process, the pressure sensed within the pump manifold **143** can provide an approximation of the pressure within the respective air chamber that is in fluid communication with the pump manifold **143**. An example method of obtaining a pump manifold pressure reading that is substantially equivalent to the actual pressure within an air chamber includes turning off pump **120**, allowing the pressure within the air chamber **114**A or **114**B and the pump manifold **143** to equalize, and then sensing the pressure within the pump manifold **143** with the pressure transducer **146**. Thus, providing a sufficient amount of time to allow the pressures within the pump manifold **143** and chamber **114**A or **114**B to equalize can result in pressure readings that are accurate approximations of the actual pressure within air chamber **114**A or **114**B. In some implementations, the pressure of the air chambers **114**A and/or **114**B can be continuously monitored using multiple pressure sensors (not shown).

(33) In some implementations, information collected by the pressure transducer **146** can be analyzed to determine various states of a person lying on the bed **112**. For example, the processor **136** can use information collected by the pressure transducer **146** to determine a heart rate or a respiration rate for a person lying in the bed **112**. For example, a user can be lying on a side of the bed **112** that includes the chamber **114**A. The pressure transducer **146** can monitor fluctuations in pressure of the chamber **114**A and this information can be used to determine the user's heart rate and/or respiration rate. As another example, additional processing can be performed using the collected data to determine a sleep state of the person (e.g., awake, light sleep, deep sleep). For example, the processor **136** can determine when a person falls asleep and, while asleep, the various sleep states of the person.

(34) Additional information associated with a user of the air bed system **100** that can be determined using information collected by the pressure transducer **146** includes motion of the user, presence of the user on a surface of the bed **112**, weight of the user, heart arrhythmia of the user, and apnea. Taking user presence detection for example, the pressure transducer **146** can be used to detect the user's presence on the bed **112**, e.g., via a gross pressure change determination and/or via one or more of a respiration rate signal, heart rate signal, and/or other biometric signals. For example, a simple pressure detection process can identify an increase in pressure as an indication that the user is present on the bed **112**. As another example, the processor **136** can determine that the user is

present on the bed **112** if the detected pressure increases above a specified threshold (so as to indicate that a person or other object above a certain weight is positioned on the bed **112**). As yet another example, the processor **136** can identify an increase in pressure in combination with detected slight, rhythmic fluctuations in pressure as corresponding to the user being present on the bed **112**. The presence of rhythmic fluctuations can be identified as being caused by respiration or heart rhythm (or both) of the user. The detection of respiration or a heartbeat can distinguish between the user being present on the bed and another object (e.g., a suit case) being placed upon the bed.

(35) In some implementations, fluctuations in pressure can be measured at the pump **120**. For example, one or more pressure sensors can be located within one or more internal cavities of the pump **120** to detect fluctuations in pressure within the pump **120**. The fluctuations in pressure detected at the pump **120** can indicate fluctuations in pressure in one or both of the chambers **114**A and **114**B. One or more sensors located at the pump **120** can be in fluid communication with the one or both of the chambers **114**A and **114**B, and the sensors can be operative to determine pressure within the chambers **114**A and **114**B. The control box **124** can be configured to determine at least one vital sign (e.g., heart rate, respiratory rate) based on the pressure within the chamber **114**A or the chamber **114**B.

(36) In some implementations, the control box **124** can analyze a pressure signal detected by one or more pressure sensors to determine a heart rate, respiration rate, and/or other vital signs of a user lying or sitting on the chamber **114**A or the chamber **114**B. More specifically, when a user lies on the bed **112** positioned over the chamber **114**A, each of the user's heart beats, breaths, and other movements can create a force on the bed **112** that is transmitted to the chamber **114**A. As a result of the force input to the chamber **114**A from the user's movement, a wave can propagate through the chamber **114**A and into the pump **120**. A pressure sensor located at the pump **120** can detect the wave, and thus the pressure signal output by the sensor can indicate a heart rate, respiratory rate, or other information regarding the user.

(37) With regard to sleep state, air bed system **100** can determine a user's sleep state by using various biometric signals such as heart rate, respiration, and/or movement of the user. While the user is sleeping, the processor **136** can receive one or more of the user's biometric signals (e.g., heart rate, respiration, and motion) and determine the user's present sleep state based on the received biometric signals. In some implementations, signals indicating fluctuations in pressure in one or both of the chambers **114**A and **114**B can be amplified and/or filtered to allow for more precise detection of heart rate and respiratory rate.

(38) The control box **124** can perform a pattern recognition algorithm or other calculation based on the amplified and filtered pressure signal to determine the user's heart rate and respiratory rate. For example, the algorithm or calculation can be based on assumptions that a heart rate portion of the signal has a frequency in the range of 0.5-4.0 Hz and that a respiration rate portion of the signal a has a frequency in the range of less than 1 Hz. The control box **124** can also be configured to determine other characteristics of a user based on the received pressure signal, such as blood pressure, tossing and turning movements, rolling movements, limb movements, weight, the presence or lack of presence of a user, and/or the identity of the user. Techniques for monitoring a user's sleep using heart rate information, respiration rate information, and other user information are disclosed in U.S. Patent Application Publication No. 20100170043 to Steven J. Young et al., titled "APPARATUS FOR MONITORING VITAL SIGNS," the entire contents of which is incorporated herein by reference.

(39) For example, the pressure transducer **146** can be used to monitor the air pressure in the chambers **114**A and **114**B of the bed **112**. If the user on the bed **112** is not moving, the air pressure changes in the air chamber **114**A or **114**B can be relatively minimal, and can be attributable to respiration and/or heartbeat. When the user on the bed **112** is moving, however, the air pressure in the mattress can fluctuate by a much larger amount. Thus, the pressure signals generated by the

pressure transducer **146** and received by the processor **136** can be filtered and indicated as corresponding to motion, heartbeat, or respiration.

(40) In some implementations, rather than performing the data analysis in the control box **124** with the processor **136**, a digital signal processor (DSP) can be provided to analyze the data collected by the pressure transducer **146**. Alternatively, the data collected by the pressure transducer **146** could be sent to a cloud-based computing system for remote analysis.

(41) In some implementations, the example air bed system **100** further includes a temperature controller configured to increase, decrease, or maintain the temperature of a bed, for example for the comfort of the user. For example, a pad can be placed on top of or be part of the bed **112**, or can be placed on top of or be part of one or both of the chambers **114**A and **114**B. Air can be pushed through the pad and vented to cool off a user of the bed. Conversely, the pad can include a heating element that can be used to keep the user warm. In some implementations, the temperature controller can receive temperature readings from the pad. In some implementations, separate pads are used for the different sides of the bed **112** (e.g., corresponding to the locations of the chambers **114**A and **114**B) to provide for differing temperature control for the different sides of the bed.

(42) In some implementations, the user of the air bed system **100** can use an input device, such as the remote control **122**, to input a desired temperature for the surface of the bed **112** (or for a portion of the surface of the bed **112**). The desired temperature can be encapsulated in a command data structure that includes the desired temperature as well as identifies the temperature controller as the desired component to be controlled. The command data structure can then be transmitted via Bluetooth or another suitable communication protocol to the processor **136**. In various examples, the command data structure is encrypted before being transmitted. The temperature controller can then configure its elements to increase or decrease the temperature of the pad depending on the temperature input into remote control **122** by the user.

(43) In some implementations, data can be transmitted from a component back to the processor **136** or to one or more display devices, such as the display **126**. For example, the current temperature as determined by a sensor element of temperature controller, the pressure of the bed, the current position of the foundation or other information can be transmitted to control box **124**. The control box **124** can then transmit the received information to remote control **122** where it can be displayed to the user (e.g., on the display **126**).

(44) In some implementations, the example air bed system **100** further includes an adjustable foundation and an articulation controller configured to adjust the position of a bed (e.g., the bed **112**) by adjusting the adjustable foundation that supports the bed. For example, the articulation controller can adjust the bed **112** from a flat position to a position in which a head portion of a mattress of the bed is inclined upward (e.g., to facilitate a user sitting up in bed and/or watching television). In some implementations, the bed **112** includes multiple separately articulable sections. For example, portions of the bed corresponding to the locations of the chambers **114**A and **114**B can be articulated independently from each other, to allow one person positioned on the bed **112** surface to rest in a first position (e.g., a flat position) while a second person rests in a second position (e.g., an reclining position with the head raised at an angle from the waist). In some implementations, separate positions can be set for two different beds (e.g., two twin beds placed next to each other). The foundation of the bed **112** can include more than one zone that can be independently adjusted. The articulation controller can also be configured to provide different levels of massage to one or more users on the bed **112**.

(45) Example of a Bed in a Bedroom Environment

(46) FIG. **3** shows an example environment **300** including a bed **302** in communication with devices located in and around a home. In the example shown, the bed **302** includes pump **304** for controlling air pressure within two air chambers **306***a* and **306***b* (as described above with respect to the air chambers **114**A-**114**B). The pump **304** additionally includes circuitry for controlling inflation and deflation functionality performed by the pump **304**. The circuitry is further

programmed to detect fluctuations in air pressure of the air chambers **306***a-b* and used the detected fluctuations in air pressure to identify bed presence of a user **308**, sleep state of the user **308**, movement of the user **308**, and biometric signals of the user **308** such as heart rate and respiration rate. In the example shown, the pump **304** is located within a support structure of the bed **302** and the control circuitry **334** for controlling the pump **304** is integrated with the pump **304**. In some implementations, the control circuitry **334** is physically separate from the pump **304** and is in wireless or wired communication with the pump **304**. In some implementations, the pump **304** and/or control circuitry **334** are located outside of the bed **302**. In some implementations, various control functions can be performed by systems located in different physical locations. For example, circuitry for controlling actions of the pump **304** can be located within a pump casing of the pump **304** while control circuitry **334** for performing other functions associated with the bed **302** can be located in another portion of the bed **302**, or external to the bed **302**. As another example, control circuitry **334** located within the pump **304** can communicate with control circuitry **334** at a remote location through a LAN or WAN (e.g., the internet). As yet another example, the control circuitry **334** can be included in the control box **124** of FIGS. **1** and **2**.

(47) In some implementations, one or more devices other than, or in addition to, the pump **304** and control circuitry **334** can be utilized to identify user bed presence, sleep state, movement, and biometric signals. For example, the bed **302** can include a second pump in addition to the pump **304**, with each of the two pumps connected to a respective one of the air chambers **306***a-b*. For example, the pump **304** can be in fluid communication with the air chamber **306***b* to control inflation and deflation of the air chamber **306***b* as well as detect user signals for a user located over the air chamber **306***b* such as bed presence, sleep state, movement, and biometric signals while the second pump is in fluid communication with the air chamber **306***a* to control inflation and deflation of the air chamber **306***a* as well as detect user signals for a user located over the air chamber **306***a*.

(48) As another example, the bed **302** can include one or more pressure sensitive pads or surface portions that are operable to detect movement, including user presence, user motion, respiration, and heart rate. For example, a first pressure sensitive pad can be incorporated into a surface of the bed **302** over a left portion of the bed **302**, where a first user would normally be located during sleep, and a second pressure sensitive pad can be incorporated into the surface of the bed **302** over a right portion of the bed **302**, where a second user would normally be located during sleep. The movement detected by the one or more pressure sensitive pads or surface portions can be used by control circuitry **334** to identify user sleep state, bed presence, or biometric signals.

(49) In some implementations, information detected by the bed (e.g., motion information) is processed by control circuitry **334** (e.g., control circuitry **334** integrated with the pump **304**) and provided to one or more user devices such as a user device **310** for presentation to the user **308** or to other users. In the example depicted in FIG. **3**, the user device **310** is a tablet device; however, in some implementations, the user device **310** can be a personal computer, a smart phone, a smart television (e.g., a television **312**), or other user device capable of wired or wireless communication with the control circuitry **334**. The user device **310** can be in communication with control circuitry **334** of the bed **302** through a network or through direct point-to-point communication. For example, the control circuitry **334** can be connected to a LAN (e.g., through a Wi-Fi router) and communicate with the user device **310** through the LAN. As another example, the control circuitry **334** and the user device **310** can both connect to the Internet and communicate through the Internet. For example, the control circuitry **334** can connect to the Internet through a WiFi router and the user device **310** can connect to the Internet through communication with a cellular communication system. As another example, the control circuitry **334** can communicate directly with the user device **310** through a wireless communication protocol such as Bluetooth. As yet another example, the control circuitry **334** can communicate with the user device **310** through a wireless communication protocol such as ZigBee, Z-Wave, infrared, or another wireless communication protocol suitable for the application. As another example, the control circuitry **334** can

communicate with the user device **310** through a wired connection such as, for example, a USB connector, serial/RS232, or another wired connection suitable for the application.

(50) The user device **310** can display a variety of information and statistics related to sleep, or user **308**'s interaction with the bed **302**. For example, a user interface displayed by the user device **310** can present information including amount of sleep for the user **308** over a period of time (e.g., a single evening, a week, a month, etc.) amount of deep sleep, ratio of deep sleep to restless sleep, time lapse between the user **308** getting into bed and the user **308** falling asleep, total amount of time spent in the bed **302** for a given period of time, heart rate for the user **308** over a period of time, respiration rate for the user **308** over a period of time, or other information related to user interaction with the bed **302** by the user **308** or one or more other users of the bed **302**. In some implementations, information for multiple users can be presented on the user device **310**, for example information for a first user positioned over the air chamber **306***a* can be presented along with information for a second user positioned over the air chamber **306***b*. In some implementations, the information presented on the user device **310** can vary according to the age of the user **308**. For example, the information presented on the user device **310** can evolve with the age of the user **308** such that different information is presented on the user device **310** as the user **308** ages as a child or an adult.

(51) The user device **310** can also be used as an interface for the control circuitry **334** of the bed **302** to allow the user **308** to enter information. The information entered by the user **308** can be used by the control circuitry **334** to provide better information to the user or to various control signals for controlling functions of the bed **302** or other devices. For example, the user can enter information such as weight, height, and age and the control circuitry **334** can use this information to provide the user **308** with a comparison of the user's tracked sleep information to sleep information of other people having similar weights, heights, and/or ages as the user **308**. As another example, the user **308** can use the user device **310** as an interface for controlling air pressure of the air chambers **306***a* and **306***b*, for controlling various recline or incline positions of the bed **302**, for controlling temperature of one or more surface temperature control devices of the bed **302**, or for allowing the control circuitry **334** to generate control signals for other devices (as described in greater detail below).

(52) In some implementations, control circuitry **334** of the bed **302** (e.g., control circuitry **334** integrated into the pump **304**) can communicate with other first, second, or third party devices or systems in addition to or instead of the user device **310**. For example, the control circuitry **334** can communicate with the television **312**, a lighting system **314**, a thermostat **316**, a security system **318**, or other house hold devices such as an oven **322**, a coffee maker **324**, a lamp **326**, and a nightlight **328**. Other examples of devices and/or systems that the control circuitry **334** can communicate with include a system for controlling window blinds **330**, one or more devices for detecting or controlling the states of one or more doors **332** (such as detecting if a door is open, detecting if a door is locked, or automatically locking a door), and a system for controlling a garage door **320** (e.g., control circuitry **334** integrated with a garage door opener for identifying an open or closed state of the garage door **320** and for causing the garage door opener to open or close the garage door **320**). Communications between the control circuitry **334** of the bed **302** and other devices can occur through a network (e.g., a LAN or the Internet) or as point-to-point communication (e.g., using Bluetooth, radio communication, or a wired connection). In some implementations, control circuitry **334** of different beds **302** can communicate with different sets of devices. For example, a kid bed may not communicate with and/or control the same devices as an adult bed. In some embodiments, the bed **302** can evolve with the age of the user such that the control circuitry **334** of the bed **302** communicates with different devices as a function of age of the user.

(53) The control circuitry **334** can receive information and inputs from other devices/systems and use the received information and inputs to control actions of the bed **302** or other devices. For

example, the control circuitry **334** can receive information from the thermostat **316** indicating a current environmental temperature for a house or room in which the bed **302** is located. The control circuitry **334** can use the received information (along with other information) to determine if a temperature of all or a portion of the surface of the bed **302** should be raised or lowered. The control circuitry **334** can then cause a heating or cooling mechanism of the bed **302** to raise or lower the temperature of the surface of the bed **302**. For example, the user **308** can indicate a desired sleeping temperature of 74 degrees while a second user of the bed **302** indicates a desired sleeping temperature of 72 degrees. The thermostat **316** can indicate to the control circuitry **334** that the current temperature of the bedroom is 72 degrees. The control circuitry **334** can identify that the user **308** has indicated a desired sleeping temperature of 74 degrees, and send control signals to a heating pad located on the user **308**'s side of the bed to raise the temperature of the portion of the surface of the bed **302** where the user **308** is located to raise the temperature of the user **308**'s sleeping surface to the desired temperature.

