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Systems and methods related to monitoring, communicating, and/or analyzing bodily movements

Abstract

Systems and methods according to the present invention include a garment outfitted with a primary circuit board and peripheral sensors to collect data on limb movements and orientation and transmit them to a related mobile application. The application involves an orientation process comprising a photo of the user and a user interface-driven marker system. The application also involves a calibration system involving quaternion calculations. Once a user has completed orientation and calibration processes, the application can receive the data, calculate the sensors' positions, and display them on a 2-dimensional model in real-time.

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References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
5014719	12/1990	McLeod	N/A	N/A
7292151	12/2006	Ferguson et al.	N/A	N/A
7825815	12/2009	Shears et al.	N/A	N/A
8120498	12/2011	Dishongh et al.	N/A	N/A
8818751	12/2013	Van Acht et al.	N/A	N/A
8988240	12/2014	Burton et al.	N/A	N/A
9770658	12/2016	Bentley	N/A	A63F 13/428
9782104	12/2016	MacEachern et al.	N/A	N/A
9997082	12/2017	Kaleal	N/A	G06T 19/00
10105108	12/2017	Taptelis	N/A	A61B 5/747
10314536	12/2018	Hansen et al.	N/A	N/A
10327670	12/2018	Etemad et al.	N/A	N/A
10357688	12/2018	Wiebe et al.	N/A	N/A
10575760	12/2019	Houmanfar et al.	N/A	N/A
10675507	12/2019	Cusey et al.	N/A	N/A
10709374	12/2019	Aginsky et al.	N/A	N/A
10726738	12/2019	Li et al.	N/A	N/A
10918332	12/2020	Belson et al.	N/A	N/A
11508474	12/2021	Hresko	N/A	G16H 40/60
2007/0252708	12/2006	Fujisawa et al.	N/A	N/A
2008/0306412	12/2007	Nieminen et al.	N/A	N/A
2010/0176952	12/2009	Bajcsy et al.	N/A	N/A
2013/0203475	12/2012	Kil et al.	N/A	N/A
2016/0198995	12/2015	Yeung et al.	N/A	N/A
2016/0232807	12/2015	Ghaffari et al.	N/A	N/A
2017/0069191	12/2016	Erkkila	N/A	N/A
2018/0092572	12/2017	Sanchez et al.	N/A	N/A
2018/0133551	12/2017	Chang et al.	N/A	N/A
2018/0140902	12/2017	Wiebe et al.	N/A	N/A

2018/0192918	12/2017	Ives	N/A	N/A
2018/0192922	12/2017	Boucher et al.	N/A	N/A
2019/0015046	12/2018	Whitehouse et al.	N/A	N/A
2019/0038187	12/2018	Letella, Jr.	N/A	N/A
2019/0046107	12/2018	Jang et al.	N/A	N/A
2019/0046839	12/2018	Jang et al.	N/A	N/A
2019/0076699	12/2018	Wiebe et al.	N/A	N/A
2019/0154723	12/2018	Kacyvenski et al.	N/A	N/A
2019/0282856	12/2018	Wiebe et al.	N/A	N/A
2019/0283247	12/2018	Chang	N/A	A61B 5/1121
2019/0306408	12/2018	Hofer	N/A	H04N 23/90
2019/0307404	12/2018	Wiebe et al.	N/A	N/A
2019/0343459	12/2018	Korzinov et al.	N/A	N/A
2019/0350496	12/2018	Gong et al.	N/A	N/A
2019/0374161	12/2018	Ly et al.	N/A	N/A
2020/0029882	12/2019	Gong et al.	N/A	N/A
2020/0054249	12/2019	Fukushi et al.	N/A	N/A
2020/0146594	12/2019	Gong et al.	N/A	N/A
2020/0206568	12/2019	Hong et al.	N/A	N/A
2020/0223071	12/2019	Mahoney et al.	N/A	N/A
2020/0238149	12/2019	Paulk, Jr. et al.	N/A	N/A
2020/0281508	12/2019	Ren et al.	N/A	N/A
2020/0281509	12/2019	Ren et al.	N/A	N/A
2020/0359944	12/2019	Raisoni	N/A	A61B 5/742
2020/0401224	12/2019	Cotton	N/A	N/A
2021/0030357	12/2020	Wiedenhoefer et al.	N/A	N/A
2021/0038167	12/2020	Martineau	N/A	N/A
2021/0195732	12/2020	Longinotti-Buitoni	N/A	H05K 3/361
2022/0054041	12/2021	Menon	N/A	G06N 20/00
2022/0126198	12/2021	Toro	N/A	A63F 13/428

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Background/Summary

RELATED APPLICATIONS (1) This application claims priority to and the benefit of U.S. provisional patent application No. 63/287,171, filed 8 Dec. 2022, and entitled "Systems and Methods Related to Monitoring, Communicating, and/or Analyzing Bodily Movements," which is incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION
(1) The present invention relates generally to animal body (e.g., human body) positioning, and more specifically to systems and methods for sensing, recording, and displaying substantially real-time bodily movements.
(2) Prior known techniques for analyzing bodily movements suffer from previously unrecognized deficiencies. One drawback to prior technologies is a requirement for multiple people to be involved in a process of observing and analyzing bodily movements, and not just the person whose

movements are being observed. Accordingly, the art of bodily movement analysis may benefit from a technology that may be used by a single person.

