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(54) **PHYSIOLOGICAL AND BEHAVIORAL SENSORS AND METHODS**

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(52) **U.S. Cl.**
USPC **600/595**

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USPC 600/587, 595, 592
See application file for complete search history.

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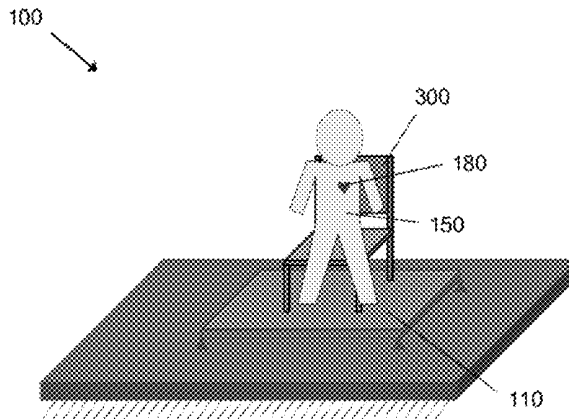
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(57) **ABSTRACT**

In various embodiments, a physiological or behavioral signal is derived from a vertical force resulting from the entire weight of a subject. A system for measuring physiological and behavioral signals in a human subject may include a measurement platform for bearing the subject, at least one force sensor for measuring vertical force imparted by an entire weight of the subject, and a signal processor for deriving at least one physiological or behavioral signal, such as a ballistocardiogram, from the measured force. The force sensor(s) may support the measurement platform and be disposed between the measurement platform and a support surface.

23 Claims, 6 Drawing Sheets



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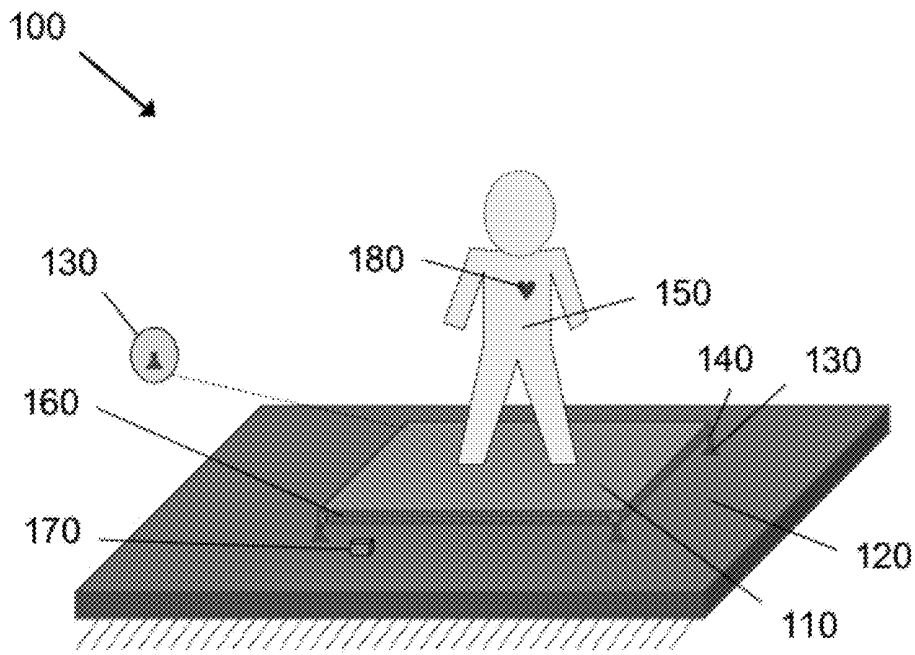