(54) The control circuitry **334** can also generate control signals controlling other devices and propagate the control signals to the other devices. In some implementations, the control signals are generated based on information collected by the control circuitry **334**, including information related to user interaction with the bed **302** by the user **308** and/or one or more other users. In some implementations, information collected from one or more other devices other than the bed **302** are used when generating the control signals. For example, information relating to environmental occurrences (e.g., environmental temperature, environmental noise level, and environmental light level), time of day, time of year, day of the week, or other information can be used when generating control signals for various devices in communication with the control circuitry **334** of the bed **302**. For example, information on the time of day can be combined with information relating to movement and bed presence of the user **308** to generate control signals for the lighting system **314**. In some implementations, rather than or in addition to providing control signals for one or more other devices, the control circuitry **334** can provide collected information (e.g., information related to user movement, bed presence, sleep state, or biometric signals for the user **308**) to one or more other devices to allow the one or more other devices to utilize the collected information when generating control signals. For example, control circuitry **334** of the bed **302** can provide information relating to user interactions with the bed **302** by the user **308** to a central controller (not shown) that can use the provided information to generate control signals for various devices, including the bed **302**.

(55) Still referring to FIG. **3**, the control circuitry **334** of the bed **302** can generate control signals for controlling actions of other devices, and transmit the control signals to the other devices in response to information collected by the control circuitry **334**, including bed presence of the user **308**, sleep state of the user **308**, and other factors. For example, control circuitry **334** integrated with the pump **304** can detect a feature of a mattress of the bed **302**, such as an increase in pressure in the air chamber **306***b*, and use this detected increase in air pressure to determine that the user **308** is present on the bed **302**. In some implementations, the control circuitry **334** can identify a heart rate or respiratory rate for the user **308** to identify that the increase in pressure is due to a person sitting, laying, or otherwise resting on the bed **302** rather than an inanimate object (such as a suitcase) having been placed on the bed **302**. In some implementations, the information indicating user bed presence is combined with other information to identify a current or future likely state for the user **308**. For example, a detected user bed presence at 11:00 am can indicate that the user is sitting on the bed (e.g., to tie her shoes, or to read a book) and does not intend to go to sleep, while a detected user bed presence at 10:00 pm can indicate that the user **308** is in bed for the evening and is intending to fall asleep soon. As another example, if the control circuitry **334** detects that the user **308** has left the bed **302** at 6:30 am (e.g., indicating that the user **308** has woken up for the day), and then later detects user bed presence of the user **308** at 7:30 am, the control circuitry **334** can use this information that the newly detected user bed presence is likely temporary (e.g., while

the user **308** ties her shoes before heading to work) rather than an indication that the user **308** is intending to stay on the bed **302** for an extended period.

(56) In some implementations, the control circuitry **334** is able to use collected information (including information related to user interaction with the bed **302** by the user **308**, as well as environmental information, time information, and input received from the user) to identify use patterns for the user **308**. For example, the control circuitry **334** can use information indicating bed presence and sleep states for the user **308** collected over a period of time to identify a sleep pattern for the user. For example, the control circuitry **334** can identify that the user **308** generally goes to bed between 9:30 pm and 10:00 pm, generally falls asleep between 10:00 pm and 11:00 pm, and generally wakes up between 6:30 am and 6:45 am based on information indicating user presence and biometrics for the user **308** collected over a week. The control circuitry **334** can use identified patterns for a user to better process and identify user interactions with the bed **302** by the user **308**.

(57) For example, given the above example user bed presence, sleep, and wake patterns for the user **308**, if the user **308** is detected as being on the bed at 3:00 pm, the control circuitry **334** can determine that the user's presence on the bed is only temporary, and use this determination to generate different control signals than would be generated if the control circuitry **334** determined that the user **308** was in bed for the evening. As another example, if the control circuitry **334** detects that the user **308** has gotten out of bed at 3:00 am, the control circuitry **334** can use identified patterns for the user **308** to determine that the user has only gotten up temporarily (for example, to use the rest room, or get a glass of water) and is not up for the day. By contrast, if the control circuitry **334** identifies that the user **308** has gotten out of the bed **302** at 6:40 am, the control circuitry **334** can determine that the user is up for the day and generate a different set of control signals than those that would be generated if it were determined that the user **308** were only getting out of bed temporarily (as would be the case when the user **308** gets out of the bed **302** at 3:00 am). For other users **308**, getting out of the bed **302** at 3:00 am can be the normal wake-up time, which the control circuitry **334** can learn and respond to accordingly.

(58) As described above, the control circuitry **334** for the bed **302** can generate control signals for control functions of various other devices. The control signals can be generated, at least in part, based on detected interactions by the user **308** with the bed **302**, as well as other information including time, date, temperature, etc. For example, the control circuitry **334** can communicate with the television **312**, receive information from the television **312**, and generate control signals for controlling functions of the television **312**. For example, the control circuitry **334** can receive an indication from the television **312** that the television **312** is currently on. If the television **312** is located in a different room from the bed **302**, the control circuitry **334** can generate a control signal to turn the television **312** off upon making a determination that the user **308** has gone to bed for the evening. For example, if bed presence of the user **308** on the bed **302** is detected during a particular time range (e.g., between 8:00 pm and 7:00 am) and persists for longer than a threshold period of time (e.g., 10 minutes) the control circuitry **334** can use this information to determine that the user **308** is in bed for the evening. If the television **312** is on (as indicated by communications received by the control circuitry **334** of the bed **302** from the television **312**) the control circuitry **334** can generate a control signal to turn the television **312** off. The control signals can then be transmitted to the television (e.g., through a directed communication link between the television **312** and the control circuitry **334** or through a network). As another example, rather than turning off the television **312** in response to detection of user bed presence, the control circuitry **334** can generate a control signal that causes the volume of the television **312** to be lowered by a pre-specified amount.

(59) As another example, upon detecting that the user **308** has left the bed **302** during a specified time range (e.g., between 6:00 am and 8:00 am) the control circuitry **334** can generate control signals to cause the television **312** to turn on and tune to a pre-specified channel (e.g., the user **308** has indicated a preference for watching the morning news upon getting out of bed in the morning).

The control circuitry **334** can generate the control signal and transmit the signal to the television **312** to cause the television **312** to turn on and tune to the desired station (which could be stored at the control circuitry **334**, the television **312**, or another location). As another example, upon detecting that the user **308** has gotten up for the day, the control circuitry **334** can generate and transmit control signals to cause the television **312** to turn on and begin playing a previously recorded program from a digital video recorder (DVR) in communication with the television **312**.

(60) As another example, if the television **312** is in the same room as the bed **302**, the control circuitry **334** does not cause the television **312** to turn off in response to detection of user bed presence. Rather, the control circuitry **334** can generate and transmit control signals to cause the television **312** to turn off in response to determining that the user **308** is asleep. For example, the control circuitry **334** can monitor biometric signals of the user **308** (e.g., motion, heart rate, respiration rate) to determine that the user **308** has fallen asleep. Upon detecting that the user **308** is sleeping, the control circuitry **334** generates and transmits a control signal to turn the television **312** off. As another example, the control circuitry **334** can generate the control signal to turn off the television **312** after a threshold period of time after the user **308** has fallen asleep (e.g., 10 minutes after the user has fallen asleep). As another example, the control circuitry **334** generates control signals to lower the volume of the television **312** after determining that the user **308** is asleep. As yet another example, the control circuitry **334** generates and transmits a control signal to cause the television to gradually lower in volume over a period of time and then turn off in response to determining that the user **308** is asleep.

(61) In some implementations, the control circuitry **334** can similarly interact with other media devices, such as computers, tablets, smart phones, stereo systems, etc. For example, upon detecting that the user **308** is asleep, the control circuitry **334** can generate and transmit a control signal to the user device **310** to cause the user device **310** to turn off, or turn down the volume on a video or audio file being played by the user device **310**.

(62) The control circuitry **334** can additionally communicate with the lighting system **314**, receive information from the lighting system **314**, and generate control signals for controlling functions of the lighting system **314**. For example, upon detecting user bed presence on the bed **302** during a certain time frame (e.g., between 8:00 pm and 7:00 am) that lasts for longer than a threshold period of time (e.g., 10 minutes) the control circuitry **334** of the bed **302** can determine that the user **308** is in bed for the evening. In response to this determination, the control circuitry **334** can generate control signals to cause lights in one or more rooms other than the room in which the bed **302** is located to switch off. The control signals can then be transmitted to the lighting system **314** and executed by the lighting system **314** to cause the lights in the indicated rooms to shut off. For example, the control circuitry **334** can generate and transmit control signals to turn off lights in all common rooms, but not in other bedrooms. As another example, the control signals generated by the control circuitry **334** can indicate that lights in all rooms other than the room in which the bed **302** is located are to be turned off, while one or more lights located outside of the house containing the bed **302** are to be turned on, in response to determining that the user **308** is in bed for the evening. Additionally, the control circuitry **334** can generate and transmit control signals to cause the nightlight **328** to turn on in response to determining user **308** bed presence or whether the user **308** is asleep. As another example, the control circuitry **334** can generate first control signals for turning off a first set of lights (e.g., lights in common rooms) in response to detecting user bed presence, and second control signals for turning off a second set of lights (e.g., lights in the room in which the bed **302** is located) in response to detecting that the user **308** is asleep.

(63) In some implementations, in response to determining that the user **308** is in bed for the evening, the control circuitry **334** of the bed **302** can generate control signals to cause the lighting system **314** to implement a sunset lighting scheme in the room in which the bed **302** is located. A sunset lighting scheme can include, for example, dimming the lights (either gradually over time, or all at once) in combination with changing the color of the light in the bedroom environment, such

as adding an amber hue to the lighting in the bedroom. The sunset lighting scheme can help to put the user **308** to sleep when the control circuitry **334** has determined that the user **308** is in bed for the evening.

(64) The control circuitry **334** can also be configured to implement a sunrise lighting scheme when the user **308** wakes up in the morning. The control circuitry **334** can determine that the user **308** is awake for the day, for example, by detecting that the user **308** has gotten off of the bed **302** (i.e., is no longer present on the bed **302**) during a specified time frame (e.g., between 6:00 am and 8:00 am). As another example, the control circuitry **334** can monitor movement, heart rate, respiratory rate, or other biometric signals of the user **308** to determine that the user **308** is awake even though the user **308** has not gotten out of bed. If the control circuitry **334** detects that the user is awake during a specified time frame, the control circuitry **334** can determine that the user **308** is awake for the day. The specified time frame can be, for example, based on previously recorded user bed presence information collected over a period of time (e.g., two weeks) that indicates that the user **308** usually wakes up for the day between 6:30 am and 7:30 am. In response to the control circuitry **334** determining that the user **308** is awake, the control circuitry **334** can generate control signals to cause the lighting system **314** to implement the sunrise lighting scheme in the bedroom in which the bed **302** is located. The sunrise lighting scheme can include, for example, turning on lights (e.g., the lamp **326**, or other lights in the bedroom). The sunrise lighting scheme can further include gradually increasing the level of light in the room where the bed **302** is located (or in one or more other rooms). The sunrise lighting scheme can also include only turning on lights of specified colors. For example, the sunrise lighting scheme can include lighting the bedroom with blue light to gently assist the user **308** in waking up and becoming active.

(65) In some implementations, the control circuitry **334** can generate different control signals for controlling actions of one or more components, such as the lighting system **314**, depending on a time of day that user interactions with the bed **302** are detected. For example, the control circuitry **334** can use historical user interaction information for interactions between the user **308** and the bed **302** to determine that the user **308** usually falls asleep between 10:00 pm and 11:00 pm and usually wakes up between 6:30 am and 7:30 am on weekdays. The control circuitry **334** can use this information to generate a first set of control signals for controlling the lighting system **314** if the user **308** is detected as getting out of bed at 3:00 am and to generate a second set of control signals for controlling the lighting system **314** if the user **308** is detected as getting out of bed after 6:30 am. For example, if the user **308** gets out of bed prior to 6:30 am, the control circuitry **334** can turn on lights that guide the user **308**'s route to a restroom. As another example, if the user **308** gets out of bed prior to 6:30 am, the control circuitry **334** can turn on lights that guide the user **308**'s route to the kitchen (which can include, for example, turning on the nightlight **328**, turning on under bed lighting, or turning on the lamp **326**).

(66) As another example, if the user **308** gets out of bed after 6:30 am, the control circuitry **334** can generate control signals to cause the lighting system **314** to initiate a sunrise lighting scheme, or to turn on one or more lights in the bedroom and/or other rooms. In some implementations, if the user **308** is detected as getting out of bed prior to a specified morning rise time for the user **308**, the control circuitry **334** causes the lighting system **314** to turn on lights that are dimmer than lights that are turned on by the lighting system **314** if the user **308** is detected as getting out of bed after the specified morning rise time. Causing the lighting system **314** to only turn on dim lights when the user **308** gets out of bed during the night (i.e., prior to normal rise time for the user **308**) can prevent other occupants of the house from being woken by the lights while still allowing the user **308** to see in order to reach the restroom, kitchen, or another destination within the house.

(67) The historical user interaction information for interactions between the user **308** and the bed **302** can be used to identify user sleep and awake time frames. For example, user bed presence times and sleep times can be determined for a set period of time (e.g., two weeks, a month, etc.). The control circuitry **334** can then identify a typical time range or time frame in which the user **308**

goes to bed, a typical time frame for when the user **308** falls asleep, and a typical time frame for when the user **308** wakes up (and in some cases, different time frames for when the user **308** wakes up and when the user **308** actually gets out of bed). In some implementations, buffer time can be added to these time frames. For example, if the user is identified as typically going to bed between 10:00 pm and 10:30 pm, a buffer of a half hour in each direction can be added to the time frame such that any detection of the user getting onto the bed between 9:30 pm and 11:00 pm is interpreted as the user **308** going to bed for the evening. As another example, detection of bed presence of the user **308** starting from a half hour before the earliest typical time that the user **308** goes to bed extending until the typical wake up time (e.g., 6:30 am) for the user can be interpreted as the user going to bed for the evening. For example, if the user typically goes to bed between 10:00 pm and 10:30 pm, if the user's bed presence is sensed at 12:30 am one night, that can be interpreted as the user getting into bed for the evening even though this is outside of the user's typical time frame for going to bed because it has occurred prior to the user's normal wake up time. In some implementations, different time frames are identified for different times of the year (e.g., earlier bed time during winter vs. summer) or at different times of the week (e.g., user wakes up earlier on weekdays than on weekends).

(68) The control circuitry **334** can distinguish between the user **308** going to bed for an extended period (such as for the night) as opposed to being present on the bed **302** for a shorter period (such as for a nap) by sensing duration of presence of the user **308**. In some examples, the control circuitry **334** can distinguish between the user **308** going to bed for an extended period (such as for the night) as opposed to going to bed for a shorter period (such as for a nap) by sensing duration of sleep of the user **308**. For example, the control circuitry **334** can set a time threshold whereby if the user **308** is sensed on the bed **302** for longer than the threshold, the user **308** is considered to have gone to bed for the night. In some examples, the threshold can be about 2 hours, whereby if the user **308** is sensed on the bed **302** for greater than 2 hours, the control circuitry **334** registers that as an extended sleep event. In other examples, the threshold can be greater than or less than two hours.

(69) The control circuitry **334** can detect repeated extended sleep events to determine a typical bed time range of the user **308** automatically, without requiring the user **308** to enter a bed time range. This can allow the control circuitry **334** to accurately estimate when the user **308** is likely to go to bed for an extended sleep event, regardless of whether the user **308** typically goes to bed using a traditional sleep schedule or a non-traditional sleep schedule. The control circuitry **334** can then use knowledge of the bed time range of the user **308** to control one or more components (including components of the bed **302** and/or non-bed peripherals) differently based on sensing bed presence during the bed time range or outside of the bed time range.

(70) In some examples, the control circuitry **334** can automatically determine the bed time range of the user **308** without requiring user inputs. In some examples, the control circuitry **334** can determine the bed time range of the user **308** automatically and in combination with user inputs. In some examples, the control circuitry **334** can set the bed time range directly according to user inputs. In some examples, the control circuity **334** can associate different bed times with different days of the week. In each of these examples, the control circuitry **334** can control one or more components (such as the lighting system **314**, the thermostat **316**, the security system **318**, the oven **322**, the coffee maker **324**, the lamp **326**, and the nightlight **328**), as a function of sensed bed presence and the bed time range.