(3) Another drawback to prior techniques is that analysis (e.g., comparison and contrasting between former and latter movements) does not generally happen substantially contemporaneously (or real-time) in connection with the movements being performed. For instance, prior methods may have involved human visual observation of a former bodily movement followed by contemporaneous or delayed notetaking or diagramming. Then, a latter bodily movement would again be visually observed and further notes and diagrams would be generated. Thereafter, the respective notes and diagrams may be compared and contrasted. This time delay can, in turn, result in delay of feedback provided to the person being monitored. While advancements have been made to record bodily movements, such as photographic and video recording, there remain delays in analysis and feedback. Accordingly, the art of bodily movement analysis may benefit from a technology that may assist in data gathering substantially contemporaneously during (and/or substantially contemporaneously with an observation of) a latter bodily positioning or movement to provide substantially real-time feedback to a user.

(4) Still another disadvantage to prior bodily movement technology and techniques is that some of them are not automatic, and therefore rely on human subjectivity or interpretation. Accordingly, the art of bodily movement analysis may benefit from a technology that is capable of automatic movement data capture and analysis without the need for human subjectivity.

(5) It thus may be desirable to provide technology to observe, communicate and/or analyze bodily movements for medical reasons (e.g., to detect changes in range of motion), to monitor and report therapeutic compliance, to analyze athletic performance, and/or to generate motion vectors related to natural human bodily movements for use in other fields, such as human factor engineering, animation, etc.

SUMMARY OF THE INVENTION

(6) Embodiments of apparatus and methods according to the present invention relate generally to systems and methods utilizing sensor devices in conjunction with a mobile computing device to display at least substantially real-time representations of animal body positioning.

(7) Generally, a system according to the present invention includes clothing garment-embedded motion sensing, transmission to a handheld electronic device, and generated display thereof.

(8) Generally, the system includes three main subsystems: a primary circuit board, one or more peripheral sensors affixed to a garment, and a mobile device (e.g., Android or iOS) with an accompanying mobile application. The primary circuit board contains a Bluetooth enabled microcontroller and battery, and is used to communicate with both the mobile device and the peripheral sensors. The peripheral sensor circuit boards are sewn to the garment with preferably conductive thread, and this thread is used to connect to the primary circuit board. These peripheral sensors help determine the orientation of the body segments they are attached to, such as the calves, thighs, and torso. The mobile application accepts peripheral sensor data transmitted by the microcontroller, stores it in a local database (e.g., SQLite), and displays it in real-time for the end user to view.

(9) In use, a garment is augmented with a number of peripheral inertial measurement units (IMUs) to enable recording of body segment position. In the case of pants, for example, an IMU is sewn to each lower leg portion (e.g., for lateral positioning next to the triceps surae (calf muscle)) and each upper leg portion (e.g., for lateral positioning next to the vastus lateralis (outer quadricep) and/or biceps femoris (outer hamstring)). Two IMUs are supported (e.g., by a garment) ex vivo adjacent to the erector spinae (i.e., the lower back) to establish torso angle and lumbar rounding.

(10) A calibration procedure initializes body segment orientation for an individual standing straight, and deviation from each calibration angle is used to determine rotations of each body segment.

(11) A mobile software application (e.g., for a smartphone or other mobile electronic device) has been developed to accompany the augmented garment. The app uses a framework to allow the

application to be run on iOS and Android mobile devices using only one codebase (e.g. React Native). It facilitates user interaction with the device and its data in two ways: at least substantially real-time display of limb orientation and record viewing. The real-time display updates limb orientation on a generated model of the human body each time a Bluetooth packet is received by the handheld device from the augmented garment primary circuit board. A complete refresh of the generated model on the mobile device occurs preferably between 20 and 60 times per second, with about 30 times per second providing sufficient substantially real-time viewing. The record viewer allows the user to review previously made recordings, and will be used to report on form during workouts when more functionality has been developed.

(12) An embodiment of a system for monitoring, communicating, and analyzing bodily movements according to the present invention includes a garment configured to be worn on a human body, a circuit board supported by the human body, and a plurality of sensors supported by the garment and in electronic communication with the circuit board. Each sensor is sewn into the garment at a sensor position and the sensors are configured to collect data to track the movements of the human body throughout an activity; The system also includes a mobile phone application and the circuit board communicates the collected data from the sensors to the mobile phone application and the mobile phone application is configured to display the tracked movements of the human body in real time.

(13) According to an embodiment of a system according to the present invention, the circuit board is supported by the garment.

(14) According to another embodiment of a system according to the present invention, the circuit board is flexible.