FIG. 1

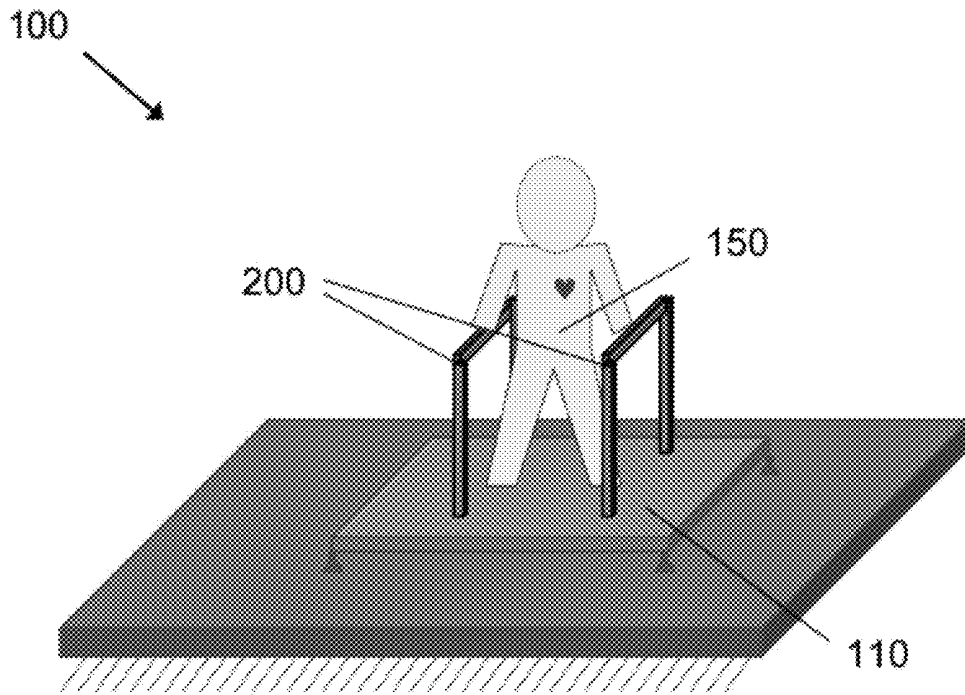


FIG. 2

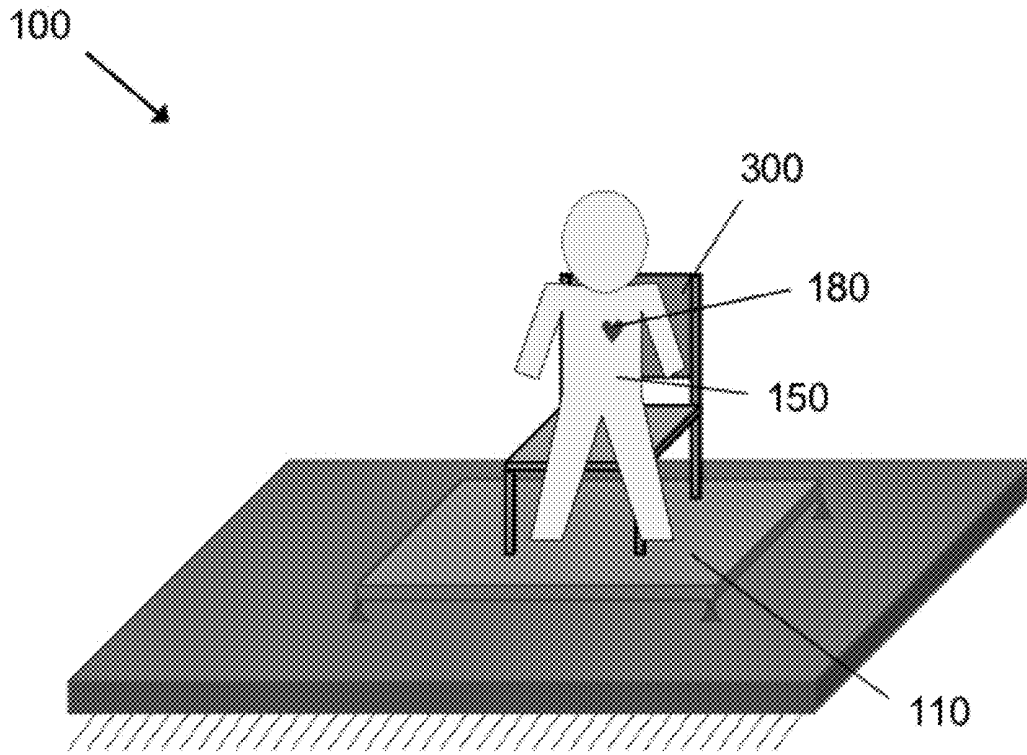


FIG. 3

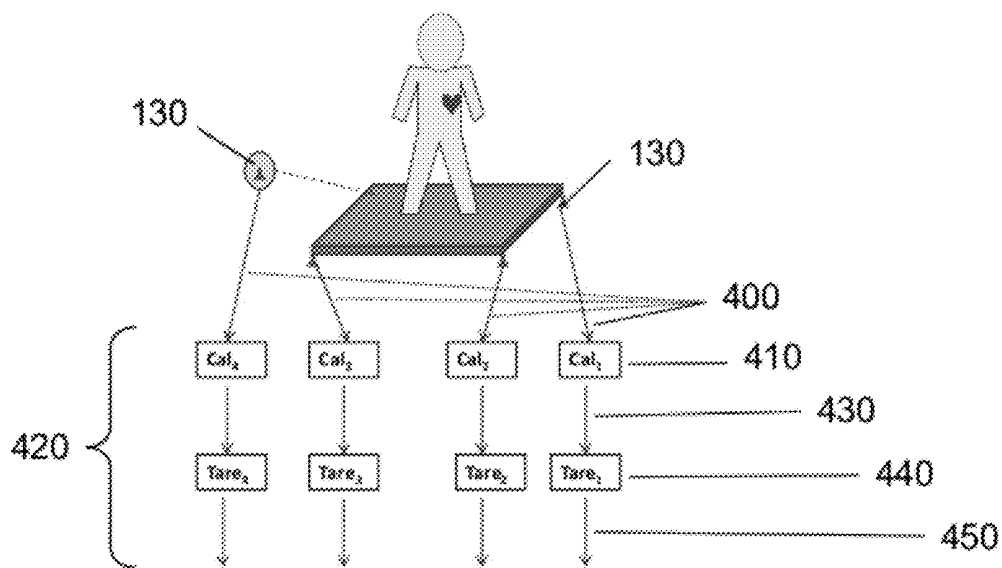


FIG. 4

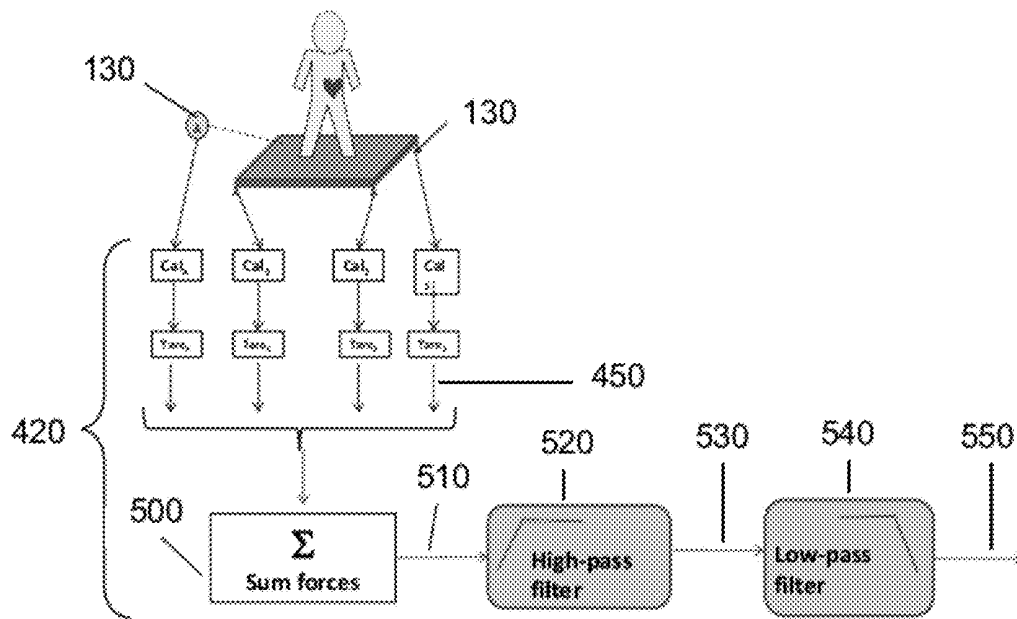


FIG. 5

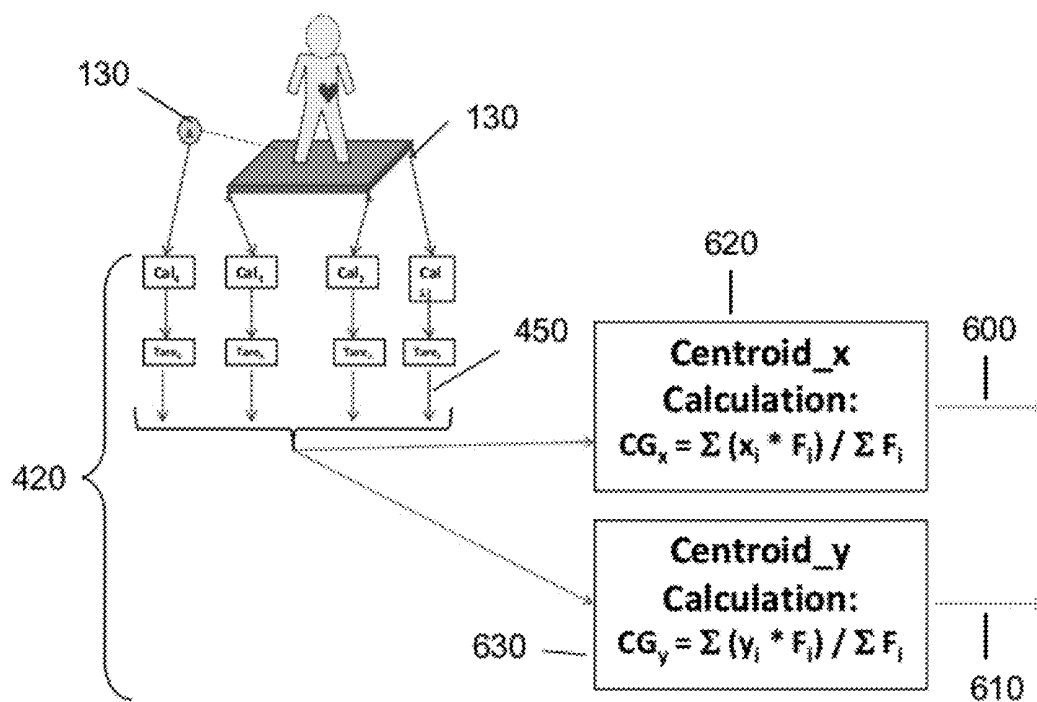


FIG. 6

PHYSIOLOGICAL AND BEHAVIORAL SENSORS AND METHODS

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

This invention was made with government support under HSHQDC-08-C-00047 and HSHQDC-10-C-00012 awarded by the U.S. Department of Homeland Security. The government has certain rights in the invention.

FIELD OF THE INVENTION

The technology disclosed herein relates generally to physiological and behavioral sensors, and in particular, to sensors for measuring, e.g., ballistocardiograms, that are unobtrusive and require no skin contact.

BACKGROUND

Various physiological (e.g., relating to heart function and/or respiration) and behavioral signals are frequently utilized to provide insight into the nervousness or truthfulness of the subject being monitored. For example, in polygraphy, a subject's fidgeting and/or muscle tensing activity is measured by means of an "activity pad" located on the seat the subject is sitting upon while being questioned by the polygrapher, thus monitoring any attempts by the subject to defeat the host of other sensors to which he/she is physically connected.

One useful physiological signal is the ballistocardiogram (BCG), which is a measure of the mechanical reaction of the human body to the pumping of blood therein. Specifically, the BCG measures mechanical activity of the heart and surrounding tissue, e.g., the impact of blood colliding with portions of the heart and blood vessels, recording the transient forces as minute changes in the weight of the subject. Unfortunately, the utility of BCG has remained quite limited in practice, as accurate measurements typically require the subject to be lying down and strapped to a complicated bed-like apparatus in order to isolate the BCG signal from gravitational effects. BCG measurement systems have even required the subject to hold his/her breath during data acquisition.