(71) The control circuitry **334** can additionally communicate with the thermostat **316**, receive information from the thermostat **316**, and generate control signals for controlling functions of the thermostat **316**. For example, the user **308** can indicate user preferences for different temperatures at different times, depending on the sleep state or bed presence of the user **308**. For example, the user **308** may prefer an environmental temperature of 72 degrees when out of bed, 70 degrees when in bed but awake, and 68 degrees when sleeping. The control circuitry **334** of the bed **302** can

detect bed presence of the user **308** in the evening and determine that the user **308** is in bed for the night. In response to this determination, the control circuitry **334** can generate control signals to cause the thermostat to change the temperature to 70 degrees. The control circuitry **334** can then transmit the control signals to the thermostat **316**. Upon detecting that the user **308** is in bed during the bed time range or asleep, the control circuitry **334** can generate and transmit control signals to cause the thermostat **316** to change the temperature to 68. The next morning, upon determining that the user is awake for the day (e.g., the user **308** gets out of bed after 6:30 am) the control circuitry **334** can generate and transmit control circuitry **334** to cause the thermostat to change the temperature to 72 degrees.

(72) In some implementations, the control circuitry **334** can similarly generate control signals to cause one or more heating or cooling elements on the surface of the bed **302** to change temperature at various times, either in response to user interaction with the bed **302** or at various pre-programmed times. For example, the control circuitry **334** can activate a heating element to raise the temperature of one side of the surface of the bed **302** to 73 degrees when it is detected that the user **308** has fallen asleep. As another example, upon determining that the user **308** is up for the day, the control circuitry **334** can turn off a heating or cooling element. As yet another example, the user **308** can pre-program various times at which the temperature at the surface of the bed should be raised or lowered. For example, the user can program the bed **302** to raise the surface temperature to 76 degrees at 10:00 pm, and lower the surface temperature to 68 degrees at 11:30 pm.

(73) In some implementations, in response to detecting user bed presence of the user **308** and/or that the user **308** is asleep, the control circuitry **334** can cause the thermostat **316** to change the temperature in different rooms to different values. For example, in response to determining that the user **308** is in bed for the evening, the control circuitry **334** can generate and transmit control signals to cause the thermostat **316** to set the temperature in one or more bedrooms of the house to 72 degrees and set the temperature in other rooms to 67 degrees.

(74) The control circuitry **334** can also receive temperature information from the thermostat **316** and use this temperature information to control functions of the bed **302** or other devices. For example, as discussed above, the control circuitry **334** can adjust temperatures of heating elements included in the bed **302** in response to temperature information received from the thermostat **316**.

(75) In some implementations, the control circuitry **334** can generate and transmit control signals for controlling other temperature control systems. For example, in response to determining that the user **308** is awake for the day, the control circuitry **334** can generate and transmit control signals for causing floor heating elements to activate. For example, the control circuitry **334** can cause a floor heating system for a master bedroom to turn on in response to determining that the user **308** is awake for the day.

(76) The control circuitry **334** can additionally communicate with the security system **318**, receive information from the security system **318**, and generate control signals for controlling functions of the security system **318**. For example, in response to detecting that the user **308** in is bed for the evening, the control circuitry **334** can generate control signals to cause the security system to engage or disengage security functions. The control circuitry **334** can then transmit the control signals to the security system **318** to cause the security system **318** to engage. As another example, the control circuitry **334** can generate and transmit control signals to cause the security system **318** to disable in response to determining that the user **308** is awake for the day (e.g., user **308** is no longer present on the bed **302** after 6:00 am). In some implementations, the control circuitry **334** can generate and transmit a first set of control signals to cause the security system **318** to engage a first set of security features in response to detecting user bed presence of the user **308**, and can generate and transmit a second set of control signals to cause the security system **318** to engage a second set of security features in response to detecting that the user **308** has fallen asleep.

(77) In some implementations, the control circuitry **334** can receive alerts from the security system

318 (and/or a cloud service associated with the security system **318**) and indicate the alert to the user **308**. For example, the control circuitry **334** can detect that the user **308** is in bed for the evening and in response, generate and transmit control signals to cause the security system **318** to engage or disengage. The security system can then detect a security breach (e.g., someone has opened the door **332** without entering the security code, or someone has opened a window when the security system **318** is engaged). The security system **318** can communicate the security breach to the control circuitry **334** of the bed **302**. In response to receiving the communication from the security system **318**, the control circuitry **334** can generate control signals to alert the user **308** to the security breach. For example, the control circuitry **334** can cause the bed **302** to vibrate. As another example, the control circuitry **334** can cause portions of the bed **302** to articulate (e.g., cause the head section to raise or lower) in order to wake the user **308** and alert the user to the security breach. As another example, the control circuitry **334** can generate and transmit control signals to cause the lamp **326** to flash on and off at regular intervals to alert the user **308** to the security breach. As another example, the control circuitry **334** can alert the user **308** of one bed **302** regarding a security breach in a bedroom of another bed, such as an open window in a kid's bedroom. As another example, the control circuitry **334** can send an alert to a garage door controller (e.g., to close and lock the door). As another example, the control circuitry **334** can send an alert for the security to be disengaged.

(78) The control circuitry **334** can additionally generate and transmit control signals for controlling the garage door **320** and receive information indicating a state of the garage door **320** (i.e., open or closed). For example, in response to determining that the user **308** is in bed for the evening, the control circuitry **334** can generate and transmit a request to a garage door opener or another device capable of sensing if the garage door **320** is open. The control circuitry **334** can request information on the current state of the garage door **320**. If the control circuitry **334** receives a response (e.g., from the garage door opener) indicating that the garage door **320** is open, the control circuitry **334** can either notify the user **308** that the garage door is open, or generate a control signal to cause the garage door opener to close the garage door **320**. For example, the control circuitry **334** can send a message to the user device **310** indicating that the garage door is open. As another example, the control circuitry **334** can cause the bed **302** to vibrate. As yet another example, the control circuitry **334** can generate and transmit a control signal to cause the lighting system **314** to cause one or more lights in the bedroom to flash to alert the user **308** to check the user device **310** for an alert (in this example, an alert regarding the garage door **320** being open). Alternatively, or additionally, the control circuitry **334** can generate and transmit control signals to cause the garage door opener to close the garage door **320** in response to identifying that the user **308** is in bed for the evening and that the garage door **320** is open. In some implementations, control signals can vary depend on the age of the user **308**.

(79) The control circuitry **334** can similarly send and receive communications for controlling or receiving state information associated with the door **332** or the oven **322**. For example, upon detecting that the user **308** is in bed for the evening, the control circuitry **334** can generate and transmit a request to a device or system for detecting a state of the door **332**. Information returned in response to the request can indicate various states for the door **332** such as open, closed but unlocked, or closed and locked. If the door **332** is open or closed but unlocked, the control circuitry **334** can alert the user **308** to the state of the door, such as in a manner described above with reference to the garage door **320**. Alternatively, or in addition to alerting the user **308**, the control circuitry **334** can generate and transmit control signals to cause the door **332** to lock, or to close and lock. If the door **332** is closed and locked, the control circuitry **334** can determine that no further action is needed.

(80) Similarly, upon detecting that the user **308** is in bed for the evening, the control circuitry **334** can generate and transmit a request to the oven **322** to request a state of the oven **322** (e.g., on or off). If the oven **322** is on, the control circuitry **334** can alert the user **308** and/or generate and

transmit control signals to cause the oven **322** to turn off. If the oven is already off, the control circuitry **334** can determine that no further action is necessary. In some implementations, different alerts can be generated for different events. For example, the control circuitry **334** can cause the lamp **326** (or one or more other lights, via the lighting system **314**) to flash in a first pattern if the security system **318** has detected a breach, flash in a second pattern if garage door **320** is on, flash in a third pattern if the door **332** is open, flash in a fourth pattern if the oven **322** is on, and flash in a fifth pattern if another bed has detected that a user of that bed has gotten up (e.g., that a child of the user **308** has gotten out of bed in the middle of the night as sensed by a sensor in the bed **302** of the child). Other examples of alerts that can be processed by the control circuitry **334** of the bed **302** and communicated to the user include a smoke detector detecting smoke (and communicating this detection of smoke to the control circuitry **334**), a carbon monoxide tester detecting carbon monoxide, a heater malfunctioning, or an alert from any other device capable of communicating with the control circuitry **334** and detecting an occurrence that should be brought to the user **308**'s attention.

(81) The control circuitry **334** can also communicate with a system or device for controlling a state of the window blinds **330**. For example, in response to determining that the user **308** is in bed for the evening, the control circuitry **334** can generate and transmit control signals to cause the window blinds **330** to close. As another example, in response to determining that the user **308** is up for the day (e.g., user has gotten out of bed after 6:30 am) the control circuitry **334** can generate and transmit control signals to cause the window blinds **330** to open. By contrast, if the user **308** gets out of bed prior to a normal rise time for the user **308**, the control circuitry **334** can determine that the user **308** is not awake for the day and does not generate control signals for causing the window blinds **330** to open. As yet another example, the control circuitry **334** can generate and transmit control signals that cause a first set of blinds to close in response to detecting user bed presence of the user **308** and a second set of blinds to close in response to detecting that the user **308** is asleep.

(82) The control circuitry **334** can generate and transmit control signals for controlling functions of other household devices in response to detecting user interactions with the bed **302**. For example, in response to determining that the user **308** is awake for the day, the control circuitry **334** can generate and transmit control signals to the coffee maker **324** to cause the coffee maker **324** to begin brewing coffee. As another example, the control circuitry **334** can generate and transmit control signals to the oven **322** to cause the oven to begin preheating (for users that like fresh baked bread in the morning). As another example, the control circuitry **334** can use information indicating that the user **308** is awake for the day along with information indicating that the time of year is currently winter and/or that the outside temperature is below a threshold value to generate and transmit control signals to cause a car engine block heater to turn on.

(83) As another example, the control circuitry **334** can generate and transmit control signals to cause one or more devices to enter a sleep mode in response to detecting user bed presence of the user **308**, or in response to detecting that the user **308** is asleep. For example, the control circuitry **334** can generate control signals to cause a mobile phone of the user **308** to switch into sleep mode. The control circuitry **334** can then transmit the control signals to the mobile phone. Later, upon determining that the user **308** is up for the day, the control circuitry **334** can generate and transmit control signals to cause the mobile phone to switch out of sleep mode.

(84) In some implementations, the control circuitry **334** can communicate with one or more noise control devices. For example, upon determining that the user **308** is in bed for the evening, or that the user **308** is asleep, the control circuitry **334** can generate and transmit control signals to cause one or more noise cancelation devices to activate. The noise cancelation devices can, for example, be included as part of the bed **302** or located in the bedroom with the bed **302**. As another example, upon determining that the user **308** is in bed for the evening or that the user **308** is asleep, the control circuitry **334** can generate and transmit control signals to turn the volume on, off, up, or down, for one or more sound generating devices, such as a stereo system radio, computer, tablet,

etc.

(85) Additionally, functions of the bed **302** are controlled by the control circuitry **334** in response to user interactions with the bed **302**. For example, the bed **302** can include an adjustable foundation and an articulation controller configured to adjust the position of one or more portions of the bed **302** by adjusting the adjustable foundation that supports the bed. For example, the articulation controller can adjust the bed **302** from a flat position to a position in which a head portion of a mattress of the bed **302** is inclined upward (e.g., to facilitate a user sitting up in bed and/or watching television). In some implementations, the bed **302** includes multiple separately articulable sections. For example, portions of the bed corresponding to the locations of the air chambers **306***a* and **306***b* can be articulated independently from each other, to allow one person positioned on the bed **302** surface to rest in a first position (e.g., a flat position) while a second person rests in a second position (e.g., a reclining position with the head raised at an angle from the waist). In some implementations, separate positions can be set for two different beds (e.g., two twin beds placed next to each other). The foundation of the bed **302** can include more than one zone that can be independently adjusted. The articulation controller can also be configured to provide different levels of massage to one or more users on the bed **302** or to cause the bed to vibrate to communicate alerts to the user **308** as described above.

(86) The control circuitry **334** can adjust positions (e.g., incline and decline positions for the user **308** and/or an additional user of the bed **302**) in response to user interactions with the bed **302**. For example, the control circuitry **334** can cause the articulation controller to adjust the bed **302** to a first recline position for the user **308** in response to sensing user bed presence for the user **308**. The control circuitry **334** can cause the articulation controller to adjust the bed **302** to a second recline position (e.g., a less reclined, or flat position) in response to determining that the user **308** is asleep. As another example, the control circuitry **334** can receive a communication from the television **312** indicating that the user **308** has turned off the television **312**, and in response the control circuitry **334** can cause the articulation controller to adjust the position of the bed **302** to a preferred user sleeping position (e.g., due to the user turning off the television **312** while the user **308** is in bed indicating that the user **308** wishes to go to sleep).

(87) In some implementations, the control circuitry **334** can control the articulation controller so as to wake up one user of the bed **302** without waking another user of the bed **302**. For example, the user **308** and a second user of the bed **302** can each set distinct wakeup times (e.g., 6:30 am and 7:15 am respectively). When the wakeup time for the user **308** is reached, the control circuitry **334** can cause the articulation controller to vibrate or change the position of only a side of the bed on which the user **308** is located to wake the user **308** without disturbing the second user. When the wakeup time for the second user is reached, the control circuitry **334** can cause the articulation controller to vibrate or change the position of only the side of the bed on which the second user is located. Alternatively, when the second wakeup time occurs, the control circuitry **334** can utilize other methods (such as audio alarms, or turning on the lights) to wake the second user since the user **308** is already awake and therefore will not be disturbed when the control circuitry **334** attempts to wake the second user.

(88) Still referring to FIG. **3**, the control circuitry **334** for the bed **302** can utilize information for interactions with the bed **302** by multiple users to generate control signals for controlling functions of various other devices. For example, the control circuitry **334** can wait to generate control signals for, for example, engaging the security system **318**, or instructing the lighting system **314** to turn off lights in various rooms until both the user **308** and a second user are detected as being present on the bed **302**. As another example, the control circuitry **334** can generate a first set of control signals to cause the lighting system **314** to turn off a first set of lights upon detecting bed presence of the user **308** and generate a second set of control signals for turning off a second set of lights in response to detecting bed presence of a second user. As another example, the control circuitry **334** can wait until it has been determined that both the user **308** and a second user are awake for the day

before generating control signals to open the window blinds **330**. As yet another example, in response to determining that the user **308** has left the bed and is awake for the day, but that a second user is still sleeping, the control circuitry **334** can generate and transmit a first set of control signals to cause the coffee maker **324** to begin brewing coffee, to cause the security system **318** to deactivate, to turn on the lamp **326**, to turn off the nightlight **328**, to cause the thermostat **316** to raise the temperature in one or more rooms to 72 degrees, and to open blinds (e.g., the window blinds **330**) in rooms other than the bedroom in which the bed **302** is located. Later, in response to detecting that the second user is no longer present on the bed (or that the second user is awake) the control circuitry **334** can generate and transmit a second set of control signals to, for example, cause the lighting system **314** to turn on one or more lights in the bedroom, to cause window blinds in the bedroom to open, and to turn on the television **312** to a pre-specified channel.

(89) Examples of Data Processing Systems Associated with a Bed

(90) Described here are examples of systems and components that can be used for data processing tasks that are, for example, associated with a bed. In some cases, multiple examples of a particular component or group of components are presented. Some of these examples are redundant and/or mutually exclusive alternatives. Connections between components are shown as examples to illustrate possible network configurations for allowing communication between components. Different formats of connections can be used as technically needed or desired. The connections generally indicate a logical connection that can be created with any technologically feasible format. For example, a network on a motherboard can be created with a printed circuit board, wireless data connections, and/or other types of network connections. Some logical connections are not shown for clarity. For example, connections with power supplies and/or computer readable memory may not be shown for clarities sake, as many or all elements of a particular component may need to be connected to the power supplies and/or computer readable memory.

(91) FIG. **4**A is a block diagram of an example of a data processing system **400** that can be associated with a bed system, including those described above with respect to FIGS. **1**-**3**. This system **400** includes a pump motherboard **402** and a pump daughterboard **404**. The system **400** includes a sensor array **406** that can include one or more sensors configured to sense physical phenomenon of the environment and/or bed, and to report such sensing back to the pump motherboard **402** for, for example, analysis. The system **400** also includes a controller array **408** that can include one or more controllers configured to control logic-controlled devices of the bed and/or environment. The pump motherboard **400** can be in communication with one or more computing devices **414** and one or more cloud services **410** over local networks, the Internet **412**, or otherwise as is technically appropriate. Each of these components will be described in more detail, some with multiple example configurations, below.