(15) According to a further embodiment of a system according to the present invention, the circuit board is both flexible and supported by the garment.

(16) According to yet another embodiment of a system according to the present invention, the garment is a pair of pants and the circuit board is supported by the pants proximate the waistline of the pants.

(17) According to still another embodiment of a system according to the present invention, the circuit board is encased within a plastic casing.

(18) According to a still further embodiment of a system according to the present invention, the plastic casing encasing the circuit board is water tight.

(19) According to a yet further embodiment of a system according to the present invention, the circuit board includes a power system, a microcontroller powered by the power system, and a peripheral communication bus controller that enables communication between the microcontroller and the sensors.

(20) According to a yet further embodiment of a system according to the present invention, the power system is a battery.

(21) According to a yet further embodiment of a system according to the present invention, each sensor includes an accelerometer, a gyroscope, and a magnetometer.

(22) According to a yet further embodiment of a system according to the present invention, each sensor is coated in epoxy resin.

(23) According to a yet further embodiment of a system according to the present invention, the sensors are positioned near the triceps surae (calf) and erector spinae (lower back).

(24) According to a yet further embodiment of a system according to the present invention, the sensors are positioned near the vastus lateralis (outer quadricep) or biceps femoris (outer hamstring).

(25) According to a yet further embodiment of a system according to the present invention, the sensors are sewn into the garment using conductive thread, which facilitates the electronic communication between the sensors and the microcontroller.

(26) According to a yet further embodiment of a system according to the present invention, the

mobile phone application includes a home page configured to open when the user engages the application, and an activity page featuring a wireless connection/disconnection button and a calibration scan button. The user can navigate between the home page and activity page using a navigation bar. The activity page is configured to display the movement data gathered by the sensors as a real-time movement model.

(27) An embodiment of a method for monitoring, communicating, and analyzing bodily movements according to the present invention includes the steps of providing a garment configured to be worn on a human body, the garment comprising a circuit board and a plurality of sensors supported by the garment. A mobile phone application is downloaded and opened, the mobile phone application comprising a home page configured to open when a user engages the application, an activity page comprising a wireless connection/disconnection button and a calibration scan button, and a navigation bar configured to allow the user to navigate between the home page and the activity page. The garment is donned on the user's body. The application is paired to the garment using an appropriate radio-frequency protocol. The application is calibrated to the garment. An activity is then begun. Each sensor is in electronic communication with the circuit board and the sensors are configured to collect data to track the movements of the human body throughout an activity. The movements of the user's body are communicated by the garment to the application and displayed on the application in real time.

(28) According to another embodiment of a method according to the present invention, the calibration step includes further steps of determining if the user has previously calibrated the application to the user's body segment lengths. Then, if the answer to the determining step is no, the application is calibrated to the body segment lengths of the user. If the answer to the determining step is yes, A previous body segment lengths calibration is selected for the user.

(29) According to still another embodiment of a method according to the present invention, the calibration step includes another step of calibrating the sensors to determine an origin position to begin tracking movements.

(30) According to yet another embodiment of a method according to the present invention, the activity page includes a record button and a database of previously recorded activity data and the step of beginning an activity includes pressing the record button before beginning the activity. The application then records the tracked movements of the user's body.

(31) According to a further embodiment of a method according to the present invention, the method includes a final step of returning at a later time to the recordings database to watch recordings of activities as real-time movement models.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a block diagram of a body motion tracking system according to the present invention.
(2) FIG. **2***a* is a front elevation view of an embodiment of a garment system according to the present invention.
(3) FIG. **2***b* is a rear elevation view of the embodiment of FIG. **2***a*.
(4) FIG. **2***c* is a right side elevation view of the embodiment of FIG. **2***a*.
(5) FIG. **3** is a representative user interface display according to the present invention.
(6) FIG. **4** is a flow chart of an embodiment of a method according to the present invention.
DESCRIPTION OF THE PREFERRED EMBODIMENT
(7) Although the disclosure hereof is detailed and exact to enable those skilled in the art to practice the invention, the physical embodiments herein disclosed merely exemplify the invention which may be embodied in other specific structures. While the preferred embodiment has been described, the details may be changed without departing from the invention.

(8) Turning now to Figures, systems and methods for monitoring, communicating, and analyzing bodily movements according to the present invention may be described. In one embodiment, the present invention incorporates a real-time body motion tracking system **100** consisting of a primary circuit board **110**, peripheral sensors **140**, and a mobile phone application **150**. The body motion tracking system **100** tracks positions of at least portions of a user's body by sensing movements, and then a substantially real-time rendering is displayed. Although the current description includes references to this rendition provided by or through a mobile phone application **150**, other forms of applications, such as desktop computer applications and videogame console applications, are contemplated as well. The user also has the ability to record movement data and rendition(s) for future analysis. This system and method are useful for a number of applications, including personal analysis of a user's own movements and fitness techniques, data tracking over periods of time, and real-time feedback systems.