For a variety of tasks, including security screening, surveillance, and high-throughput medical screening, the ability to quickly and efficiently measure physiological signals such as the BCG, heart rate, respiration rate, and weight, as well as behavioral signals such as center-of-gravity ("CG") changes, for human subjects would prove quite useful. For example, changes in behavioral signals may indicate nervous jitter (or fidgeting) behavior. Similarly, a sudden decrease in such movements may indicate a behavioral response termed "hypervigilance" or the "freeze response." Furthermore, the ability to make such measurements unobtrusively would facilitate screening throughput (i.e., requiring no delays for subjects to undress or have electrodes placed on their skin) and reduce anxiety, embarrassment, or distraction due to awareness of the measurement system, any of which could influence the quality of the measured data.

SUMMARY

In accordance with various embodiments of the invention, one or more selected physiological and/or behavioral signals are unobtrusively measured. For purposes hereof, an "unobtrusive" measurement is one that does not utilize electrodes contacting the subject, and does not require exposure of any specific area of the subject's skin. The physiological signals

can include, e.g., the BCG, weight, and/or respiration rate, and the behavioral signals can include, e.g., measurement of the location of the subject's CG, including metrics based on the magnitude and/or direction of CG movements and their rates of change. The subject may be free-standing, standing with support from a railing or similar structure, or seated. Thus, the subject is generally vertically oriented, at least above the waist, enabling faster and less intrusive measurements to be made on the subject compared to systems requiring the subject to be horizontally oriented.

In various preferred embodiments, physiological signals such as the BCG are measured irrespective of (and/or without concomitant determination of) changes of a subject's CG, e.g., swaying or shifting in position. Thus, accurate measurement of, e.g., BCG may be insensitive to lateral weight shifts and accomplished even when the subject is not completely still.

Measurement systems in accordance with embodiments of the invention typically feature a rigid, substantially horizontal platform that supports the entire weight of the subject. Optionally, a chair, railing, or other support structure may be included, preferably resting entirely on the platform such that no force or weight transmitted thereto by the subject is unmeasured. One or more force sensors support the platform and measure the forces supporting (and/or imposed by) the platform, the subject, and any optional support structure. In various embodiments, a mechanical device such as a bearing is utilized between the platform and each force sensor in order to permit the transmission of forces to the force sensor but prohibit the transmission of torque thereto. One or more ancillary sensors may be utilized to measure (and facilitate compensation for) tilt and/or vibration of the platform during signal acquisition. Finally, a signal processor is utilized to derive the desired physiological and/or behavioral signals from the measured data.

In one aspect, embodiments of the invention feature a system for measuring physiological and behavioral signals in a human subject, which includes or consists essentially of one or more force sensors for measuring vertical force imparted by the entire weight of the subject, as well as a signal processor for deriving a physiological or behavioral signal from the measured force. The force sensor(s) may measure only substantially vertical force. The system may include a structure for supporting the posture of the subject that includes a substantially vertical thorax.

Embodiments of the invention may include one or more of the following, in any of a variety of combinations. The system may include a platform for bearing the subject. The system may include a bearing disposed between each force sensor and the platform, the bearing substantially transmitting vertical force but not torque from the platform to the force sensor. At least three non-collinear force sensors may be disposed proximate the periphery of the platform. A substantially stationary support and/or a chair may be disposed entirely on the platform such that its entire weight is supported by the platform.

The signal processor may include at least one calibration module for calibrating the vertical force, thereby substantially eliminating bias, slope error, hysteresis, and/or non-linearity from the vertical force. The signal processor may include at least one taring module for subtracting from the vertical force the weight contribution from the platform (and/or any support or chair thereon). The system may feature multiple force sensors, and the signal processor may include a summation module for summing vertical force measured by each of the force sensors. The signal processor may include a high-pass filtering module for removing a steady-state com-

ponent from a total vertical force measured by the force sensor(s). The high-pass filtering module may remove from the total vertical force a spectral component having a frequency below a cardiac frequency of interest (e.g., below approximately 0.5 Hz). The high-pass filtering module may include or consist essentially of a Bessel filter.

The signal processor may include a low-pass filtering module for removing, from the total vertical force measured by the force sensor(s), a spectral component having a frequency above a cardiac frequency of interest (e.g., above approximately 10 Hz, above approximately 30 Hz, or even above approximately 50 Hz). The physiological or behavioral signal may include or consist essentially of a ballistocardiogram. The signal processor may include a centroid-calculating module for determining a center of gravity of the subject based on the measured force. The physiological or behavioral signal may include or consist essentially of jitter and/or hypervigilance.

In another aspect, embodiments of the invention feature a method for measuring physiological and behavioral signals. The vertical force imparted by the entire weight of a human subject having a substantially vertical thorax is measured, and a physiological or behavioral signal is extracted from the measured vertical force. The physiological or behavioral signal may be extracted without sensors attached to the subject.

Embodiments of the invention may include one or more of the following, in any of a variety of combinations. The measured vertical force may be calibrated to substantially eliminate bias, slope error, hysteresis, and/or non-linearity. The subject may be supported by a platform, and the weight contribution of the platform may be subtracted from the vertical force. Extracting the physiological or behavioral signal may include removing from the measured vertical force at least one spectral component having a frequency above or below a cardiac frequency of interest (and/or a range of cardiac frequencies of interest). Extracting the physiological or behavioral signal may include removing from the measured vertical force a steady-state component corresponding to the entire weight of the subject. The physiological or behavioral signal may include or consist essentially of a ballistocardiogram. Extracting the physiological or behavioral signal may include determining a center of gravity of the subject. The physiological or behavioral signal may include or consist essentially of jitter and/or hypervigilance. The vertical force may be measured by multiple force sensors disposed proximate a periphery and supporting a platform, the platform supporting the subject. The subject may be interviewed and/or subjected to a cognitive stimulus while measuring the vertical force.