(92) In this example, a pump motherboard **402** and a pump daughterboard **404** are communicably coupled. They can be conceptually described as a center or hub of the system **400**, with the other components conceptually described as spokes of the system **400**. In some configurations, this can mean that each of the spoke components communicates primarily or exclusively with the pump motherboard **402**. For example, a sensor of the sensor array may not be configured to, or may not be able to, communicate directly with a corresponding controller. Instead, each spoke component can communicate with the motherboard **402**. The sensor of the sensor array **406** can report a sensor reading to the motherboard **402**, and the motherboard **402** can determine that, in response, a controller of the controller array **408** should adjust some parameters of a logic controlled device or otherwise modify a state of one or more peripheral devices. In one case, if the temperature of the bed is determined to be too hot, the pump motherboard **402** can determine that a temperature controller should cool the bed.

(93) One advantage of a hub-and-spoke network configuration, sometimes also referred to as a star-shaped network, is a reduction in network traffic compared to, for example, a mesh network with dynamic routing. If a particular sensor generates a large, continuous stream of traffic, that traffic

may only be transmitted over one spoke of the network to the motherboard **402**. The motherboard **402** can, for example, marshal that data and condense it to a smaller data format for retransmission for storage in a cloud service **410**. Additionally or alternatively, the motherboard **402** can generate a single, small, command message to be sent down a different spoke of the network in response to the large stream. For example, if the large stream of data is a pressure reading that is transmitted from the sensor array **406** a few times a second, the motherboard **402** can respond with a single command message to the controller array to increase the pressure in an air chamber. In this case, the single command message can be orders of magnitude smaller than the stream of pressure readings.

(94) As another advantage, a hub-and-spoke network configuration can allow for an extensible network that can accommodate components being added, removed, failing, etc. This can allow, for example, more, fewer, or different sensors in the sensor array **406**, controllers in the controller array **408**, computing devices **414**, and/or cloud services **410**. For example, if a particular sensor fails or is deprecated by a newer version of the sensor, the system **400** can be configured such that only the motherboard **402** needs to be updated about the replacement sensor. This can allow, for example, product differentiation where the same motherboard **402** can support an entry level product with fewer sensors and controllers, a higher value product with more sensors and controllers, and customer personalization where a customer can add their own selected components to the system **400**.

(95) Additionally, a line of air bed products can use the system **400** with different components. In an application in which every air bed in the product line includes both a central logic unit and a pump, the motherboard **402** (and optionally the daughterboard **404**) can be designed to fit within a single, universal housing. Then, for each upgrade of the product in the product line, additional sensors, controllers, cloud services, etc., can be added. Design, manufacturing, and testing time can be reduced by designing all products in a product line from this base, compared to a product line in which each product has a bespoke logic control system.

(96) Each of the components discussed above can be realized in a wide variety of technologies and configurations. Below, some examples of each component will be further discussed. In some alternatives, two or more of the components of the system **400** can be realized in a single alternative component; some components can be realized in multiple, separate components; and/or some functionality can be provided by different components.

(97) FIG. **4**B is a block diagram showing some communication paths of the data processing system **400**. As previously described, the motherboard **402** and the pump daughterboard **404** may act as a hub for peripheral devices and cloud services of the system **400**. In cases in which the pump daughterboard **404** communicates with cloud services or other components, communications from the pump daughterboard **404** may be routed through the pump motherboard **402**. This may allow, for example, the bed to have only a single connection with the internet **412**. The computing device **414** may also have a connection to the internet **412**, possibly through the same gateway used by the bed and/or possibly through a different gateway (e.g., a cell service provider).

(98) Previously, a number of cloud services **410** were described. As shown in FIG. **4**B, some cloud services, such as cloud services **410***d* and **410***e*, may be configured such that the pump motherboard **402** can communicate with the cloud service directly—that is the motherboard **402** may communicate with a cloud service **410** without having to use another cloud service **410** as an intermediary. Additionally or alternatively, some cloud services **410**, for example cloud service **410***f*, may only be reachable by the pump motherboard **402** through an intermediary cloud service, for example cloud service **410***e*. While not shown here, some cloud services **410** may be reachable either directly or indirectly by the pump motherboard **402**.

(99) Additionally, some or all of the cloud services **410** may be configured to communicate with other cloud services. This communication may include the transfer of data and/or remote function calls according to any technologically appropriate format. For example, one cloud service **410** may

request a copy for another cloud service's **410** data, for example, for purposes of backup, coordination, migration, or for performance of calculations or data mining. In another example, many cloud services **410** may contain data that is indexed according to specific users tracked by the user account cloud **410***c* and/or the bed data cloud **410***a*. These cloud services **410** may communicate with the user account cloud **410***c* and/or the bed data cloud **410***a* when accessing data specific to a particular user or bed.

(100) FIG. **5** is a block diagram of an example of a motherboard **402** that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1-3**. In this example, compared to other examples described below, this motherboard **402** consists of relatively fewer parts and can be limited to provide a relatively limited feature set.

(101) The motherboard includes a power supply **500**, a processor **502**, and computer memory **512**. In general, the power supply includes hardware used to receive electrical power from an outside source and supply it to components of the motherboard **402**. The power supply can include, for example, a battery pack and/or wall outlet adapter, an AC to DC converter, a DC to AC converter, a power conditioner, a capacitor bank, and/or one or more interfaces for providing power in the current type, voltage, etc., needed by other components of the motherboard **402**.

(102) The processor **502** is generally a device for receiving input, performing logical determinations, and providing output. The processor **502** can be a central processing unit, a microprocessor, general purpose logic circuity, application-specific integrated circuity, a combination of these, and/or other hardware for performing the functionality needed.

(103) The memory **512** is generally one or more devices for storing data. The memory **512** can include long term stable data storage (e.g., on a hard disk), short term unstable (e.g., on Random Access Memory) or any other technologically appropriate configuration.

(104) The motherboard **402** includes a pump controller **504** and a pump motor **506**. The pump controller **504** can receive commands from the processor **502** and, in response, control the function of the pump motor **506**. For example, the pump controller **504** can receive, from the processor **502**, a command to increase the pressure of an air chamber by 0.3 pounds per square inch (PSI). The pump controller **504**, in response, engages a valve so that the pump motor **506** is configured to pump air into the selected air chamber, and can engage the pump motor **506** for a length of time that corresponds to 0.3 PSI or until a sensor indicates that pressure has been increased by 0.3 PSI. In an alternative configuration, the message can specify that the chamber should be inflated to a target PSI, and the pump controller **504** can engage the pump motor **506** until the target PSI is reached.

(105) A valve solenoid **508** can control which air chamber a pump is connected to. In some cases, the solenoid **508** can be controlled by the processor **502** directly. In some cases, the solenoid **508** can be controlled by the pump controller **504**.

(106) A remote interface **510** of the motherboard **402** can allow the motherboard **402** to communicate with other components of a data processing system. For example, the motherboard **402** can be able to communicate with one or more daughterboards, with peripheral sensors, and/or with peripheral controllers through the remote interface **510**. The remote interface **510** can provide any technologically appropriate communication interface, including but not limited to multiple communication interfaces such as WiFi, Bluetooth, and copper wired networks.

(107) FIG. **6** is a block diagram of an example of a motherboard **402** that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1-3**. Compared to the motherboard **402** described with reference to FIG. **5**, the motherboard in FIG. **6** can contain more components and provide more functionality in some applications.

(108) In addition to the power supply **500**, processor **502**, pump controller **504**, pump motor **506**, and valve solenoid **508**, this motherboard **402** is shown with a valve controller **600**, a pressure

sensor **602**, a universal serial bus (USB) stack **604**, a WiFi radio **606**, a Bluetooth Low Energy (BLE) radio **608**, a ZigBee radio **610**, a Bluetooth radio **612** and a computer memory **512**.

(109) Similar to the way that the pump controller **504** converts commands from the processor **502** into control signals for the pump motor **506**, the valve controller **600** can convert commands from the processor **502** into control signals for the valve solenoid **508**. In one example, the processor **502** can issue a command to the valve controller **600** to connect the pump to a particular air chamber out of the group of air chambers in an air bed. The valve controller **600** can control the position of the valve solenoid **508** so that the pump is connected to the indicated air chamber.

(110) The pressure sensor **602** can read pressure readings from one or more air chambers of the air bed. The pressure sensor **602** can also preform digital sensor conditioning.

(111) The motherboard **402** can include a suite of network interfaces, including but not limited to those shown here. These network interfaces can allow the motherboard to communicate over a wired or wireless network with any number of devices, including but not limited to peripheral sensors, peripheral controllers, computing devices, and devices and services connected to the Internet **412**.

(112) FIG. **7** is a block diagram of an example of a daughterboard **404** that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1-3**. In some configurations, one or more daughterboards **404** can be connected to the motherboard **402**. Some daughterboards **404** can be designed to offload particular and/or compartmentalized tasks from the motherboard **402**. This can be advantageous, for example, if the particular tasks are computationally intensive, proprietary, or subject to future revisions. For example, the daughterboard **404** can be used to calculate a particular sleep data metric. This metric can be computationally intensive, and calculating the sleep metric on the daughterboard **404** can free up the resources of the motherboard **402** while the metric is being calculated. Additionally and/or alternatively, the sleep metric can be subject to future revisions. To update the system **400** with the new sleep metric, it is possible that only the daughterboard **404** that calculates that metric need be replaced. In this case, the same motherboard **402** and other components can be used, saving the need to perform unit testing of additional components instead of just the daughterboard **404**.

(113) The daughterboard **404** is shown with a power supply **700**, a processor **702**, computer readable memory **704**, a pressure sensor **706**, and a WiFi radio **708**. The processor can use the pressure sensor **706** to gather information about the pressure of the air chamber or chambers of an air bed. From this data, the processor **702** can perform an algorithm to calculate a sleep metric. In some examples, the sleep metric can be calculated from only the pressure of air chambers. In other examples, the sleep metric can be calculated from one or more other sensors. In an example in which different data is needed, the processor **702** can receive that data from an appropriate sensor or sensors. These sensors can be internal to the daughterboard **404**, accessible via the WiFi radio **708**, or otherwise in communication with the processor **702**. Once the sleep metric is calculated, the processor **702** can report that sleep metric to, for example, the motherboard **402**.

(114) FIG. **8** is a block diagram of an example of a motherboard **800** with no daughterboard that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1-3**. In this example, the motherboard **800** can perform most, all, or more of the features described with reference to the motherboard **402** in FIG. **6** and the daughterboard **404** in FIG. **7**.

(115) FIG. **9** is a block diagram of an example of a sensory array **406** that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1-3**. In general, the sensor array **406** is a conceptual grouping of some or all the peripheral sensors that communicate with the motherboard **402** but are not native to the motherboard **402**.

(116) The peripheral sensors of the sensor array **406** can communicate with the motherboard **402**

through one or more of the network interfaces of the motherboard, including but not limited to the USB stack **604**, a WiFi radio **606**, a Bluetooth Low Energy (BLE) radio **608**, a ZigBee radio **610**, and a Bluetooth radio **612**, as is appropriate for the configuration of the particular sensor. For example, a sensor that outputs a reading over a USB cable can communicate through the USB stack **604**.

(117) Some of the peripheral sensors **900** of the sensor array **406** can be bed mounted **900**. These sensors can be, for example, embedded into the structure of a bed and sold with the bed, or later affixed to the structure of the bed. Other peripheral sensors **902** and **904** can be in communication with the motherboard **402**, but optionally not mounted to the bed. In some cases, some or all of the bed mounted sensors **900** and/or peripheral sensors **902** and **904** can share networking hardware, including a conduit that contains wires from each sensor, a multi-wire cable or plug that, when affixed to the motherboard **402**, connect all of the associated sensors with the motherboard **402**. In some embodiments, one, some, or all of sensors **902**, **904**, **906**, **908**, and **910** can sense one or more features of a mattress, such as pressure, temperature, light, sound, and/or one or more other features of the mattress. In some embodiments, one, some, or all of sensors **902**, **904**, **906**, **908**, and **910** can sense one or more features external to the mattress. In some embodiments, pressure sensor **902** can sense pressure of the mattress while some or all of sensors **902**, **904**, **906**, **908**, and **910** can sense one or more features of the mattress and/or external to the mattress.

(118) FIG. **10** is a block diagram of an example of a controller array **408** that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1-3**. In general, the controller array **408** is a conceptual grouping of some or all peripheral controllers that communicate with the motherboard **402** but are not native to the motherboard **402**.

(119) The peripheral controllers of the controller array **408** can communicate with the motherboard **402** through one or more of the network interfaces of the motherboard, including but not limited to the USB stack **604**, a WiFi radio **606**, a Bluetooth Low Energy (BLE) radio **608**, a ZigBee radio **610**, and a Bluetooth radio **612**, as is appropriate for the configuration of the particular sensor. For example, a controller that receives a command over a USB cable can communicate through the USB stack **604**.

(120) Some of the controllers of the controller array **408** can be bed mounted **1000**. These controllers can be, for example, embedded into the structure of a bed and sold with the bed, or later affixed to the structure of the bed. Other peripheral controllers **1002** and **1004** can be in communication with the motherboard **402**, but optionally not mounted to the bed. In some cases, some or all of the bed mounted controllers **1000** and/or peripheral controllers **1002** and **1004** can share networking hardware, including a conduit that contains wires for each controller, a multi-wire cable or plug that, when affixed to the motherboard **402**, connects all of the associated controllers with the motherboard **402**.

(121) FIG. **11** is a block diagram of an example of a computing device **412** that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1-3**. The computing device **412** can include, for example, computing devices used by a user of a bed. Example computing devices **412** include, but are not limited to, mobile computing devices (e.g., mobile phones, tablet computers, laptops) and desktop computers.

(122) The computing device **412** includes a power supply **1100**, a processor **1102**, and computer readable memory **1104**. User input and output can be transmitted by, for example, speakers **1106**, a touchscreen **1108**, or other not shown components such as a pointing device or keyboard. The computing device **412** can run one or more applications **1110**. These applications can include, for example, application to allow the user to interact with the system **400**. These applications can allow a user to view information about the bed (e.g., sensor readings, sleep metrics), or configure the behavior of the system **400** (e.g., set a desired firmness to the bed, set desired behavior for peripheral devices). In some cases, the computing device **412** can be used in addition to, or to

replace, the remote control **122** described previously.

(123) FIG. **12** is a block diagram of an example bed data cloud service **410***a* that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1**-**3**. In this example, the bed data cloud service **410***a* is configured to collect sensor data and sleep data from a particular bed, and to match the sensor and sleep data with one or more users that use the bed when the sensor and sleep data was generated.

(124) The bed data cloud service **410***a* is shown with a network interface **1200**, a communication manager **1202**, server hardware **1204**, and server system software **1206**. In addition, the bed data cloud service **410***a* is shown with a user identification module **1208**, a device management **1210** module, a sensor data module **1210**, and an advanced sleep data module **1214**.

(125) The network interface **1200** generally includes hardware and low level software used to allow one or more hardware devices to communicate over networks. For example the network interface **1200** can include network cards, routers, modems, and other hardware needed to allow the components of the bed data cloud service **410***a* to communicate with each other and other destinations over, for example, the Internet **412**. The communication manger **1202** generally comprises hardware and software that operate above the network interface **1200**. This includes software to initiate, maintain, and tear down network communications used by the bed data cloud service **410***a*. This includes, for example, TCP/IP, SSL or TLS, Torrent, and other communication sessions over local or wide area networks. The communication manger **1202** can also provide load balancing and other services to other elements of the bed data cloud service **410***a*.

(126) The server hardware **1204** generally includes the physical processing devices used to instantiate and maintain bed data cloud service **410***a*. This hardware includes, but is not limited to processors (e.g., central processing units, ASICs, graphical processers), and computer readable memory (e.g., random access memory, stable hard disks, tape backup). One or more servers can be configured into clusters, multi-computer, or datacenters that can be geographically separate or connected.

(127) The server system software **1206** generally includes software that runs on the server hardware **1204** to provide operating environments to applications and services. The server system software **1206** can include operating systems running on real servers, virtual machines instantiated on real servers to create many virtual servers, server level operations such as data migration, redundancy, and backup.

(128) The user identification **1208** can include, or reference, data related to users of beds with associated data processing systems. For example, the users can include customers, owners, or other users registered with the bed data cloud service **410***a* or another service. Each user can have, for example, a unique identifier, user credentials, contact information, billing information, demographic information, or any other technologically appropriate information.

(129) The device manager **1210** can include, or reference, data related to beds or other products associated with data processing systems. For example, the beds can include products sold or registered with a system associated with the bed data cloud service **410***a*. Each bed can have, for example, a unique identifier, model and/or serial number, sales information, geographic information, delivery information, a listing of associated sensors and control peripherals, etc. Additionally, an index or indexes stored by the bed data cloud service **410***a* can identify users that are associated with beds. For example, this index can record sales of a bed to a user, users that sleep in a bed, etc.