(9) In preferred embodiments, a garment **10** incorporates and/or supports both the primary circuit board **110** and the peripheral sensors **140** of the system. Alternatively, the circuit board **110** may be supported by a separate support structure (e.g., support strap) apart from the garment **10**, but in any event is preferably supported on an animal body. In this way, the system **100** can actively track the movements of a user's limbs throughout an activity (e.g., random and/or choreographed exercise, movement and/or task). While current embodiments feature conventional (e.g., ABS or fiberglass) circuit boards, other embodiments in which the primary circuit board **110** and the peripheral sensors **140** may be flexible (e.g., polyimide/copper layered films) to allow for the user to easily move without resistance from a rigid board are also contemplated. For the purposes of brevity, embodiments of the present invention will be described with relation to a pair of workout pants representing the garment **10**, however other types of garments (e.g. shirts, gloves, shoes, etc.) are also contemplated.

(10) In general, the primary circuit board **110** is preferably affixed to or otherwise supported at or near a waistline of the pants. This support may be accomplished via a pocket sewn into the garment itself for receiving the board **110** or, for example, a plastic casing or sleeve (not shown) supported by (e.g., temporarily clipped or securely affixed) to the garment **10**. Such plastic casing may protect the primary circuit board **110** during use, while also allowing a user to remove the primary circuit board **110** from the casing to replace parts when needed or to wash the garment **10**. Alternatively, the plastic casing may be watertight and/or hermetically sealed (and may further include a desiccant disposed therein) to enable laundering of the garment **10** without removing the board **110**. During use, the primary circuit board **110** preferably serves as a reference point (or origin) for use in calculating and/or determining a respective angle and/or position of the body segment, discussed further below.

(11) The primary circuit board **110** preferably includes a power system **120**, a microcontroller **112** powered by the power system **120**, and a peripheral communication bus controller **130**, enabling communication between the microcontroller **112** and the peripheral sensors **140**.

(12) The power system **120** preferably includes one or more lithium-ion battery(ies), although other types of batteries and power source(s) are contemplated for alternative embodiments. A nominal output voltage of the battery may generally be approximately 3.7 volts, and the battery preferably has a capacity of at least about 500 mAh. The actual battery output voltage can fluctuate from around 4.2V to 3.5V, but it may be regulated on the primary board **110**, or proximate to the peripheral sensors **140**, to about 1.8V (or other voltage) as required by or specified for use with the peripheral sensors **140**. The power system **120** also includes a power activation and/or deactivation switch, used to control the supply of power from the lithium-ion battery. When the power switch is activated (i.e. when the switch is turned on), the battery is allowed to power the primary circuit board **110**.

(13) When the power switch is turned off (or otherwise using previously existing charging methodologies), the battery may be charged and/or recharged by use of a battery charging circuit

and a power connector disposed on the primary circuit board **110**. The connector may be a connector known in the art, such as a micro-USB connector, USB connector, or the like. Additionally or alternatively, the circuit board **110** may include circuitry to allow the battery to be charged with a wireless (e.g., inductive) charging device. When the battery needs to be charged, the power connector is connected to an outside power source (not shown), such as a wall outlet, generator, or other electronic device. The power connector is in electronic communication with the charging circuit, such that the circuit may draw power from the outside power source to charge the battery. The charging process of a lithium-ion battery is presently generally understood in the art.

(14) The microcontroller **112** preferably includes a wireless communication system **114** and a controlling system **116**. The microcontroller **112** is also in electronic communication with the power system **120** such that the wireless communication system **114** and the controlling system **116** are provided an effective amount of electric power to operate. The controlling system **116** includes a processor known in the art (e.g. an ARM® processor), which is preferably programmable and may control the settings of the charging circuit of the power system **120**. The controlling system **116** also preferably controls the functions of the wireless communication system **114**, which can utilize Bluetooth® technology, Bluetooth Low Energy (BLE), near field communication (NFC), Wi-Fi™, or any other radio frequency (RF) protocol to connect the wireless communication system **114** to a compatible device. The wireless communication system **114** communicates with a mobile electronic device (e.g., mobile phone), ultimately communicating data to the mobile phone application **150**, allowing a steady stream of data transfer between the sensors **140**, microcontroller **112**, and application **150**, preferably contemporaneously with movement of a body wearing a garment **10** according to the present invention.

(15) The microcontroller **112** preferably includes at least a relatively low-cost wireless communication system **114** (e.g. a BT832F Bluetooth® Low Energy module) and a connector (e.g. an SWD connector). The microcontroller **112** sends pre-programmed commands to the peripheral sensors **140** and receives feedback and data from each sensor **140** on its respective position and angle, which may be in relation to an original respective position (calibrated or origin position) of that sensor **140**, a comparison to a direction of gravity, comparison to a direction of magnetic north, and/or GPS location from or related to a calibrated or previous location. The wireless communication system **114** communicates with the mobile electronic device (e.g., mobile phone), ultimately communicating data to the mobile phone application **150**, allowing a steady stream of at least substantially real-time data transfer between the sensors **140**, microcontroller **112**, and application **150**, again preferably contemporaneously with movement of a body wearing a garment **10** according to the present invention.