These and other objects, along with advantages and features of the invention, will become more apparent through reference to the following description, the accompanying drawings, and the claims. Furthermore, it is to be understood that the features of the various embodiments described herein are not mutually exclusive and can exist in various combinations and permutations. As used herein, the term "substantially" means $\pm 10\%$, and, in some embodiments, $\pm 5\%$. The term "consists essentially of" means excluding other materials that contribute to function, unless otherwise defined herein.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

In the following description, various embodiments of the present invention are described with reference to the following drawings, in which:

FIGS. 1-3 schematically depict perspective views of various measurement systems for measurement of physiological and/or behavioral signals from a human subject, in accordance with embodiments of the invention; and

FIGS. 4-6 schematically depict various portions of signal processors for deriving physiological and/or behavioral signals from data measured by a measurement system, as well as flowcharts of the flow of such data, in accordance with embodiments of the invention.

DETAILED DESCRIPTION

FIG. 1 depicts a measurement system **100** that includes a rigid, substantially horizontal platform **110**, which is supported from a stationary surface **120** by one or more force sensors (i.e., load cells) **130**. (Note that, as depicted, one of the force sensors **130** is obscured by platform **110** and is shown schematically offset from its true position.) In an embodiment, the force sensor **130** measures only compressive forces, although force sensors **130** that measure only tensile forces or that measure both tensile and compressive forces may be utilized. Examples of force sensors **130** that may be utilized in various embodiments of the invention include the LGP 382 Compression Only Ultra Precision Load Cell and the LGP 380 Ultra Precision Tension/Compression Load Cell, available from Cooper Instruments & Systems of Warrenton, Va., as well as the SMD 5400, available from Strain Measurement Devices of Wallingford, Conn.

A bearing **140** (or equivalent mechanical device) is preferably disposed between each load cell **130** and the platform **110** such that the forces applied to the platform **110** are transferred through the bearing **140** to load cell **130**. The bearing **140** may include or consist essentially of, e.g., a load button or a rod end (e.g., the LBC-012 Load Button or the REC-012M Rod End, available from Omega Engineering of Stamford, Conn.). The bearings **140** transmit vertical forces, but not torques (i.e., moment loads), from the platform **110** to the force sensors **130**. Thus, in preferred embodiments, force sensors **130** only measure vertical forces and are substantially insensitive to non-vertical forces or torques. In an embodiment, one or more of the force sensors **130** is a multi-axis load cell (which may also measure torque), from which only the measured vertical force is utilized. Typically a bearing **140** will not be utilized with such a multi-axis load cell; rather, a substantially rigid attachment will be utilized in order to transmit forces along the multiple axes. Force sensors **130** generally support platform **110** and are not embedded therein (thus, a subject being measured does not directly contact force sensors **130**).

The force sensors **130** are generally disposed at or near the periphery of platform **110** such that a load (e.g., a human subject) on the platform may be measured irrespective of its position on the platform **110**. Thus, in most embodiments, no other structure supports the platform **110**. In preferred embodiments, at least three non-collinear force sensors **130** are utilized to support platform **110**, thereby defining the measurement "plane," but four (as shown in FIG. 1) or even more force sensors **130** may be utilized (Herein, multiple sensors being non-collinear means that all of the sensors do not fall on the same line, while any fewer than the entire number of sensors may do so.) The use of four or more force sensors **130** enables the utilization of a rectangular measurement plane (i.e., with four force sensors **130** at the corners), which facilitates force measurement (all of the forces will be

of the same sign when subject **150** is within the rectangular area), thus simplifying the bearing design and enabling use of a wider choice of force sensors **130**.

In an embodiment, force sensors **130** may be mounted to platform **110** via a kinematic or quasi-kinematic mount to minimize internal forces or torques due to, e.g., differential thermal expansion of platform **110** or structural deflection of platform **110** or surface **120**. As known in the art, a kinematic mount is one in which all six degrees of freedom are singly constrained, thus assuring prevention of movement and non-introduction of stress into the system. Kinematic and quasi-kinematic mountings are further described in M. L. Culpepper, "Design of quasi-kinematic couplings," *Precision Engineering*, Vol. 28, pp. 338-357 (2004), the entire contents of which are incorporated by reference herein. Generally, quasi-kinematic mounts are preferred for systems having four or more force sensors **130**, while systems having three force sensors **130** may utilize kinematic or quasi-kinematic mounts.

During operation of measurement system **100**, a human subject **150** is positioned entirely on the platform **110**, thus applying his/her full weight to the platform **110** and thus, to force sensors **130**. Preferably the subject **150** is substantially vertical, at least above the waist, i.e., at least the heart, lungs, and thorax of subject **150** are substantially vertical. The subject **150** may be instructed to remain fairly still, i.e., to refrain from gross movements or shift locations of his/her feet. Force sensors **130** then measure at least the vertical forces at the location of each force sensor **130**, which are generally due to the weight of the subject **150**, the weight of platform **110** (and any additional structures thereon, as detailed below with respect to FIGS. 2 and 3), and any additional forces due to motion and/or vibration of subject **150**. Such additional forces include forces due to, e.g., cardiac activity, respiratory activity, and/or swaying or shifting of the center of gravity of subject **150**. As detailed below, the measured forces are processed and utilized to identify particular physiological and/or behavioral signals from subject **150**, e.g., signs of nervousness, anxiety, and/or deception. The subject **150** may be interviewed or subjected to other cognitive stimuli during the measurement of the forces described above. Such interviews or exposure to cognitive stimuli may be intermittent, i.e., may involve multiple spaced-apart questions or exposures such that a baseline reading may be established prior to and/or during the interview or exposure.