(130) The sensor data **1212** can record raw or condensed sensor data recorded by beds with associated data processing systems. For example, a bed's data processing system can have a temperature sensor, pressure sensor, and light sensor. Readings from these sensors, either in raw form or in a format generated from the raw data (e.g. sleep metrics) of the sensors, can be communicated by the bed's data processing system to the bed data cloud service **410***a* for storage in the sensor data **1212**. Additionally, an index or indexes stored by the bed data cloud service **410***a*

can identify users and/or beds that are associated with the sensor data **1212**.

(131) The bed data cloud service **410***a* can use any of its available data to generate advanced sleep data **1214**. In general, the advanced sleep data **1214** includes sleep metrics and other data generated from sensor readings. Some of these calculations can be performed in the bed data cloud service **410***a* instead of locally on the bed's data processing system, for example, because the calculations are computationally complex or require a large amount of memory space or processor power that is not available on the bed's data processing system. This can help allow a bed system to operate with a relatively simple controller and still be part of a system that performs relatively complex tasks and computations.

(132) FIG. **13** is a block diagram of an example sleep data cloud service **410***b* that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1**-**3**. In this example, the sleep data cloud service **410***b* is configured to record data related to users' sleep experience.

(133) The sleep data cloud service **410***b* is shown with a network interface **1300**, a communication manager **1302**, server hardware **1304**, and server system software **1306**. In addition, the sleep data cloud service **410***b* is shown with a user identification module **1308**, a pressure sensor manager **1310**, a pressure based sleep data module **1312**, a raw pressure sensor data module **1314**, and a non-pressure sleep data module **1316**.

(134) The pressure sensor manager **1310** can include, or reference, data related to the configuration and operation of pressure sensors in beds. For example, this data can include an identifier of the types of sensors in a particular bed, their settings and calibration data, etc.

(135) The pressure based sleep data **1312** can use raw pressure sensor data **1314** to calculate sleep metrics specifically tied to pressure sensor data. For example, user presence, movements, weight change, heart rate, and breathing rate can all be determined from raw pressure sensor data **1314**. Additionally, an index or indexes stored by the sleep data cloud service **410***b* can identify users that are associated with pressure sensors, raw pressure sensor data, and/or pressure based sleep data.

(136) The non-pressure sleep data **1316** can use other sources of data to calculate sleep metrics. For example, user entered preferences, light sensor readings, and sound sensor readings can all be used to track sleep data. Additionally, an index or indexes stored by the sleep data cloud service **410***b* can identify users that are associated with other sensors and/or non-pressure sleep data **1316**.

(137) FIG. **14** is a block diagram of an example user account cloud service **410***c* that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1**-**3**. In this example, the user account cloud service **410***c* is configured to record a list of users and to identify other data related to those users.

(138) The user account cloud service **410***c* is shown with a network interface **1400**, a communication manager **1402**, server hardware **1404**, and server system software **1406**. In addition, the user account cloud service **410***c* is shown with a user identification module **1408**, a purchase history module **1410**, an engagement module **1412**, and an application usage history module **1414**.

(139) The user identification module **1408** can include, or reference, data related to users of beds with associated data processing systems. For example, the users can include customers, owners, or other users registered with the user account cloud service **410***a* or another service. Each user can have, for example, a unique identifier, and user credentials, demographic information, or any other technologically appropriate information.

(140) The purchase history module **1410** can include, or reference, data related to purchases by users. For example, the purchase data can include a sale's contact information, billing information, and salesperson information. Additionally, an index or indexes stored by the user account cloud service **410***c* can identify users that are associated with a purchase.

(141) The engagement **1412** can track user interactions with the manufacturer, vendor, and/or manager of the bed and or cloud services. This engagement data can include communications (e.g.,

emails, service calls), data from sales (e.g., sales receipts, configuration logs), and social network interactions.

(142) The usage history module **1414** can contain data about user interactions with one or more applications and/or remote controls of a bed. For example, a monitoring and configuration application can be distributed to run on, for example, computing devices **412**. This application can log and report user interactions for storage in the application usage history module **1414**. Additionally, an index or indexes stored by the user account cloud service **410***c* can identify users that are associated with each log entry.

(143) FIG. **15** is a block diagram of an example point of sale cloud service **1500** that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1**-**3**. In this example, the point of sale cloud service **1500** is configured to record data related to users' purchases.

(144) The point of sale cloud service **1500** is shown with a network interface **1502**, a communication manager **1504**, server hardware **1506**, and server system software **1508**. In addition, the point of sale cloud service **1500** is shown with a user identification module **1510**, a purchase history module **1512**, and a setup module **1514**.

(145) The purchase history module **1512** can include, or reference, data related to purchases made by users identified in the user identification module **1510**. The purchase information can include, for example, data of a sale, price, and location of sale, delivery address, and configuration options selected by the users at the time of sale. These configuration options can include selections made by the user about how they wish their newly purchased beds to be setup and can include, for example, expected sleep schedule, a listing of peripheral sensors and controllers that they have or will install, etc.

(146) The bed setup module **1514** can include, or reference, data related to installations of beds that users' purchase. The bed setup data can include, for example, the date and address to which a bed is delivered, the person that accepts delivery, the configuration that is applied to the bed upon delivery, the name or names of the person or people who will sleep on the bed, which side of the bed each person will use, etc.

(147) Data recorded in the point of sale cloud service **1500** can be referenced by a user's bed system at later dates to control functionality of the bed system and/or to send control signals to peripheral components according to data recorded in the point of sale cloud service **1500**. This can allow a salesperson to collect information from the user at the point of sale that later facilitates automation of the bed system. In some examples, some or all aspects of the bed system can be automated with little or no user-entered data required after the point of sale. In other examples, data recorded in the point of sale cloud service **1500** can be used in connection with a variety of additional data gathered from user-entered data.

(148) FIG. **16** is a block diagram of an example environment cloud service **1600** that can be used in a data processing system that can be associated with a bed system, including those described above with respect to FIGS. **1**-**3**. In this example, the environment cloud service **1600** is configured to record data related to users' home environment.

(149) The environment cloud service **1600** is shown with a network interface **1602**, a communication manager **1604**, server hardware **1606**, and server system software **1608**. In addition, the environment cloud service **1600** is shown with a user identification module **1610**, an environmental sensor module **1612**, and an environmental factors module **1614**.

(150) The environmental sensors module **1612** can include a listing of sensors that users' in the user identification module **1610** have installed in their bed. These sensors include any sensors that can detect environmental variables—light sensors, noise sensors, vibration sensors, thermostats, etc. Additionally, the environmental sensors module **1612** can store historical readings or reports from those sensors.

(151) The environmental factors module **1614** can include reports generated based on data in the

environmental sensors module **1612**. For example, for a user with a light sensor with data in the environment sensors module **1612**, the environmental factors module **1614** can hold a report indicating the frequency and duration of instances of increased lighting when the user is asleep.

(152) In the examples discussed here, each cloud service **410** is shown with some of the same components. In various configurations, these same components can be partially or wholly shared between services, or they can be separate. In some configurations, each service can have separate copies of some or all of the components that are the same or different in some ways. Additionally, these components are only supplied as illustrative examples. In other examples each cloud service can have different number, types, and styles of components that are technically possible.

(153) FIG. **17** is a block diagram of an example of using a data processing system that can be associated with a bed (such as a bed of the bed systems described herein) to automate peripherals around the bed. Shown here is a behavior analysis module **1700** that runs on the pump motherboard **402**. For example, the behavior analysis module **1700** can be one or more software components stored on the computer memory **512** and executed by the processor **502**. In general, the behavior analysis module **1700** can collect data from a wide variety of sources (e.g., sensors, non-sensor local sources, cloud data services) and use a behavioral algorithm **1702** to generate one or more actions to be taken (e.g., commands to send to peripheral controllers, data to send to cloud services). This can be useful, for example, in tracking user behavior and automating devices in communication with the user's bed.

(154) The behavior analysis module **1700** can collect data from any technologically appropriate source, for example, to gather data about features of a bed, the bed's environment, and/or the bed's users. Some such sources include any of the sensors of the sensor array **406**. For example, this data can provide the behavior analysis module **1700** with information about the current state of the environment around the bed. For example, the behavior analysis module **1700** can access readings from the pressure sensor **902** to determine the pressure of an air chamber in the bed. From this reading, and potentially other data, user presence in the bed can be determined. In another example, the behavior analysis module can access a light sensor **908** to detect the amount of light in the bed's environment.

(155) Similarly, the behavior analysis module **1700** can access data from cloud services. For example, the behavior analysis module **1700** can access the bed cloud service **410**a to access historical sensor data **1212** and/or advanced sleep data **1214**. Other cloud services **410**, including those not previously described can be accessed by the behavior analysis module **1700**. For example, the behavior analysis module **1700** can access a weather reporting service, a 3.sup.rd party data provider (e.g., traffic and news data, emergency broadcast data, user travel data), and/or a clock and calendar service.

(156) Similarly, the behavior analysis module **1700** can access data from non-sensor sources **1704**. For example, the behavior analysis module **1700** can access a local clock and calendar service (e.g., a component of the motherboard **402** or of the processor **502**).

(157) The behavior analysis module **1700** can aggregate and prepare this data for use by one or more behavioral algorithms **1702**. The behavioral algorithms **1702** can be used to learn a user's behavior and/or to perform some action based on the state of the accessed data and/or the predicted user behavior. For example, the behavior algorithm **1702** can use available data (e.g., pressure sensor, non-sensor data, clock and calendar data) to create a model of when a user goes to bed every night. Later, the same or a different behavioral algorithm **1702** can be used to determine if an increase in air chamber pressure is likely to indicate a user going to bed and, if so, send some data to a third-party cloud service **410** and/or engage a peripheral controller **1002**.

(158) In the example shown, the behavioral analysis module **1700** and the behavioral algorithm **1702** are shown as components of the motherboard **402**. However, other configurations are possible. For example, the same or a similar behavioral analysis module and/or behavior algorithm can be run in one or more cloud services, and the resulting output can be sent to the motherboard

402, a controller in the controller array **408**, or to any other technologically appropriate recipient.

(159) FIG. **18** shows an example of a computing device **1800** and an example of a mobile computing device that can be used to implement the techniques described here. The computing device **1800** is intended to represent various forms of digital computers, such as laptops, desktops, workstations, personal digital assistants, servers, blade servers, mainframes, and other appropriate computers. The mobile computing device is intended to represent various forms of mobile devices, such as personal digital assistants, cellular telephones, smart-phones, and other similar computing devices. The components shown here, their connections and relationships, and their functions, are meant to be exemplary only, and are not meant to limit implementations of the inventions described and/or claimed in this document.

(160) The computing device **1800** includes a processor **1802**, a memory **1804**, a storage device **1806**, a high-speed interface **1808** connecting to the memory **1804** and multiple high-speed expansion ports **1810**, and a low-speed interface **1812** connecting to a low-speed expansion port **1814** and the storage device **1806**. Each of the processor **1802**, the memory **1804**, the storage device **1806**, the high-speed interface **1808**, the high-speed expansion ports **1810**, and the low-speed interface **1812**, are interconnected using various busses, and can be mounted on a common motherboard or in other manners as appropriate. The processor **1802** can process instructions for execution within the computing device **1800**, including instructions stored in the memory **1804** or on the storage device **1806** to display graphical information for a GUI on an external input/output device, such as a display **1816** coupled to the high-speed interface **1808**. In other implementations, multiple processors and/or multiple buses can be used, as appropriate, along with multiple memories and types of memory. Also, multiple computing devices can be connected, with each device providing portions of the necessary operations (e.g., as a server bank, a group of blade servers, or a multi-processor system).

(161) The memory **1804** stores information within the computing device **1800**. In some implementations, the memory **1804** is a volatile memory unit or units. In some implementations, the memory **1804** is a non-volatile memory unit or units. The memory **1804** can also be another form of computer-readable medium, such as a magnetic or optical disk.

(162) The storage device **1806** is capable of providing mass storage for the computing device **1800**. In some implementations, the storage device **1806** can be or contain a computer-readable medium, such as a floppy disk device, a hard disk device, an optical disk device, or a tape device, a flash memory or other similar solid state memory device, or an array of devices, including devices in a storage area network or other configurations. A computer program product can be tangibly embodied in an information carrier. The computer program product can also contain instructions that, when executed, perform one or more methods, such as those described above. The computer program product can also be tangibly embodied in a computer- or machine-readable medium, such as the memory **1804**, the storage device **1806**, or memory on the processor **1802**.

(163) The high-speed interface **1808** manages bandwidth-intensive operations for the computing device **1800**, while the low-speed interface **1812** manages lower bandwidth-intensive operations. Such allocation of functions is exemplary only. In some implementations, the high-speed interface **1808** is coupled to the memory **1804**, the display **1816** (e.g., through a graphics processor or accelerator), and to the high-speed expansion ports **1810**, which can accept various expansion cards (not shown). In the implementation, the low-speed interface **1812** is coupled to the storage device **1806** and the low-speed expansion port **1814**. The low-speed expansion port **1814**, which can include various communication ports (e.g., USB, Bluetooth, Ethernet, wireless Ethernet) can be coupled to one or more input/output devices, such as a keyboard, a pointing device, a scanner, or a networking device such as a switch or router, e.g., through a network adapter.

(164) The computing device **1800** can be implemented in a number of different forms, as shown in the figure. For example, it can be implemented as a standard server **1820**, or multiple times in a group of such servers. In addition, it can be implemented in a personal computer such as a laptop

computer **1822**. It can also be implemented as part of a rack server system **1824**. Alternatively, components from the computing device **1800** can be combined with other components in a mobile device (not shown), such as a mobile computing device **1850**. Each of such devices can contain one or more of the computing device **1800** and the mobile computing device **1850**, and an entire system can be made up of multiple computing devices communicating with each other.

(165) The mobile computing device **1850** includes a processor **1852**, a memory **1864**, an input/output device such as a display **1854**, a communication interface **1866**, and a transceiver **1868**, among other components. The mobile computing device **1850** can also be provided with a storage device, such as a micro-drive or other device, to provide additional storage. Each of the processor **1852**, the memory **1864**, the display **1854**, the communication interface **1866**, and the transceiver **1868**, are interconnected using various buses, and several of the components can be mounted on a common motherboard or in other manners as appropriate.

(166) The processor **1852** can execute instructions within the mobile computing device **1850**, including instructions stored in the memory **1864**. The processor **1852** can be implemented as a chipset of chips that include separate and multiple analog and digital processors. The processor **1852** can provide, for example, for coordination of the other components of the mobile computing device **1850**, such as control of user interfaces, applications run by the mobile computing device **1850**, and wireless communication by the mobile computing device **1850**.

(167) The processor **1852** can communicate with a user through a control interface **1858** and a display interface **1856** coupled to the display **1854**. The display **1854** can be, for example, a TFT (Thin-Film-Transistor Liquid Crystal Display) display or an OLED (Organic Light Emitting Diode) display, or other appropriate display technology. The display interface **1856** can comprise appropriate circuitry for driving the display **1854** to present graphical and other information to a user. The control interface **1858** can receive commands from a user and convert them for submission to the processor **1852**. In addition, an external interface **1862** can provide communication with the processor **1852**, so as to enable near area communication of the mobile computing device **1850** with other devices. The external interface **1862** can provide, for example, for wired communication in some implementations, or for wireless communication in other implementations, and multiple interfaces can also be used.

(168) The memory **1864** stores information within the mobile computing device **1850**. The memory **1864** can be implemented as one or more of a computer-readable medium or media, a volatile memory unit or units, or a non-volatile memory unit or units. An expansion memory **1874** can also be provided and connected to the mobile computing device **1850** through an expansion interface **1872**, which can include, for example, a SIMM (Single In Line Memory Module) card interface. The expansion memory **1874** can provide extra storage space for the mobile computing device **1850**, or can also store applications or other information for the mobile computing device **1850**. Specifically, the expansion memory **1874** can include instructions to carry out or supplement the processes described above, and can include secure information also. Thus, for example, the expansion memory **1874** can be provide as a security module for the mobile computing device **1850**, and can be programmed with instructions that permit secure use of the mobile computing device **1850**. In addition, secure applications can be provided via the SIMM cards, along with additional information, such as placing identifying information on the SIMM card in a non-hackable manner.

(169) The memory can include, for example, flash memory and/or NVRAM memory (non-volatile random access memory), as discussed below. In some implementations, a computer program product is tangibly embodied in an information carrier. The computer program product contains instructions that, when executed, perform one or more methods, such as those described above. The computer program product can be a computer- or machine-readable medium, such as the memory **1864**, the expansion memory **1874**, or memory on the processor **1852**. In some implementations, the computer program product can be received in a propagated signal, for example, over the

transceiver **1868** or the external interface **1862**.