(16) The peripheral communication bus controller **130** may include of a series of tri-state buffers that communicate with the peripheral sensors **140** located on the garment **10**, or each sensor **140** may have its own dedicated bus. The buffers may be oriented or adapted to be used according to a serial communication bus standard (e.g. an I.sup.2C bus) that facilitates data transfer between the peripheral sensors **140** and the microcontroller **112**. The buffers receive signals from the microcontroller **112** that may prioritize which sensor **140** has control of the bus at any given time to deliver data to the microcontroller **112**, the microcontroller **112** thus serving as the bus arbiter.

(17) The peripheral sensors **140** are generally inertial measurement unit pieces that are used to determine the position and orientation with reference to a predefined or previous location of the respective sensor **140**, which may then be used to calculate or interpret a position of a user's body, or portion thereof, during activity. During manufacturing, the sensors **140** (including related circuitry) may be mounted on the same piece of material that forms the primary circuit board **110**. As such, a sensor base (to support a sensing component and supporting circuitry) may be made of the same material as the primary circuit board **110**, the sensor base(s) being separated from the primary circuit board **110** after component placement, such as by cutting. Each sensor **140** includes a sensing component, which includes at least an accelerometer, gyroscope, and magnetometer,

among other possible parts. The sensing component may be known in the art (e.g. an ICM 20948 9-axis motion sensor, including a 3-axis gyroscope, a 3-axis accelerometer, and a 3-axis compass) or it may be custom made. The sensor base supports and connects the necessary components to facilitate connection between the sensing component and the primary circuit board **110**, and ultimately to the microprocessor **112**.

(18) With the sensors **140** positioned on the waistline as a stable reference point, a user may follow a calibration process, more thoroughly discussed below in connection with the mobile application **150**, to establish a baseline orientation position of the sensors **140**. During activity, the movement of the user's limbs relative to the baseline orientation establishes a vector in three dimensions. This vector position and orientation may then be calculated or represented in quaternions (or representations thereof) and transmitted from the sensors **140** on the peripheral communication bus **130** to the microprocessor **112**. The sensors **140** continually run these calculations to update the positions of the limbs, allowing an accurate stream of data transmitting the movement of the sensors (and indirectly, the movement of a user) during activity.

(19) When the system **100** is being assembled, the sensors **140** are disconnected from the primary circuit board **110** and sewn into pre-determined areas (e.g., pockets) of the garment **10** using thread (which may be electrically conductive thread). The areas of the garment **10** that the sensors **140** are sewn into are generally determined by what areas give the optimal data detection for the user's body segment positions, which is generally determined by the type of garment **10** (e.g., sock, pants, shirt, hat, helmet, gloves, sleeve, etc.) being used. Further, during manufacturing, the sensors **140** (including related circuitry) may be coated in an epoxy resin (e.g., potted), both to make the sensors **140** more durable during rigorous use and to protect them from water ingress when the garment **10** is being washed. In the example shown in FIGS. **2**A and **2**C, one sensor **140** is preferably sewn to or otherwise supported by the garment **10** at each lower leg portion (e.g., for lateral positioning next to the triceps surae (calf muscle)) and each upper leg portion (e.g., for lateral positioning next to the vastus lateralis (outer quadricep) and/or biceps femoris (outer hamstring)). Two sensors **140** are preferably supported ex vivo adjacent to the erector spinae (i.e., the lower back) to establish torso angle and lumbar rounding. The conductive thread preferably electrically connects the peripheral sensors **140** to the microcontroller **112**, and may also be used to help keep the sensors in place. The conductive thread may be sewn in when the garment **10** itself is created or may be added later when the system **100** is ready to be implemented into the garment **10**. One end of each strand of conductive thread is preferably looped tightly around vias and conductive pads located on the peripheral sensors **140** (e.g., on/in/through the sensor base). The thread is then woven into the pattern of the garment **10**. The second end is preferably connected to the primary circuit board **110** to allow electronic communication and data transfer between the systems. In alternative embodiments, the thread securing the sensors **140** to the garment **140** may be non-electrically conductive thread and the garment **10** may further include thin strips of conductive fabric or wires (not shown) instead, to electrically couple the sensors **140** to the microcontroller **112**. The conductive fabric is preferably implemented into the fabric of the garment **10**, forming some structure thereof.