The weight and weight distribution of platform **110** are typically constant and known. One or more ancillary sensors may optionally be attached either to the platform itself, or to the supporting surface in the proximity of the platform. For example, one or more side-contact sensors **160** may be placed on one or more of the sides of the platform **110** (or elsewhere) to detect whether some other structure or person is contacting the platform **110**, thus degrading the quality and/or accuracy of the signals derived by system **100**. One or more tilt or vibration sensors **170** may be placed either on the platform **110** or on the supporting structure **120** near the platform **110**, in order to measure tilt or vibrations that may require filtering (or other compensation) to improve the accuracy of the measured signals.

Since the platform **110** is completely supported by the force sensors **130**, all of the vertical forces are measurable by the sensors **130**; that is, there are no alternative load paths by which any vertical force from the platform **110** or the subject **150** can escape measurement. Consequently, forces due to the entire weight of subject **150** are captured, and there are no portions of platform **110** where portions of the subject's weight might go unmeasured. The individual forces mea-

sured by the force sensors **130** may vary depending on the position of subject **150** on the platform **110**. For example, if the subject **150** sways while standing on the platform **110**, the individual forces will generally vary as functions of time and position. However, the total of the vertical forces measured by the force sensors **130** will generally be independent of the subject's location or horizontal motions. The total of the vertical forces is almost constant—but not exactly constant—due to, e.g., the forces resulting from the action of the heart **180** of the subject **150**. Specifically, the total force will typically vary due to the inertial reaction resulting from the pulsating nature of the heartbeat and the elastic nature of the heart and the aortal tissue.

FIG. 2 depicts the measurement system **100** incorporating a support structure **200** (as described above). Thus, during signal acquisition, the subject **150** may not be entirely free-standing. Rather, the subject **150** may steady himself/herself by touching or grasping the support structure **200** (here depicted as two railings) that is located on (and thus supported by) the platform **110**. Since the support structure **200** is entirely supported by the platform **110**, the entire weight of subject **150** is transmitted to the platform (a portion of the weight through support structure **200**), thus enabling the force sensors **130** to measure the entire weight and weight distribution of the subject **150**. (The constant additional weight of the support structure **200**, which is known, may be compensated for as detailed below.) Support structure **200** is preferably mounted on platform **110** such that it is substantially stationary in a fixed location during signal acquisition from a subject **150**. Herein, while a substantially stationary support has a fixed location, it may not be entirely incapable of motion. For example, a support structure **200** may be designed to "wobble" or tilt slightly, thus encouraging the subject **150** not to rest his/her entire weight thereon.

Referring now to FIG. 3, in various embodiments, measurement system **100** includes a chair **300** that is entirely supported by the platform **110**. As shown, the subject **150** may be seated in chair **300** during the measurement procedure. The thorax of subject **150** generally remains substantially vertical, such that the heart **180** has substantially the same orientation as in FIGS. 1 and 2. Chair **300** may incorporate multiple legs (as shown in FIG. 3), or may have a single substantially flat base. Chair **300** may not necessarily have a back support, but may rather be a stool or other structure for supporting the entire weight of a seated subject **150**. Since, like support structure **200** in FIG. 2, the chair **300** is entirely supported by the platform **110**, the entire weight of subject **150** is transmitted, directly or indirectly, to the platform **110**. Thus, as detailed above, the force sensors **130** measure the entire weight and weight distribution upon the platform **110** of subject **150**. The constant additional weight of the chair (and its distribution among the force sensors **130**), which is known, may be compensated for as detailed below. Chair **300** is preferably mounted on platform **110** such that it is stationary in a fixed location during signal acquisition from a subject **150**. In some embodiments, chair **300** replaces, rather than supplements, platform **110**. Specifically, force sensor(s) **130** directly support the entire weight of chair **300** (and subject **150** sitting thereon) without platform **110** therebetween.

FIGS. 4-6 schematically depict a representative manipulation and processing of the measured signals from the force sensors **130** in order to obtain the desired physiological and/or behavioral signals. In FIG. 4, the raw signals **400** from the force sensors **130** are processed by one or more calibration modules **410** of a signal processor **420**. Signal processor **420** (and the modules therein) is in electronic communication with force sensors **130**, and may include or consist essentially

of, e.g., dedicated analog and/or digital circuitry. (Herein, the term “electronic communication” includes having electrical connections through intervening electronic components, such as computers, as well as wired and wireless, or even optical, connections.) In preferred embodiments, an individual calibration module **410** is associated with and tailored to each force sensor **130**. For example, a force sensor **130** may be subjected to known, well-characterized loads, and its output mapped as a function of the known loads. Calibration module **410** incorporates the output map to correct for any peculiarities of the particular force sensor **130**. In some embodiments, a single calibration module **410** is utilized for multiple, or even all, of the force sensors **130**. Outputs **430** from the calibration modules are the calibrated vertical forces from the force sensors **130**, i.e., force quantities substantially free of bias, slope error, hysteresis, and/or non-linearity. In various embodiments, the calibration by calibration module(s) **410** enables the identification and separation of small physiological signals (e.g., the BCG) from other substantially larger variations in the measured forces due to, e.g., sway-induced changes in the location of the center of gravity of subject **150** or variations in the measurement behavior of individual force sensors **130**.