(170) The mobile computing device **1850** can communicate wirelessly through the communication interface **1866**, which can include digital signal processing circuitry where necessary. The communication interface **1866** can provide for communications under various modes or protocols, such as GSM voice calls (Global System for Mobile communications), SMS (Short Message Service), EMS (Enhanced Messaging Service), or MMS messaging (Multimedia Messaging Service), CDMA (code division multiple access), TDMA (time division multiple access), PDC (Personal Digital Cellular), WCDMA (Wideband Code Division Multiple Access), CDMA2000, or GPRS (General Packet Radio Service), among others. Such communication can occur, for example, through the transceiver **1868** using a radio-frequency. In addition, short-range communication can occur, such as using a Bluetooth, WiFi, or other such transceiver (not shown). In addition, a GPS (Global Positioning System) receiver module **1870** can provide additional navigation- and location-related wireless data to the mobile computing device **1850**, which can be used as appropriate by applications running on the mobile computing device **1850**.

(171) The mobile computing device **1850** can also communicate audibly using an audio codec **1860**, which can receive spoken information from a user and convert it to usable digital information. The audio codec **1860** can likewise generate audible sound for a user, such as through a speaker, e.g., in a handset of the mobile computing device **1850**. Such sound can include sound from voice telephone calls, can include recorded sound (e.g., voice messages, music files, etc.) and can also include sound generated by applications operating on the mobile computing device **1850**.

(172) The mobile computing device **1850** can be implemented in a number of different forms, as shown in the figure. For example, it can be implemented as a cellular telephone **1880**. It can also be implemented as part of a smart-phone **1882**, personal digital assistant, or other similar mobile device.

(173) Various implementations of the systems and techniques described here can be realized in digital electronic circuitry, integrated circuitry, specially designed ASICs (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations can include implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which can be special or general purpose, coupled to receive data and instructions from, and to transmit data and instructions to, a storage system, at least one input device, and at least one output device.

(174) These computer programs (also known as programs, software, software applications or code) include machine instructions for a programmable processor, and can be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms machine-readable medium and computer-readable medium refer to any computer program product, apparatus and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term machine-readable signal refers to any signal used to provide machine instructions and/or data to a programmable processor.

(175) To provide for interaction with a user, the systems and techniques described here can be implemented on a computer having a display device (e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor) for displaying information to the user and a keyboard and a pointing device (e.g., a mouse or a trackball) by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback (e.g., visual feedback, auditory feedback, or tactile feedback); and input from the user can be received in any form, including acoustic, speech, or tactile input.

(176) The systems and techniques described here can be implemented in a computing system that

includes a back end component (e.g., as a data server), or that includes a middleware component (e.g., an application server), or that includes a front end component (e.g., a client computer having a graphical user interface or a Web browser through which a user can interact with an implementation of the systems and techniques described here), or any combination of such back end, middleware, or front end components. The components of the system can be interconnected by any form or medium of digital data communication (e.g., a communication network). Examples of communication networks include a local area network (LAN), a wide area network (WAN), and the Internet.

(177) The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

(178) FIG. **19** is a pipeline diagram of an example of a pipeline **1900** that can be used to collect acoustic readings and pressure readings for home automation. The pipeline **1900** can be used by a bed system that include functionality to send control signals to home automation devices in response to the detection of snoring by a user on the bed. For example, the pipeline **1900** may be included in a controller of an air bed that also controls the firmness and elevation of the bed. In some examples, the pipeline **1900** can be used by other data processing systems. For example, the acoustic sensor **1902** may be integrated into a different element of a home-automation system that is in communication with a bed system.

(179) The acoustic sensor **1902** may include hardware and software configured to generate a data stream responsive to acoustic energy in the environment. The acoustic sensor **1902** may include, for example, one or more microphones built into a bedframe or a mattress on a bed. The acoustic sensor **1902** may include, for example, a plurality of sensors placed through a building such as a home or hospital. In some cases, the acoustic sensor **1902** can include different types of sensors from different sources. For examples, sensors built into a bed and a sensor on a phone can work together to generate one or more data streams from their individual sensing.

(180) The acoustic sensor **1902** can generate an analog acoustic stream **1904**. Some acoustic sensors **1902** generate an analog signal that is an analog electric signal that is proportional to the acoustic energy received by the sensor **1902**. For example, if the acoustic energy is a pressure wave having a particular shape, the sensor **1902** can generate an analog acoustic stream **1904** having an electrical wave with the same particular shape.

(181) A digitizer **1906** can receive the analog acoustic stream **1904** and generate a digital acoustic stream **1908**. For example, the digitizer **1906** can receive the analog acoustic stream **1904** having a wave with the particular shape, and generate a stream of digital values that describe that wave according to a predetermined conversion algorithm. This digital stream, in some implementations, is a two's-compliment binary number proportional to the input wave's value at a particular sample rate.

(182) In some implementations, the sensor **1902** does not generate an acoustic stream **1904** but instead generates a digital acoustic stream **1908**. In some cases, more than one acoustic stream is used, whether digital or analog. For clarity, the following description will be made with reference to a pipeline **1900** that uses a single sensor **1902** that generates a single analog acoustic stream **1904**, but other configurations are possible.

(183) A framer **1910** generates digital acoustic frames **1912** from the digital acoustic stream **1908**. For example, if the digital analog stream **1908** is a stream of binary digits, the framer **1910** can generate digital acoustic frames **1912** that include all of the binary digits within a fixed time window.

(184) In some implementations, the digital acoustic frames **1912** can overlap. For example, each frame may be 100 ms long, and may overlap the previous digital acoustic frame by 50 ms and may overlap the next digital acoustic frame by 50 ms. In another example, each frame may be 200 ms

long, and may overlap the two adjacent digital acoustic frames by 10 ms each. In another example, each frame may be 20 s long, and may overlap the two adjacent digital acoustic frames by 1 s each.

(185) The pipeline **1900** can also include a pressure sensor **1914**. For example, the pressure sensor **1914** can be included in a bed such as an airbed and include hardware and software configured to generate a data stream responsive to pressure applied to the bed by the user or users that are on the bed. The pressure sensor **1914** may include, for example, a transducer or flexible membrane fluidically coupled to an air bladder by a hose. In some cases, the pressure sensor **1914** may be separable from the bed, for example in the form of a pad, strip, puck, or sheet that can be placed on or under the mattress of the bed.

(186) The pressure sensor **1914** can generate an analog pressure stream **1916**. Some pressure sensors **1916** generate an analog signal that is an analog electric signal that is proportional to the pressure received by the sensor **1914**. For example, if the pressure is a pressure wave having a particular shape, the sensor **1914** can generate an analog pressure stream **1916** having an electrical wave with the same particular shape.

(187) A digitizer **1918** can receive the analog pressure stream **1916** and generate a digital pressure stream **1920**. For example, the digitizer **1918** can receive the analog pressure stream **1916** having a wave with the particular shape, and generate a stream of digital values that describe that wave according to a predetermined conversion algorithm. This digital stream, in some implementations, is a two's-compliment binary number proportional to the input wave's value at a particular sample rate. In some cases, the digitizers **1906** and **1918** may use the same sampling rates. In some cases, the digitizers **1906** and **1918** may use different sampling rates.

(188) In some implementations, the sensor **1914** does not generate a pressure stream **1916** but instead generates a digital pressure stream **1920**. In some cases, more than one pressure stream is used, whether digital or analog. For clarity, the following description will be made with reference to a pipeline **1900** that uses a single sensor **1914** that generates a single analog pressure stream **1916**, but other configurations are possible.

(189) A framer **1922** generates digital pressure frames **1924** from the digital pressure stream **1920**. For example, if the digital pressure stream **1920** is a stream of binary digits, the framer **1922** can generate digital pressure frames **1924** that include all of the binary digits within a fixed time window.

(190) In some implementations, the digital pressure frames **1924** can overlap. For example, each frame may be 100 ms long, and may overlap the previous digital acoustic frame by 50 ms and may overlap the next digital acoustic frame by 50 ms. In another example, each frame may be 200 ms long, and may overlap the two adjacent digital acoustic frames by 10 ms each. In another example, each frame may be 30 seconds long, and may overlap the previous and subsequent digital acoustic frames by 1 second.

(191) The digital acoustic frames **1912** and digital pressure frames **1924** can be used by an encryption/compression engine **1932** to prepare the digital acoustic frames **1912** and digital pressure frames **1924** for storage. The encryption/compression engine **1932** can create encrypted/compressed readings **1934** that contain securely encrypted and compressed data that, when decrypted and decompressed, produces the digital acoustic frames **1912** and digital pressure frames **1924**. The encryption/compression engine **1932** can send the encrypted/compressed readings **1934** to an off-site or local storage **1936** such as a cloud storage.

(192) A snore analyzer **1926** can also use the digital acoustic frames **1912** and digital pressure frames **1924** in order to make determinations about a snore state of a user on a bed. As will be shown below, one or more machine learning processes, for example, may be used, and the snore analyzer **1926** can generate a corresponding control signal **1928** based on that snore-state determination. A controller array **1930** can receive the control signal and engage a controllable device in accordance with the control signal to alter the user's environment.

(193) The snore analyzer **1926** can use one or a combination of calculations to make these

determinations about snore states. For example, within each frame, features corresponding to temporal and spectral characteristics of acoustic readings can be generated. Examples of such features include, but are not limited to, min, max, mean, median, standard deviation, and a function of the amplitude, width and location of the peaks of the audio signal within the epoch; min, max, mean, median, standard deviation, and a function of the amplitude, width and location of the peaks of the envelope of the audio signal within the epoch; min, max, mean, median, standard deviation, and a function of the amplitude, width and location of the peaks of the spectrum of the audio signal within the epoch; min, max, mean, median, standard deviation, and a function of the amplitude, width and location of the peaks of the spectrum of the envelope of the audio signal within the epoch; an acoustic snore index calculated as a ratiometric measure of different spectral subbands from the spectrum of the audio signal within the epoch; and mel-frequency coefficients from the cepstrum of the audio signal within the epoch.

(194) For example, within each frame, features corresponding to temporal and spectral characteristics of pressure readings can be generated. Examples of such features include, but are not limited to, a function of the rate of breathing measured from pressure variations; a function of the amplitude of breathing measured from pressure variations; a function of the duration of breathing measured from pressure variations; min, max, mean, median, standard deviation, and a function of the amplitude, width and location of the peaks of the pressure signal within the epoch; min, max, mean, median, standard deviation, and a function of the amplitude, width and location of the peaks of the spectrum of the pressure signal within the epoch; and a pressure snore index calculated as a ratiometric measure of different spectral subbands from the spectrum of the pressure signal within the epoch.

(195) FIGS. **20**A and **20**B are swimlane diagrams of example processes for training and using machine-learning classifiers to determine and classify snore events in a bed. For clarity, the processes **2000** and **2050** are being described with reference to a particular set of components. However, other system or systems can be used to perform the same or a similar process.

(196) In the process **2000**, a bed system uses the reading of pressure/acoustic sensors **2002** to learn what effect a user has on the pressure of the bed and the acoustics a user generates when the user snores or does not snore. The bed system is able to use these readings as signals for a decision engine that classifies the snore state of the user into one of a plurality of possible snore states. The snore state may include two states (e.g., snoring or not snoring) or a greater number of snore states that more granularly describe the snoring of the user.

(197) In operation, the bed can determine the snore state of the user and operate according to the snore state. For example, the user may configure the bed system so that it alters the pressure when they snore so in an effort to minimize their snoring. The bed may operate to iteratively or constantly determine snore state based on a series of live readings from the pressure/acoustic sensor **2002**. When the snore state transitions to "snore," for example from "no snore," the bed system can instruct the pump to alter the pressure of the mattress under the user.

(198) A pressure/acoustic sensor **2002** senses pressure **2012**. For example, the pressure sensor may create a live stream of pressure readings that reflect the pressure inside of an air bladder within a bed system. This live stream of pressure readings may be provided to a bed controller **2004** in the form of analog or digital information on a substantially constant basis, thus reflecting pressure as within the air bladder due to a user (or other object) on the bed system or when the bed is empty.

(199) At the same time, the acoustic sensor may create a live stream of acoustic readings that reflect acoustic energy in the environment around the user of the bed system. This live stream of acoustic readings may be provided to the bed controller **2004** in the form of analog or digital information on a substantially constant basis, thus reflecting acoustic conditions around the user due to acoustics created by the user due to snoring, speaking, etc.

(200) The bed controller **2004** receives the pressure/acoustic readings **2014**. For example, the bed controller **2004** can place pressure/acoustic readings in a computer memory structure such as a

rolling buffer that makes the most recent N readings available to the bed controller. The bed controller **2004** may aggregate these pressure/acoustic readings, subsample the readings, or store them all individually.

(201) The bed controller **2004** transmits the pressure/acoustic readings **2016** and a cloud reporting service **2006** receives the pressure/acoustic readings **2018**. For example, the bed controller **2004** can transmit all pressure/acoustic readings or determine that some pressure/acoustic readings—and not others—should be transmitted to the cloud reporting service **2006** that is configured to receive pressure/acoustic readings and in some cases other types of data. The pressure/acoustic readings sent to the cloud reporting service **2006** may be unchanged by the bed controller **2004**, aggregated (e.g., averages, maximums and minimums, etc.), or otherwise changed by the bed controller **2004**.

(202) A classifier factory **2008** generates classifiers from the pressure/acoustic readings **2020**. The classifier factory **2008** can train classifiers by first obtaining a large set of pre-classified reading variation patterns. For example, one bed or many beds may report reading data to a cloud reporting service **2006**. This reading data may be tagged, recorded, and stored for analysis in the creation of pressure classifiers to be used by the bed controller **2004** and/or other bed controllers.

(203) The classifier factory **2008** can generate features from the readings. For example, the stream of pressure signals and the stream of acoustic signals may be broken into buffers of, for example, 1 second, 2.125 seconds, 3 seconds, or 20 seconds, to generate features in time or frequency domains. These features may be direct measure of pressure/acoustics within those buffers. For example, such features may include a maximum, minimum, or random pressure/acoustic value. These features may be derived from the readings within those buffers. For example, such features may include an average reading value, a standard deviation, or a slope value that indicates an increase or decrease over time within that buffer. The values of the feature vectors may be in binary or numerical form. For each buffer, the values may be stored in a predetermined order creating a vector that is composed of a series of fields, where every vector has the same series of fields and data in those fields. Some other features may be computed from the transform domain representations of the pressure and acoustic signal such as from the Fourier or Wavelet Transform coefficients.

(204) As another example, the classifier factory can identify instances within the readings where the readings match a pattern or rules for a pattern. In one example, a repeating pattern may be defined as a sinusoid or saw tooth shape in pressure or acoustic streams—including a marked increase or a sharp fluctuation. Such patterns may be identified, and corresponding synthetic information about the pattern in time or frequency (e.g., timestamp, duration, maximum envelope amplitude, spectral peaks) may be synthesized from the pressure and acoustic signals and/or other outside information (e.g., a real-time clock).

(205) The classifier factory **2008** can combine or reduce the features. For example, the extracted features can be combined using principal component analysis. For a principal component analysis of the features, the classifier factory **2008** can determine a subset of all features that are discriminant of the snore state of the user. That is, the classifier factory **2008** can sort features into those features that are useful for determining snore state and those features that are less useful, and the more useful features may be kept. This process may be done on a trial-and-error basis, in which random combinations of features are tested. This process may be done with the use of one or more systematic processes. For example, a linear discriminant analysis or generalized discriminant analysis may be used.

(206) In some cases, a proper subset of features may be selected out of the set of all available features. This selection may be done once per classifier if multiple classifiers are being created. Alternatively, this selection may be done once for a plurality or all classifiers if multiple classifiers are being created.

(207) For example, a random (or pseudorandom) number may be generated and that number of features may be removed. In some cases, a plurality of features may be aggregated into a single

aggregate feature. For example, for a case in which a plurality of repeating patterns are identified in the pressure or acoustic readings, the repeating patterns and/or synthetic data related to the repeating patterns may be aggregated. For example, the duration of all snore patterns may be aggregated into a mean, a standard deviation, a minimum, and/or a maximum duration.

(208) The classifier factory **2008** can process the features. For example, the remaining features may then be processed to rationalize their values so that each feature is handled with a weight that corresponds to how discriminant the feature is. If a feature is found to be highly discriminant so that is highly useful in classifying state, that feature may be given a larger weight than other features. If a second feature is found to be less discriminant than other features, that second feature can be given a lower weight.