(20) A mobile software application **150** has been developed for a variety of uses. The application **150** may be available on iOS and Android mobile devices by remote download, or the application may be recorded on a computer readable medium and provided or packaged with other products (e.g., exercise device(s)) in a kit. When the application **150** is launched on a mobile device **20**, a display **154** features options and pages for a user to select. A home page **156** acts as the entry screen for the application **150** and thus the first screen of the display series, with artwork displayed and a navigation bar **157** located at the bottom of the page for the user to navigate to other screens. Turning now to FIG. **3**, the application preferably includes an activity page **158**, which the user can locate on the navigation bar **157**. The activity page **158** features a wireless connection/disconnection button **159**, which the user can tap to pair the mobile device **20** with the

wireless communication system **114** via Bluetooth®, Bluetooth Low Energy (BLE), near field communication (NFC), Wi-Fi™, or another type of radio frequency (RF) or other wireless protocol. Once connection is established, the user then taps a calibration scan button **161** to facilitate the calibration process.

(21) The calibration process generally begins with calculating or establishing or estimating the user's limb (or other body segment) lengths. First, the user taps the calibration scan button **161** in the mobile application **150**, which connects the application **150** to the camera of the mobile device **20** (through device permissions, if necessary). A full body picture of the user to be calibrated is taken, preferably standing straight up, facing the camera, including head and feet in the frame of the picture. This picture may be taken by the user using a time delay function on the mobile device or by another person. Alternatively, a user may take a photo of a previously taken reference photo that has been printed, or the user may select an adequate photo from a database of photos on the mobile device. Next, the user drags and drops positional markers onto specific body points (usually at or proximate a joint, or other desirable reference point) one at a time using the application **150** user interface, forming a two-dimension skeleton model. The user drags and drops position markers, while the application **150** stores the marker as a pair of x-y coordinates on the image's pixel grid. Position markers are preferably positioned at least at or proximate the following locations in the photograph: crown of the head, at least one talocrural (ankle) joint, and the pubic crest. Additional markers are placed at least at or proximate joints of upper and/or lower limbs to be analyzed (monitored and/or recorded). If an upper body is to be analyzed, markers are preferably placed at the following locations: the suprasternal notch (top of the sternum), at least one glenohumeral (shoulder) joint, an elbow joint on the same arm as the at least one glenohumeral joint, and a radiocarpal (wrist) joint on that same arm. Both arms may be mapped in similar fashion. If a lower body or spinal (e.g., lumbar) rounding is to be analyzed, markers are preferably placed at the following locations: at least one coxal (hip) joint, the tibiofemoral (knee) joint on the same leg as the at least one coxal joint, and a talocrural (ankle) joint on that same leg (if not previously marked). In a preferred embodiment, all listed locations are marked.

(22) The user also enters his or her overall height, as measured by conventional or other means. The application **150** includes an algorithm that establishes a pixel to unit distance (e.g. cm or inch) conversion factor based on the height information provided. The application **150** then uses the conversion factor in connection with the placed position markers to approximate the distances between those markers (which are representative of approximate joint positions), displays them in real units for the user to review and/or confirm, and stores them, preferably in nonvolatile memory for later retrieval and use. Accordingly, this calibration procedure may need to be performed only once per user. In future uses of the system **100**, the user can select a previously performed limb length calibration to use in new analyses.

(23) Upon completion of the body segment lengths calibration, or selection of a previously completed body segment length calibration, the user then initiates a sensor calibration process for the sensors **140** by tapping a sensor calibration button **164**, which may also be located on the activity page **158**. If not already paired to the camera(s) on the device, the application **150** then asks the user to allow access to the camera(s). The sensor calibration process begins by instructing the user to stand straight up and face the device camera, with feet positioned hip-width apart and arms relaxed, such that the user's entire body (including head and feet) is visible in the camera frame. Next, the application **150** records a quaternion from each sensor and continues to record quaternions at a predetermined frequency repeatedly while calibration is ongoing during a predetermined calibration time, resulting in a plurality of recorded quaternion values for each respective sensor **140**. The mean (average) of these first recorded quaternions for each sensor **140** is calculated and recorded as the initial (or calibration or origin) quaternion of the respective sensor **140**. The user can then begin using the system **100** during an activity.

(24) During use, each sensor **140** continues to communicate quaternions to the application **150** and

the application **150** calculates the position of each sensor **140** by subtracting the recorded initial quaternion from the in-activity quaternion that the sensor **140** reports. The resulting quaternion describes the rotation from standing position to the current orientation of the user. This rotation is then applied on an at least substantially real-time three-dimension model (e.g., of a human body) displayed on the activity page **158**, allowing the user to see movements in a third-person view or mirrored by the model. This sensor calibration process is performed at the beginning of each use of the system **100**, or prior to a movement to be analyzed that, as well as other times (or periodically) as needed due to sensor drift, changes in garment position, and other factors that may affect calculations.

(25) Also during use, the activity page **158** (see FIG. **3**) facilitates user interaction with the body motion tracking system **100** in two ways. First, the page **158** displays the limb orientation of the user in at least substantially real-time due to the effective contemporaneous data transfer between the application **150** and the microcontroller **112**. This allows the user to see movements represented on a mobile device **20** with minimal delay, which is useful for checking technique and movement sequences in a variety of activities (e.g. yoga, sports, stretches, etc.) and/or analyzing stretch or position goals.