Outputs **430** are preferably input into one or more taring modules **440** that subtract therefrom the known weight contributions from the (empty) platform **110** and any fixtures thereon (such as support structure **200** and/or chair **300**). The outputs **450** from the taring modules **440** are a set of vertical force signals (also depicted in FIG. 6 as F_i), that are due solely to the subject **150** and the subject’s motions and vibrations (both external from, e.g., swaying, and internal from, e.g., the heartbeat). In an embodiment, the outputs **430** are processed as detailed below without intermediate taring by taring modules **440**.

In FIG. 5, the outputs **450**, are further processed by signal processor **420** to produce a physiological or behavioral signal, e.g., the BCG signal. The outputs **450** are summed together by a summation module **500**, thus producing a total vertical force signal **510** (also depicted in FIG. 6 as ΣF_i). The total vertical force signal **510** is typically not constant as a function of time, but varies slightly due to motions or vibrations (internal or external) of subject **150**. Among these vibrations is the BCG, which is determined as detailed below.

The total vertical force signal **510** is filtered by a high-pass filtering module **520** that removes both the steady-state (i.e., direct-current or DC) component (i.e., due to the weight of subject **150**) and the spectral components that are below the cardiac frequencies of interest, thereby producing the output **530**. In various embodiments, the cardiac frequencies of interest range from approximately 0.5 Hz to approximately 50 Hz, and thus include higher frequencies indicative of harmonics and/or overtones of a human heartbeat. The upper range of the cardiac frequencies of interest may, in other embodiments, depend on noise in the measurement system and/or measurements, and may only range to approximately 30 Hz, or even only to approximately 10 Hz.

High-pass filtering module **520** may be implemented in, e.g., analog and/or digital circuitry. High-pass filtering module **520** may utilize a single-pole high-pass filter; however, in preferred embodiments, high-pass filtering module **520** utilizes one or more Bessel filters (or similar linear filters with substantially constant group delay across the passband).

The output **530** is filtered by a low-pass filtering module **540** to remove high-frequency components substantially above the spectral content of, and unrelated to, the action of the heart **180** of subject **150** (such as, e.g., vibrations from nearby ventilation or air-conditioning systems). While herein

high-pass filtering module **520** and low-pass filtering module **540** have been described as separate and discrete, in practice they may be combined into a single band-pass filtering module within signal processor **420**. The filtering produces a BCG signal **550** that has been band-pass filtered to preferentially pass the spectral components in the cardiac band of interest. In an exemplary embodiment, the BCG signal **550** is a force-based BCG and is an extremely small fraction (e.g., less than 1%, or between approximately 0.02% and approximately 0.3%) of the total weight of subject **150**.

Once obtained, BCG signal **550** may be utilized in, e.g., detection of nervousness, anxiety, and/or deception in security screening or surveillance, or even detection of proper and improper cardiac function in medical screening. In many embodiments, BCG signal **550** is determined without reference to, concomitant measurement of, or dependence on any sway of subject **150** (i.e., movements of the subject’s center of gravity, as described below). Thus, for example, the BCG signal **550** of a subject **150** attempting to mask signs of anxiety by intentional sway may still be obtained and utilized as a valuable measure of nervousness or deception. And, as described above, BCG signal **550** is obtained without any conventional BCG apparatus or the requirement that subject **150** be oriented horizontally.

In additional embodiments, BCG signal **550** may be analyzed via, e.g., Fourier-transform, time-domain, and/or wavelet-based techniques to produce an average heart rate over a particular time interval or to measure the inter-beat interval (IBI). BCG signal **550** may be utilized to measure the degree of respiratory-sinus arrhythmia (RSA), i.e., variations in heart rate with respiration. Changes in IBI and/or RSA have been correlated with levels of elevated stress and/or deception (see e.g., B. Verschuere et al., “Autonomic and behavioral responding to concealed information: Differentiating orienting and defensive responses,” *Psychophysiology*, vol. 41, pp. 461-466 (2004), and *The Polygraph and Lie Detection*, National Research Council (2003), the entire contents of both of which are incorporated by reference herein).

System **100** and signal processor **420** may also be utilized to measure sway (in any direction within the plane of surface **110**) of the subject **150**. In FIG. 6, the outputs **450** are processed, together with the locations of the force sensors **130**, to produce two signals **600**, **610** indicative of the location of the subject’s center of gravity in the horizontal plane, i.e., the x- and y-components of the center of gravity of subject **150** (also respectively depicted in FIG. 6 as CG_x and CG_y). The outputs **450** are processed by two centroid-calculating modules **620**, **630**, together with the locations of the load cells **130**, to produce signals **600**, **610**. In various embodiments, centroid-calculating modules **620**, **630** apply the centroid formula (i.e., the ratio of the position-weighted sum of the outputs **450** over the un-weighted sum), together with the respective location data (x_i or y_i respectively, in FIG. 6) of the force sensors **130** to produce signals **600**, **610**. Once obtained, signals **600**, **610** may be utilized in, e.g., detection of nervousness, anxiety, and/or deception in security screening or surveillance, as the relative amount of change in center of gravity is generally related to emotional states such as anxiety or fear. Analysis of signals **600**, **610** in the time and frequency domains may enable detection of a “freeze” response, in which a subject becomes more still in response to fear-provoking stimuli. Specifically, a subject will generally shift its center of gravity less during fear-provoking stimuli than during neutral stimuli. In various embodiments, signals **600**, **610** may be utilized to detect the degree of nervous jitter or hypervigilance in subject **150**.