(209) Once mapped into kernel space, the features can be standardized to center the data points at a predetermined mean and to scale the features to have unit standard deviation. This can allow the features to all have, for example, a mean value of 0 and a standard deviation of 1. The extracted features are then converted to a vector format using the same vector format as described above.

(210) In some cases, the remaining features can be processed by applying a kernel function to map the input data into a kernel space. A kernel space allows a high-dimensional space (e.g., the vector space populated with vectors of feature data) to be clustered such that different clusters can represent different states. The kernel function may be of any appropriate format, including linear, quadratic, polynomial, radial basis, multilayer perceptron, or custom.

(211) The classifier factory **2008** can train the classifiers. For example, a pattern recognizer algorithm can use the vectors of extracted features and their corresponding presence state labels as a dataset to train the classifiers with which new pressure readings can be classified. In some cases, this can include storing the classifiers with the training data for later use.

(212) The classifier factory **2008** can transmit the classifiers **2022** and the bed controller **2004** can receive the classifiers **2024**. For example, the classifier or classifiers created by the classifier factory **2008** can be transmitted to the bed controller **2004** and/or other bed controllers. In some cases, the classifiers can be transmitted on non-transitory computer readable mediums like a compact disk (CD), a Universal Serial Bus (USB) drive, or other device. The classifiers may be loaded onto the bed controller **2004** and/or other bed controllers as part of a software installation, as part of a software update, or as part of another process. In some cases, the classifier factory **2008** can transmit a message to the bed controller **2004** and/or other bed controllers, and the message can contain data defining one or more classifiers that use streams of pressure readings and/or streams of acoustic readings to classify the bed into one of a plurality of snore states. In some configurations, the classifier factory **2008** can transmit the classifiers at once, either in one message or a series of messages near each other in time. In some configurations, the classifier factory **2008** can send the classifiers separated in time. For example, the classifier factory **2008** may generate and transmit classifiers. Later, with more pressure sensor data available, the classifier factory **2008** may generate an updated classifier or a new classifier unlike one already created.

(213) The classifier may be defined in one or more data structures. For example, the classifier factory **2008** can record a classifier in an executable or interpretable files such as a software library, executable file, or object file. The classifier may be stored, used, or transmitted as a structured data object such as an extensible markup language (XML) document or a JavaScript object notation (JSON) object. In some examples, a classifier may be created in a binary or script format that the bed controller **2004** can run (e.g., execute or interpret). In some examples, a classifier may be created in a format that is not directly run, but in a format with data that allows the bed controller **2004** to construct the classifier according to the data.

(214) The bed controller **2004** can also use the stream of pressure readings and the stream of acoustic readings to classify snore **2026**. For example, the bed controller **2004** can run one or more classifiers using data from the stream of pressure readings and the stream of acoustic readings. The classifier can categorize this data into one of a plurality of states (e.g., no snore, light snore, etc.)

For example, the classifier may convert the data stream into a vector format described above. The classifier may then examine the vector to mathematically determine if the vector is more like training data labeled as one state or more like training data labeled as another state. Once this similarity is calculated, the categorizer can return a response indicating that state.

(215) The snore analyzer uses one or more machine learning classifiers to classify frames of pressure and/or acoustic readings into snore intensity levels. In one example, the classifier classifies epochs into two classes: without snore and with snore. In another example, the classifier classifies epochs into three classes: without snore, intermittent snore and consistent snore. In another example, the classifier classifies epochs into four classes: without snore, light snore, mild snore, and loud snore. In another example, the classifier classifies epochs into five classes: without snore, light snore, mild snore, moderate snore, and loud snore. In another example, the classifier classifies epochs into five classes: without snore, light snore, mild snore, moderate snore, moderate to loud snore, and loud snore. Such classification is in accordance with the clinical grade snore categorization.

(216) The bed controller **2004** can use more than one classifier. That is, the bed controller **2004** may have access to a plurality of classifiers that each function differently and/or use different training data to generate classifications. In such cases, classifier decisions can be treated as a vote and vote aggregation can be used to determine presence or absence of snore. If only one classifier is used, the vote of that classifier is the only vote and the vote is used as the snore state detection. If there are multiple classifiers, the different classifiers can produce conflicting votes, and the bed controller can select a vote-winning snore state.

(217) Various vote-counting schemes are possible. In some cases, the bed controller **1094** can count the votes for each presence state and the presence state with the most votes is the determined snore state state. In some cases, the bed controller **2004** can use other vote-counting schemes. For example, votes from different classifiers may be weighed based on the classifiers historical accuracy. In such a scheme, classifiers that have been historically shown to be more accurate can be given greater weight while classifiers with lesser historical accuracy can be given less weight. This accuracy may be tracked on a population level or on a particular user level.

(218) In some instances, votes may be cast by systems other than a machine-learning system, and those votes may be incorporated into the vote totals to impact the outcomes of the voting decision. For example, non-machine-learning pressure categorizing algorithms may cast votes based on, for example, comparisons with threshold values.

(219) In some instances, the system may have different operational modes, and may tally votes differently depending on the mode. For example, when a bed is in the process of adjusting or when the adjustable foundation is moving or a portion of the bed is elevated, different vote strategies may be used. In some modes, some classifiers may be given greater weight or lesser weight or no weight as compared to some other modes. This may be useful, for example, when a classifier is shown to be accurate in one mode (e.g. with the bed flat) versus another mode (e.g., with the head of the bed elevated by the foundation).

(220) In some cases, the bed controller **2004** can ensure that there is a user in bed and/or asleep before determining snore state. For example, using one or both of the pressure and/or acoustic readings, the bed controller can initially determine if the user is in the bed or if the bed is empty. If the user is determined to be in the bed, the bed controller **2004** can determine if the user is asleep in the bed. Depending on the configuration, once the presences and sleep of the user is confirmed, the bed controller **2004** can determine snore **2026**.

(221) In some cases, the bed controller **2004** can store a rolling buffer of the N most recent snore determinations and only acts on when some subset (e.g., M of the N) past snore determinations turns out positive. In some cases, a false positive could be considered very disadvantageous while a false negative is much less disadvantageous. Consider a user whose foundation articulates when they are not asleep and yet make a sound consistent with snoring versus a sleeping and snoring user

whose bed does not articulate. The awake user could be upset if the bed takes an action when not needed, while the user whose bed did not automatically actuate could be less upset.

(222) In order to bias toward inaction, the bed controller **2004** could act on a snore determination only when a sufficient aggregation of positive snore determinations is found. For example, confidence values of snore determination may be stored in the rolling buffer, and an aggregation of the confidence must reach a minimum threshold before actuation. This aggregation may be a simple mean or median, or may be a more complex aggregation (e.g., the square of the confidence) that penalizes low-confidence values and boosts high-confidence values.

(223) The bed controller **2004** selects a device operation **2028**. For example, responsive to a determination that the user is not snoring, or in response to a determination that the user is snoring, the bed controller **2004** can select a device operation to be processed. A ruleset stored in computer-readable storage, e.g. locally or on a remote machine, can identify actions that a user or another system have requested based on snore state. For example, a user can document through a graphical user interface that they wish a while-noise machine to engage when they snore. That is to say, white-noise should cover their snore so as not to annoy their partner, but only when they snore.

(224) Based on the ruleset and the snore determination, the bed controller **2004** can send messages to appropriate device controllers **2010** in order to engage the peripherals or bed-system elements called for. For example, based on the snore determination, the bed controller **2004** can send a message to the bed foundation to adjust the head or foot angle, a speaker to begin emitting white-noise, a message to a pump to adjust the firmness of the bed-system, a message to a foot-warming controller to engage foot heaters, and a message to a white-noise controller to adjust white-noise.

(225) A device controller **2010** can control a peripheral device **2030**. For example, a white-noise controller may initiate a script for the white-noise in the room around the bed to begin emitting white-noise.

(226) In general, the process **2000** can be organized into a training time and an operating time. The training time can include actions that are generally used to create snore classifiers, while the operating time can include actions that are generally used to determine a snore state with the classifiers. Depending on the configuration of the bed system, the actions of one or both of the times may be engaged or suspended. For example, when a user newly purchases a bed, the bed may have access to no pressure readings caused by the user on the bed, and no acoustic readings produced by the user when snoring. When the user begins using the bed for the first few nights, the bed system can collect those pressure and acoustic readings and supply them to the cloud reporting service **2006** once a critical mass of readings have been collected (e.g. a certain number of readings, a certain number of nights, a certain number of expected entry and exit events based on different tests or heuristics).

(227) The bed system may operate in the training time to update or expand the classifiers. The bed controller **2004** may continue actions of the training time after receipt of the classifiers. For example, the bed controller **2004** may transmit pressure and acoustic readings to the cloud reporting service **2006** on a regular basis, when computational resources are free, at user direction, etc. The classifier factory **2008** may generate and transmit new or updated classifiers, or may transmit messages indicating that one or more classifiers on the bed controller **2004** should be retired.

(228) The bed controller **2004** can receive rules and setting that define how the home-automation connected to the bed-system should operate. With the classifiers, the bed system can perform the actions of the operating time in order to cause the home-automation to perform according to the rules and settings.

(229) The bed system can use the same pressure readings from the pressure sensor and acoustic readings from the acoustic sensor **2002** to operate in the training time and the operating time concurrently. For example, the bed system can use the stream of pressure readings and acoustic readings to determine a snore state and control the environment based on snore categorizers that are

currently in use. In addition, the bed system can also use the same pressure/acoustic readings from the stream of pressure/acoustic readings in the training time actions to improve the categorizers. In this way, a single stream of pressure and acoustic readings may be used to both improve the function of the bed system and to drive automation events.

(230) In some cases, a generic set of classifiers may be used instead of, or in conjunction with, personalized classifier. For example, when a bed is newly purchased or reset to factory settings, the bed system may operate with generic or default snore classifiers that are created based on population-level, not individual, pressure and acoustic readings. That is, generic classifiers may be created for use in a bed system before the bed system has had an opportunity to learn about the particular pressure readings associated with a particular user. These generic classifiers may be generated using machine learning techniques, such as those described in this document, on population-level training data. These generic classifiers may additionally or alternatively be generated using non-machine learning techniques. For example, a classifier may include a threshold value (e.g., pressure, pressure change over time), and an acoustic measure over that threshold may be used to determine one snore state while acoustic readings under that threshold may be used to determine another snore state.

(231) While a particular number, order, and arrangement of elements are described here, other alternatives are possible. For example, while the generation of classifiers **2020** is described as being performed on a classifier factory **2008**, classifiers can be instead or additionally generated by the bed controller **2006**, possibly without reporting pressure and acoustic data to a cloud service.

(232) In some implementations, the bed system may accommodate two users. In such a case the process **2000** can be adapted in one or more way to accommodate two users. For example, for each user, the bed system may use two sets of classifiers (with or without some classifiers being simultaneously in both sets.) For example, one set may be used when the other side of the bed is occupied, and one set may be used when the other side of the bed is occupied. This may be useful, for example, when the presence or absence of the second user has an impact on pressure and acoustic readings on the first user's side of the bed.

(233) In some cases, the user may wish to control their home-automation environment contingent upon the snore-state of both users. For example, a rule may specify that the white-noise should be engaged only when one user is snoring in the bed, not when both users are snoring in the bed.

(234) This example is shown with a single bed controller **2004** providing pressures/acoustics **2016** and then later receiving classifiers **2024**. However, it will be understood that this system is applicable with many more beds and bed controllers. For example, pressures/acoustics may be received from many bed controllers (e.g., hundreds of thousands), and training data can be synthesized from these many beds, providing data about bed use by many users. The classifiers can then be distributed to some, none, or all of those beds that provided training data. For example, some beds may receive a software updated with new classifiers. Or as another example, the new classifiers may only be included on newly manufactured beds. Or as another example, each bed may receive classifiers that are particularly tailored to the users of that particular bed.

(235) FIG. **20**B is a swimlane diagram of an example process **2050** for training and using machine-learning classifiers to determine and classify snore in a bed. Unlike in the process **2000**, the process **2050** includes generating classifiers **2052** with the use of deep learning styles of machine learning. In the example shown, a deep neural network (DNN) that is a computer model (as opposed to an organic brain) is being described. However, as will be understood, other types of artificial neural networks and/or other types of deep learning (e.g., convolutional neural networks, recurrent neural network, long short-term memory-LSTM, etc.) may be used in the process **2050**. Further, it will be understood that other types of machine learning can be used in the processes **2000** and **2050** in order to generate classifiers (**1920** and **2052**.)

(236) In general, in the classifier generation **2052**, the classifier factory **2008** receives labeled training data from the cloud reporting service. However, unlike in the process **2000**, explicit

features are not created as a stand-alone process. Instead, the training of the classifiers works directly on the labeled training data, not features created from the labeled training data.

(237) The classifier factory **2008** generates classifiers from the pressure/acoustic readings **2052**. For example, the classifier factory **2008** may perform artificial neural network type machine learning to generate the classifiers. The classifier factory **2008** can train classifiers by first obtaining a large set of pre-classified reading variation patterns. For example, one bed or many beds may report reading data to a cloud reporting service **2006**. This reading data may be labeled, recorded, and stored for analysis in the creation of pressure classifiers to be used by the bed controller **2004** and/or other bed controllers.

(238) The tagged data is provided to one or more DNN trainers. The DNN trainers generate an initial DNN by arranging groups of artificial neurons into layers, and then connecting the output of one layer with the input of another layer. Generally speaking, these artificial neurons are computer-operable functions that take several inputs, perform their function, and produce output. Often these functions are defined based on a two-part mathematical function—first some linear combination is performed, then a non-linear function (also called activation function) is performed. However, as will be understood, any technologically appropriate function may be used.

(239) Neurons in one layer are all grouped, and the output of each neuron in the layer is provided as an input to neurons of the next layer. The number of connections between each layer is a function of the number of inputs of each neuron in the layer. For example, for a network in which each layer has ten neurons and each neuron has three inputs, the network would have thirty (i.e. ten time three) connections between one layer and the next. The number of layers, number of neurons per layer, and number of inputs per neuron are each parameters that the classifier factory **2008** can adjust in the process of initializing an DNN. For example, the network may have tens of layers, each layer having hundreds of neurons, each neuron having tens of inputs. More or less complexity (numbers of layers, neurons, and/or inputs) is possible.

(240) Each connection, from one neuron's output to the next neuron's input, is given a weight value. This weight value is initialized, for example to a random (or pseudorandom) number, or by selecting from a list of possible weights. When the output of one neuron is passed to the input of the next neuron, the value is adjusted by the weight. For example, the weight may be a number ranging from 0 to 1, and the value passed may be multiplied by the weight.

(241) With this initial DNN generated, it is capable of receiving the training data and operating on the training data. That is, the training data, stored on disk as an ordered sequence of binary data, can be provided as input into the head of the DNN (that is, the original input neuron for the first layer of the DNN.) As will be understood, providing input the first layer of the DNN causes the DNN to execute neurons of the layers of the DNN and produce an output in the form of a second ordered sequence of binary data. Here, the second ordered sequence of binary data may then be interpreted as a classification with a confidence score—that is, the output "tells" a reader what state the DNN has classified the data into (e.g., snore, no-snore, light-snore) along with a confidence value from 0 to 1.

(242) With the initial DNN generated, the classifier factory **2008** can refine the DNN to improve the classification results created by the DNN. In order to do so, the classifier factory **2008** can calculate a loss function and iteratively modify the DNN until the loss function for the DNN passes a test such as falling below a threshold or failing to improve over iterative refinements.

(243) A loss function can be selected that defines how well the DNN has classified a sample of tagged training data. In the example with a confidence of values 0 to 1, a loss function may be used that assigns a loss-value of 1 for an incorrect classification, and a loss value of 1-confidene for a correct classification. In this way, an incorrect classification provides a maximum value loss, while a correct classification provides a small loss when confidence is high.

(244) The classifier factory **2008** begins refining the DNN in order to reduce the loss value of the DNN. For example, the classifier factory **2008** can iteratively perform the steps of i) adjusting the

DNN, ii) providing training data to the DNN, and iii) calculate the loss value for the DNN.

(245) In order to adjust the DNN, the classifier factory can select one or more optimization algorithms. In general, many of these algorithms operate by adjusting the weights of connections between neuron outputs and neuron inputs. In doing so, they adjust the actual, weighted inputs that are used by neurons of the DNN, which produces a different results for the DNN.