(26) Further, the application **150** may optionally include a pose detection and classification method. As the application **150** displays movements in real-time, the pose detection and classification method may compare the movements or stationary position of the user (or a recording thereof) to a pre-saved catalogue of exemplary positions (either model positions or prior user positions). Body segment (e.g., limb or portion thereof) data (or sensor data) with a number (N) of variations for each pose are stored in a 3N-dimensional locality preserving hash (LPH). The method may further utilize an automated machine learning framework (AutoML) to facilitate pose classification (i.e. SensiML™ or Edge Impulse). The AutoML may learn various poses or orientations according to the following procedure. First, a user may activate the AutoML to collect training data for a motion such as swinging a baseball bat, transitioning between yoga poses, performing a physical therapy/weightlifting exercise, or completing any physical motion, such as stretching or task completion (e.g., occupational mechanics). Such training data includes both the motion being classified and other unrelated motions. The data may then be labelled, segmented, and separated into training, validation, and test data. Through repeated collection of training data, a classification model may be built, trained, and tested using the AutoML framework. To reduce processing power demands on the connected mobile device, the classification model may be exported as a C library to the microcontroller **112** of the system **100**, allowing some processing to be completed at the garment **10** and subsequent processing or review to be completed at the handheld device **20**. This process also increases the bandwidth of the system **100** when the classification model is used concurrently with the real-time orientation display. In use, a frame of orientation data is stored in the LPH and a nearest neighbor search is performed. If a neighbor pose is found in the LPH, and within a certain variation tolerance, the pose is identified and displayed with the real-time display of the user. The variation tolerance may be experimentally determined and/or hard-coded as a certain pixel distance from the reference pose data and related to a particular sensor **140** or group thereof.

(27) The second way the activity page **158** facilitates user interaction with the body motion tracking system **100** is through a recording button **165**. By using this button **165**, the user can record movement data from a particular session (multiple movements) or during a particular pose for later review.

(28) The activity page **158** further preferably includes a recording button **165** (e.g., a virtual or soft button). By using this button **165**, a user can record movements for later review. The recordings are preferably stored in a local database (e.g. an SQlite database) and are available for viewing on a recordings page, accessible through another menu button **166**. Also located on the navigation bar **157**, the recordings page button **166** preferably allows the user to re-watch selected recorded

activity and save/organize recordings on the mobile device **20**. The recordings page may optionally include the ability to transfer recordings to other users having a separate copy of the application **150** or to other devices or an outside storage device via text message, iMessage, email, or a different form of data transfer.

(29) When the user wants to view recorded activity, the recordings page **166** accesses the data storage database. The data storage database is preferably an embedded system that is capable of storing many recordings of activity (e.g. an SQlite database). The database is stored locally on the device **20** and is accessible by the application **150**, allowing a user to quickly and easily access recordings stored therein (recorded by that mobile device **20** or a separate device and transferred into the database). The mobile device application **150** further includes a settings selection **168**, enabling users to view settings and make changes specific to the application **150**.

(30) Turning now to FIG. **4**, a flow diagram for embodiments of a method **200** for tracking body motion according to the present invention is shown. The method utilizes sensors **140**, the mobile device application **150**, and real-time viewings and recordings. While the method is shown in stepwise order for clarity, it is to be understood that some of the steps may be undertaken in different chronological order, unless otherwise required. An application **150** is downloaded to a mobile device **20** and opened in step **210**. The application **150** is generally available for free download on both iOS and Android stores, allowing a wide variety of users to make use of the system **100** and method **200**. In another step **220**, a user dons an augmented garment **10**, such as the pants example used above. The augmented garment **10** has been manufactured to preferably incorporate a primary circuit board **110**, located on the lower back/waist area of the pants, and peripheral sensors **140**, located on the calves, quadriceps, and lower back areas of the pants. These parts are preferably attached to the garment **10** or sewn into the fabric to prevent jostling or detachment while the augmented garment **10** is being worn. The sensors **140** are connected to the primary circuit board **110** via the conductive thread that forms patterns and seams in the garment **10**, or otherwise operatively connected. In step **230**, the user begins the body motion tracking system **100** by powering on the primary circuit board **110**, such as by using a switch. On the application **150**, the user pairs (or otherwise confirms communication between the primary circuit board **110** and the mobile device **20**) using an appropriate RF protocol compatible with the device **20**.

(31) In step **240**, the user must determine whether or not to perform a body segment lengths calibration process. This decision may depend on whether or not the user has performed the body segment lengths calibration process in the past. If not, or if the user wishes to calibrate again, the user may proceed to step **250** by selecting the calibration scan button **161** and following the body segment lengths calibration process as described more fully above. The application **150** then saves the data from the completed body segment lengths calibration process in the application for later use. If the user has performed the body segment lengths calibration process in the past, a previously stored body segment lengths calibration may be selected in step **255** instead of repeating the body segment lengths calibration process. When body segment lengths calibration is completed or selected, the application **150** may notify the user.