Although the modules in signal processor 420 have been described separately, this is for clarity of presentation only. As long as signal processor 420 and system 100 perform all necessary functions, it is immaterial how they are distributed therewithin and the programming or hardware architecture thereof. Furthermore, the above-described implementation is exemplary only. Other hardware approaches are possible, e.g., the various modules of embodiments of the invention may be implemented on a general-purpose computer programmed with appropriate software instructions implementing the functions described below, or as hardware circuits (e.g., as an application-specific integrated circuit, or ASIC), analog and/or hybrid analog/digital implementations, or as mixed hardware-software combinations. In various embodiments, system 100 and/or signal processor 420 may include one or more displays for depicting the measured and/or calculated signals, and/or for displaying alerts to users based upon the calculated signals (e.g., if anxiety or deception is detected in a subject). A mass storage device for storage of measured and derived signals may be included, as may additional analysis modules for computation of other physiological or behavioral signals based on the measured data. System 100 may also include, e.g., a keyboard and/or a position-sensing device (e.g., a mouse) to facilitate user interaction therewith.

The terms and expressions employed herein are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

What is claimed is:

1. A system for measuring physiological and behavioral signals in a human subject, the system comprising:
 - a measurement platform for bearing the subject;
 - at least one of a substantially stationary support or a chair disposed entirely on the platform such that an entire weight of the support or chair is supported by the platform;
 - at least one force sensor for measuring vertical force imparted by an entire weight of the subject, the at least one force sensor supporting the measurement platform and disposed between the measurement platform and a support surface; and
 - a signal processor for deriving at least one physiological or behavioral signal, including a ballistocardiogram, from the measured force.
2. The system of claim 1, wherein the at least one force sensor measures only substantially vertical force.
3. The system of claim 1, further comprising a bearing disposed between each said at least one force sensor and the platform, the bearing substantially transmitting vertical force but not torque from the platform to the force sensor.
4. The system of claim 1, wherein the at least one force sensor comprises at least three non-collinear force sensors disposed proximate a periphery of the platform.
5. The system of claim 1, wherein the signal processor comprises at least one calibration module for calibrating the vertical force, thereby substantially eliminating at least one of bias, slope error, hysteresis, or non-linearity from the vertical force.
6. The system of claim 1, wherein the signal processor comprises at least one taring module for subtracting from the vertical force a weight contribution from the platform.
7. The system of claim 1, wherein (i) the at least one force sensor comprises a plurality of force sensors, and (ii) the

signal processor comprises a summation module for summing vertical force measured by each of the force sensors.

8. The system of claim 1, wherein the signal processor comprises a high-pass filtering module for removing a steady-state component from a total vertical force measured by the at least one force sensor.

9. The system of claim 8, wherein the high-pass filtering module removes from the total vertical force a spectral component having a frequency below a cardiac frequency of interest.

10. The system of claim 8, wherein the high-pass filtering module comprises a Bessel filter.

11. The system of claim 1, wherein the signal processor comprises a low-pass filtering module for removing, from a total vertical force measured by the at least one force sensor, a spectral component having a frequency above a cardiac frequency of interest.

12. The system of claim 1, wherein the signal processor comprises a centroid-calculating module for determining a center of gravity of the subject based on the measured force.

13. The system of claim 12, wherein at least one derived physiological or behavioral signal comprises at least one of jitter or hypervigilance.

14. A method for measuring physiological and behavioral signals, the method comprising:

- measuring a vertical force imparted by an entire weight of a human subject having a substantially vertical thorax and disposed upon a measurement platform, the vertical force measured by at least one force sensor that supports the measurement platform and is disposed between the measurement platform and a support surface, at least one of a substantially stationary support or a chair being disposed entirely on the platform such that an entire weight of the support or chair is supported by the platform; and
- extracting at least one physiological or behavioral signal, including a ballistocardiogram, from the measured vertical force.

15. The method of claim 14, wherein the at least one physiological or behavioral signal is extracted without sensors attached to the subject.

16. The method of claim 14, further comprising calibrating the measured vertical force to substantially eliminate at least one of bias, slope error, hysteresis, or non-linearity therefrom.

17. The method of claim 14, further comprising subtracting from the vertical force a weight contribution of the platform.

18. The method of claim 14, wherein extracting the at least one physiological or behavioral signal comprises removing from the measured vertical force at least one spectral component having a frequency above or below a cardiac frequency of interest.

19. The method of claim 14, wherein extracting the at least one physiological or behavioral signal comprises removing from the measured vertical force a steady-state component corresponding to the entire weight of the subject.

20. The method of claim 14, wherein extracting the at least one physiological or behavioral signal comprises determining a center of gravity of the subject.

21. The method of claim 14, wherein at least one extracted physiological or behavioral signal comprises at least one of jitter or hypervigilance.

22. The method of claim 14, wherein the vertical force is measured by a plurality of force sensors disposed proximate a periphery of the platform.

23. The method of claim 14, further comprising at least one of interviewing the subject or subjecting the subject to a cognitive stimulus while measuring the vertical force.

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摘要(译)

在各种实施例中，生理或行为信号源自受试者的整个体重产生的垂直力。用于测量人类受试者中的生理和行为信号的系统可以包括用于承载受试者的测量平台，用于测量由受试者的整个重量施加的垂直力的至少一个力传感器，以及用于导出至少一个生理信号的信号处理器或来自测量力的行为信号，例如心冲击描记图。力传感器可以支撑测量平台并且设置在测量平台和支撑表面之间。