(246) One of these algorithms is called a gradient descent algorithm. Gradient descent is a first-order iterative optimization algorithm for finding a minimum of the loss function. In each iteration of the gradient descent, the current weights of the connections between neurons are considered and modified in a way that reduces the loss value for the DNN by at least a small amount. To make these modifications, the classifier factory **2008** can determine the gradient of the loss function for the DNN with respect to all of the weights of the DNN. Using the gradient, new weights that would reduce the loss function by a learning rate are calculated. The gradient descent algorithm may also incorporate elements to avoid being trapped in local minima. Example elements include stochastic, batch, and mini-batch gradient descents.

(247) Once the DNN has been adjusted, the classifier factory **2008** can generate a classifier or classifiers from the DNN. For example, the classifier factory **2008** can identify neurons with all input weights of zero and remove them, as they do not contribute to the classifications performed with the DNN.

(248) FIG. **21** is a flowchart of an example process for training classifiers on pressure and/or acoustic signals. The process **2100** may be used, for example, as part of the process to generate classifiers **2020**.

(249) A feature set is determined **2102**. For example, raw pressure data can be separated into rolling windows of pressure data and raw acoustic data can be separated into rolling windows of acoustic data. In one example, each window represents 1 second of data with 100 readings each. In one example, pressure data uses a window of a first length and acoustic data uses a window of a second, different window. A vector can be created, with the first 100 fields of the vector being used to store each of the 100 readings in order. Additional fields in the vector are used to store data calculated from the 100 readings. For example, a field may be used to store the amplitude of the spectral peaks corresponding to the pressure/acoustic data stream. This value may be used as an approximate proxy of the snore presence, with a high amplitude indicating a snore presence state. Another field may be used to store the greatest difference between the values of the pressure/acoustic data stream, which may be indicative of the sound level in the readings. Furthermore, some features may be created without having a clear or logical description outside of their mathematical determination. For example, a count of readings with odd or even values may be stored in one field of the vector. These fields may be defined by human design, or may be generated programmatically.

(250) Training data is mapped to kernel space **2104**. For example, the vectors may be mapped into a high-dimensional space. This high dimensional space may have the same number of dimensions as the vectors have fields, or a subset of N fields of the vector may be used and the vector can be mapped to an N dimensional space. A kernel function may be found that is able to partition the space into partitions that each have one cluster of vectors in them. For example, in a 2D space, the vectors may map to one cluster around the coordinate [1,1] and another cluster around the coordinate [100, 100]. A decision boundary y=100−x would thus partition the space so that one cluster is generally above the line of the function and one cluster is generally below the line of the function.

(251) Finding the kernel function may be an automated process, or it may involve human interaction. For example, a Monte Carlo process may be used to search for a kernel function in an automated process. In a human-involved process, a computer may present a human with a series of 2 dimension views of the vector and the human can create 2 dimensional functions to partition the 2 dimensional space, and the computer system can compose a higher dimensional function from

these 2 dimensional functions.

(252) Classifiers are trained with mapped feature sets **2106**. With the feature sets now clustered, the training data can be trained in order to identify which clusters are indicative of a particular state. In some cases, this may be a supervised training. In supervised training, a human can identify clusters and provide labels for each cluster. For example, each time window may be tagged by a different process to identify the snore state when the pressure and acoustic readings for the time window are generated. In some cases, an explicit test may be run to generate the data. A recording of known snores may be sampled, and humans laying on beds while snoring may be measured. Logs from this test session may be annotated with the different snore states so that pressure data and acoustic data are appropriately labeled.

(253) In some cases, other state-identification processes may be used. For example, a threshold analysis may be used to produce reliable state annotations, but such an analysis may require significantly longer pressure and acoustic data (several minutes to hours). In such a case, a threshold analysis may be run over historic pressure and acoustic data to label the snore state of the pressure and acoustic data. Because this historic analysis can be run after-the-fact, it may be useful for this purpose even if it is not useful or not as useful for real-time snore-state determination for purposes such as home automation. That is to say, an analysis that takes 30 minutes of data to make a determination may be used here even if the analysis would produce an unacceptable 30-minute lag adjusting the bed firmness or elevating the head of the adjustable base.

(254) In some cases, the training may be unsupervised training. For example, the training may be performed only with analysis of the pressure or acoustic data and no outside intelligence provided. This may include unsupervised clustering of the data. Clustering techniques include, but are not limited to, k-means clustering, mixture modeling, hierarchical clustering, self-organizing mapping, and hidden Markov modelling. This may also or alternatively include unsupervised labeling of the data. For example, instead of training the data with a predetermined set of a predetermined number of states, instead the supervision may produce a number of clusters and use that number of clusters to determine the number of possible states. These states may be given a unique identifier that does not have any particular meaning (e.g., cluster1, cluster2, stateA, stateB). Then, once supervision is finished, a human can analyze the state information to determine meaningful labels for the states.

(255) FIG. **22** shows an example system **2200** for generating new classifiers. In this example, a set of beds **2202** generates pressure and acoustic readings that are used to generate classifiers that are installed on a set of beds **2208**. For example, the beds **2202** can report pressure readings and/or acoustic readings to a classifier server **2204**. The classifier server **2204** can generate classifiers and provide the classifiers to a software server **2206**. The software server **2206** can generate a software installation or update for the beds **2208**.

(256) This type of system may be used, for example, in preparing a new model of bed or operating system for market. In this case, the new bed or operating system may not yet have a large user-base of bed to provide a variety of training data. Instead, pressure and/or acoustic readings from existing beds may be used to create classifiers. These classifiers can be included in a software installation for the new beds, or in a software update. This installation can take the form of a networked installation or update, or may be provided with a physical data-storage device.

(257) FIG. **23** shows an example system **2300** for generating new classifiers. In this example, a set of beds **2302** generates pressure readings and/or acoustic readings that are used to generate classifiers that are installed on the set of beds **22302**. For example, the beds **2302** can report pressure and/or acoustic readings to a classifier server **2304**. The classifier server **2304** can generate classifiers, and provide the classifiers to a software server **2306**. The software server **2306** can generate a software installation or update for the beds **2302**.

(258) This type of system may be used, for example, to update the beds **2302**. For example, the system **2300** may periodically generate new classifiers that are designed to be of higher accuracy than existing classifiers on the beds **2302**. This accuracy increase may be a result of having more

data available for training, improved techniques for generating classifiers, or from increased personalization of data or classifiers. These classifiers can be included in a software installation for the beds, or in a software update. This installation can take the form of a networked installation or update, or may be provided with a physical data-storage device.

(259) This document has described examples in which a single user is sleeping on a single bed. However, it will be understood that this technology can also be used when two users share a bed. For example, a plurality (e.g., two for two sleepers) of acoustic sensing measurements can be extracted from both the acoustic signals and pressure variation signals. An independent measure of breathing from the pressure signals of the mattress system can used to synchronize the acoustics and pattern of snoring to the breathing cycle.

(260) One or more parameter values of the pressure variations from each side of the bed are cross referenced to one or more parameter values of the sound waves from each microphone. Measures of bed presence, phase synchronization, cross entropy, cross latency, cross amplitude modulation, and cross frequency modulation between the sound wave signal and the pressure signal from left and right side of the bed are computed to determine which side is snoring.

(261) FIG. **24** is a swimlane diagram of an example process **2400** for personalizing machine-learning classifiers based on a particular user's usage history. For clarity, the process **2400** is being described with reference to a particular set of components. However, other system or systems can be used to perform the same or a similar process.

(262) In the process **2400**, the classifier factory **20008** provides the bed controller **2004** with not only one or more classifiers to be used on data from the sensors **2002**, the classifier factory **2008** is also providing the bed controller **2004** with parameters to use in conjunction with the classifiers in order to help the bed function better for the particular user or users that use the bed **2004**. This process, sometimes called personalization, generally involves the use of a particular user or user's history in order to refine parameters of operation that have been generated to work well for entire populations. This may be beneficial, for example, for users such as those that have physiological factors that are outside of what is typical of a population (e.g., a very heavy sleep, very sensitive to stimulus while asleep) or for users who have different tastes (e.g., who prefer a very cold sleeping environment.)

(263) Classifiers are collected **2402**. For example, the classifier factory can collect one or more machine-learning or non-machine-learning classifiers for a particular bed, and collect these classifiers into a package for distribution to one or more beds. These classifiers can include, but are not limited to, classifiers that have been generated as part of the processes **2000** and/or **2500**. This may include as part of a new product launch, where the classifiers are to be placed on the bed as part of a manufacturing or installation process. This may include as part of a software update that is sent to a bed already in use.

(264) If personalized data is available **2404**, personalized data is accessed **2406**. For example, if the bed is owned or to be used by a known user, that user may have historic usage data or similar data available in a cloud service. In such cases, the classifier factory **2008** can access this personalized usage data. If personalized data is not available **2406**, population usage data accessed instead.

(265) With either the personalized or population usage data, the classifier factory can generate one or more parameters or use with the classifiers. It will be understood that the parameters made from population data may be generated once, cached, and distributed to many users.

(266) As stored on computer-readable memory or in transit, these parameters may take any technologically appropriate form, including as a vector or array of numeric values, a JSON object, an XML object, etc. Each parameter value can define, for the bed controller **2004**, some aspect of how the bed controller should operate.

(267) Some parameters can be classifier specific. For example, some classifiers may have different modes of operation, and the parameter may specify which mode of operation is to be used. Some parameters can be interaction specific. For example, some classifiers may specify how different

classifier outputs should be aggregated. In one example, a minimum-confidence-threshold defines a minimum confidence score to be used in the operation of the bed controller. Any classifier that produce a confidence score lower than the minimum-confidence-threshold can be ignored by the bed controller, and any that produce a confidence score equal to or above the minimum-confidence-threshold can be include a classification task. Some parameters can be algorithm specific. For example, a detection algorithm may have available one or more conditioning templates that can be applied to raw sensor data to condition the data to remove noise. A parameter may specify which template should be used, or if no template should be used.

(268) The classifiers and parameters are sent **2410** and received **2412**. For example, the classifier factory can transmit the classifiers and the parameters to the bed controller **2004**. This transmission may occur in a single message or in more than one message. The messages may be passed on physical media, via a data network, etc.

(269) The classifiers are operated with the parameters, and results are reported **2414**. For example, the bed controller **2004** can operate, using the parameters to set thresholds, aggregation types, modes of operations, etc. Historic usage data is analyzed **2416**. For example, as the bed controller operates, the bed controller can collect data about how the bed is used by the user or users. For example, in a sequence where the bed identifies bed presence, identifies snore and restless sleep, actuates a bed foundation, and then senses cessation of snore, these identifications and actuations can be reported to the classifier factory.

(270) Personalized data is updated **2418**. For example, periodically or in response to received updates, the classifier factory can generate or revise personalized parameters for the user of the bed. To do so, the classifier factory **2008** can examine the historical data to determine if a different set of parameters could be expected to produce outcomes better than those that actually occurred. For example, if a parameter was set to raise the user's head via the foundation, and if the classifier factory determines that raising the head and beginning a white-noise machine would be likely to produce better sleep in the user, a personalize parameter can be created that specifies both the foundation articulation and the engagement of a white-noise machine.

(271) As will be understood, the parameters may be personalized by the bed controller in addition to or in the alternative to being personalized by the cloud factory **2008**.

(272) The foregoing detailed description and some embodiments have been given for clarity of understanding only. No unnecessary limitations are to be understood therefrom. It will be apparent to those skilled in the art that many changes can be made in the embodiments described without departing from the scope of the invention. For example, a different order and type of operations may be used to generate classifiers. Additionally, a bed system may aggregate output from classifiers in different ways. Thus, the scope of the present invention should not be limited to the exact details and structures described herein, but rather by the structures described by the language of the claims, and the equivalents of those structures. Any feature or characteristic described with respect to any of the above embodiments can be incorporated individually or in combination with any other feature or characteristic, and are presented in the above order and combinations for clarity only.

Claims

1. A bed system comprising: a first bed comprising: a first mattress; a first pressure sensor in communication with the first mattress to sense pressure applied to the first mattress; a first acoustic sensor placed to sense acoustics from a user on the first mattress; a first controller in data communication with the first pressure sensor and in data communication with the first acoustic sensor, the first controller configured to: receive, from the first pressure sensor, first pressure readings indicative of the sensed pressure of the first mattress; receive, from the first acoustic sensor, first acoustic readings indicative of the sensed acoustic acoustics from the user; and

transmit the first pressure readings and the first acoustic readings to a remote server such that the remote server is able to generate one or more snore classifiers that, when run by a controller on incoming pressure readings and on incoming acoustic readings, provide a snore vote; a second bed comprising: a second mattress; a second pressure sensor in communication with the second mattress to sense pressure applied to the second mattress; a second acoustic sensor placed to sense acoustics from a user on the second mattress; and a second controller in data communication with the second pressure sensor and in data communication with the second acoustic sensor, the controller configured to: receive the one or more snore classifiers; run the received snore classifiers on second pressure readings and on second acoustic readings in order to collect one or more snore votes from the running snore classifiers; determine, from the one or more snore votes, a snore state of a user on the second bed; responsive to the determined snore state, operate the bed system according to the determined snore state.

2. The bed system of claim 1, wherein operating the bed system according to the determined snore state comprises one of the list comprising turning on a light, turning off a light, turning on a warming feature, changing firmness of the second mattress, begin emitting white-noise, and articulating a foundation of the bed system.

3. The bed system of claim 1, the bed system further comprising the remote server.

4. The bed system of claim 3, wherein the remote server is physically remote from the first controller and the second controller; and wherein the remote server is in data communication with the first controller and the second controller.

5. The bed system of claim 3, wherein the remote server is configured to: generate training data from the first pressure data and from the first acoustic data; generate, from the training data, the one or more snore classifiers; and send, to the second controller, the one or more snore classifiers.

6. The bed system of claim 5, wherein generating, from the training data, the one or more snore classifiers comprises: generating a feature set from the training data; mapping the training data to a kernel space; training a classifier with the feature set so that, based on the training data in kernel space, the classifier is able to classify unseen data.

7. The bed system of claim 6, wherein training a classifier comprises unsupervised training.

8. The bed system of claim 7, wherein the unsupervised training comprises at least one of the group comprising k-means clustering, mixture modeling, hierarchical clustering, self-organizing mapping, and hidden Markov modelling.

9. The bed system of claim 6, wherein training a classifier comprises supervised training.

10. The bed system of claim 9, wherein the supervised training comprises providing the remote server with a set of annotations for the training data.

11. The bed system of claim 10, wherein the annotations for the training data are provided by a human.

12. The bed system of claim 10, wherein the annotations for the training data are provided programmatically.

13. The bed system of claim 5, wherein generating the one or more snore classifiers comprises training a deep learning model on the training data.

14. The bed system of claim 13, wherein training the deep learning model on the training data comprises generating an initial neural network configured to receive pressure data and generate snore votes.

15. The bed system of claim 14, wherein the snore vote comprises a snore classification and a confidence value.

16. The bed system of claim 14, wherein generating the one or more snore classifiers comprises: determining a loss value for the initial neural network; and iteratively refining, beginning with the initial neural network, to a final neural network having a lower loss value than the initial neural network.

17. The bed system of claim 16, wherein the iterative refining is performed with a gradient descent

process until a lower loss value cannot be found with the gradient descent process.

18. The bed system of claim 1, wherein a particular snore classifier is used for multiple users in multiple beds.

19. The bed system of claim 1, wherein the snore classifiers are personalized for a single user such that the snore classifiers are generated from training data of the single user's use of the bed system and the snore classifiers are used to detect snore of the single user on the second bed.

20. A bed system comprising: a first bed comprising: a first inflatable chamber; a first pressure sensor in communication with the first inflatable chamber to sense pressure applied to the first inflatable chamber; a first acoustic sensor placed to sense acoustics from a user on the first inflatable chamber; a first controller in data communication with the first pressure sensor and in data communication with the first acoustic sensor, the first controller configured to: receive, from the first pressure sensor, first pressure readings indicative of the sensed pressure of the first inflatable chamber; receive, from the first acoustic sensor, first acoustic readings indicative of the sensed acoustic acoustics from the user; and transmit the first pressure readings and the first acoustic readings to a remote server such that the remote server is able to generate one or more snore classifiers that, when run by a controller on incoming pressure readings and on incoming acoustic readings, provide a snore vote; a second bed comprising: a second inflatable chamber; a second pressure sensor in communication with the second inflatable chamber to sense pressure applied to the second inflatable chamber; a second acoustic sensor placed to sense acoustics from a user on the second inflatable chamber; and a second controller in data communication with the second pressure sensor and in data communication with the second acoustic sensor, the controller configured to: receive the one or more snore classifiers; run the received snore classifiers on second pressure readings and on second acoustic readings in order to collect one or more snore votes from the running snore classifiers; determine, from the one or more snore votes, a snore state of a user on the second bed; responsive to the determined snore state, operate the bed system according to the determined snore state.