(32) Once body segment lengths calibration process is complete, the user begins the sensor calibration process by pressing the calibration button **164** in step **260**. The user then follows the sensor calibration process outlined above and the application **150** alerts the user of a successful calibration. The system **100** is then ready for active use.

(33) After completing calibration in step **260**, the user may have a choice of how to use the body motion tracking system **100**. The device **20** preferably automatically receives transmissions of sensor position from the primary circuit board **110**, allowing the application **150** to provide a real-time display of the garment **10** position. This shows the user a representation of bodily limb orientation. In using the system **100** further, the user can either begin activity and simply view the display **154** showing a real-time model of movements in step **280** and/or the record button **165** may

be selected in step **270**. If recording, the application automatically catalogs and saves sensor **140** data and the real-time display **154** to the application database. In the final optional step (not shown), the user can return to the database at a later time and watch the recordings of activities as saved as real-time movement models displaying the sensor's transmitted data.

(34) The foregoing is considered as illustrative only of the principles of the invention. Furthermore, because numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described. For instance, though the term "real-time" is utilized throughout, it is to be and will be understood by those having skill in the art that there is some finite processing time that is necessary or desirable prior to the real-time result, and the term includes such variability. While the preferred embodiment has been described, the details may be changed without departing from the invention.

Claims

1. A system for monitoring, communicating, and analyzing bodily movements comprising: a garment configured to be worn on a human body; a circuit board; a plurality of sensors supported by the garment and in electronic communication with the circuit board, wherein each sensor is coupled to the garment at a sensor position and the sensors are configured to collect data representative of movements of the human body throughout an activity; and a mobile phone application comprising: a home page configured to open when the user engages the application; and an activity page comprising a wireless connection/disconnection button and a calibration scan button, wherein the user may navigate between the home page and activity page using a navigation bar, wherein the activity page is configured to display the movement data gathered by the sensors as a real-time movement model, wherein the circuit board communicates the collected data from the sensors to the mobile phone application and the mobile phone application is configured to display the movements of the human body, wherein the circuit board supports a power system, a microcontroller powered by the power system, and a peripheral communication bus controller that enables communication between the microcontroller and the sensors, and wherein the mobile phone application is calibrated to the user's body segment lengths.

2. The system of claim 1, wherein the display of the movements of the human body occurs at least substantially in real time.

3. The system of claim 1, wherein the circuit board is supported by the garment.

4. The system of claim 3, wherein the circuit board is flexible.

5. The system of claim 4, wherein the circuit board is supported by the garment.

6. The system of claim 3, wherein the garment comprises a pair of pants and wherein the circuit board is supported proximate a waistline of the pants.

7. The system of claim 6, further comprising: a plastic casing substantially enclosing the circuit board.

8. The system of claim 7, wherein the plastic casing is watertight.

9. The system of claim 6, wherein a first sensor position comprises proximate a triceps surae of the human body and a second sensor position comprises proximate an erector spinae of the human body.

10. The system of claim 9, wherein a third sensor position comprises proximate at least one of a vastus lateralis of the human body and a biceps femoris for the human body.

11. The system of claim 1, wherein the sensors are supported by the garment by sewing.

12. The system of claim 11, wherein the sewing comprises conductive thread and the conductive thread facilitates electronic communication between the sensors and the microcontroller.

13. The system of claim 1, wherein the power system comprises a battery.

14. The system of claim 13, wherein each sensor comprises an accelerometer, gyroscope, and a magnetometer.

15. The system of claim 14, wherein each sensor is coated in epoxy resin.

16. A method for monitoring, communicating, and analyzing bodily movements comprising the steps of: providing a garment configured to be worn on a human body, the garment comprising a circuit board and a plurality of sensors supported by the garment, wherein each sensor is in electronic communication with the circuit board and the sensors are configured to collect data representative of movements of the human body throughout an activity; activating a mobile phone application, the mobile phone application comprising a home page configured to open when a user engages the application, an activity page comprising a wireless connection/disconnection button and a calibration scan button, and a navigation bar configured to allow the user to navigate between the home page and the activity page; donning the garment on the user's body; pairing the application to the garment using an appropriate radio-frequency protocol; calibrating the application to the garment by determining if the user has previously calibrated the application to the user's body segment lengths, wherein, if the answer is no, calibrating the application to the body segment lengths of the user, and wherein, if answer is yes, selecting a previous body segment lengths calibration for the user; and beginning the activity, wherein the data are communicated from the garment to the application and the movements are displayed on the application.

17. The method of claim 16, wherein the calibration step further includes the step of: calibrating the sensors to define a sensor origin position.

18. The method of claim 17, wherein the activity page further comprises a record button and a database of previously recorded activity data and the beginning an activity step further comprises the step of: pressing the record button before beginning the activity, wherein the application records the movements.

19. The method of claim 18, further comprising the steps of accessing the recordings database and displaying a recording of the activity as a real-time movement model.

20. The method of claim 16, wherein the movements are displayed on the application substantially in real time.