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Canadian Intellectual Property Office
An agency of Industry Canada

CA 2902045 A1 2014/08/28

(21) 2 902 045

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2014/02/21
(87) Date publication PCT/PCT Publication Date: 2014/08/28
(85) Entrée phase nationale/National Entry: 2015/08/20
(86) N° demande PCT/PCT Application No.: US 2014/017799
(87) N° publication PCT/PCT Publication No.: 2014/130871
(30) Priorité/Priority: 2013/02/22 (US61/768,322)

(51) Cl.Int./Int.Cl. *G06F 13/14* (2006.01), *G06F 1/16* (2006.01), *G06F 3/01* (2006.01)

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(54) Titre : PROCEDES ET DISPOSITIFS COMBINANT DES SIGNAUX DE CAPTEUR D'ACTIVITE MUSCULAIRE ET DES SIGNAUX DE CAPTEUR INERTIEL POUR UNE COMMANDE GESTUELLE

(54) Title: METHODS AND DEVICES THAT COMBINE MUSCLE ACTIVITY SENSOR SIGNALS AND INERTIAL SENSOR SIGNALS FOR GESTURE-BASED CONTROL

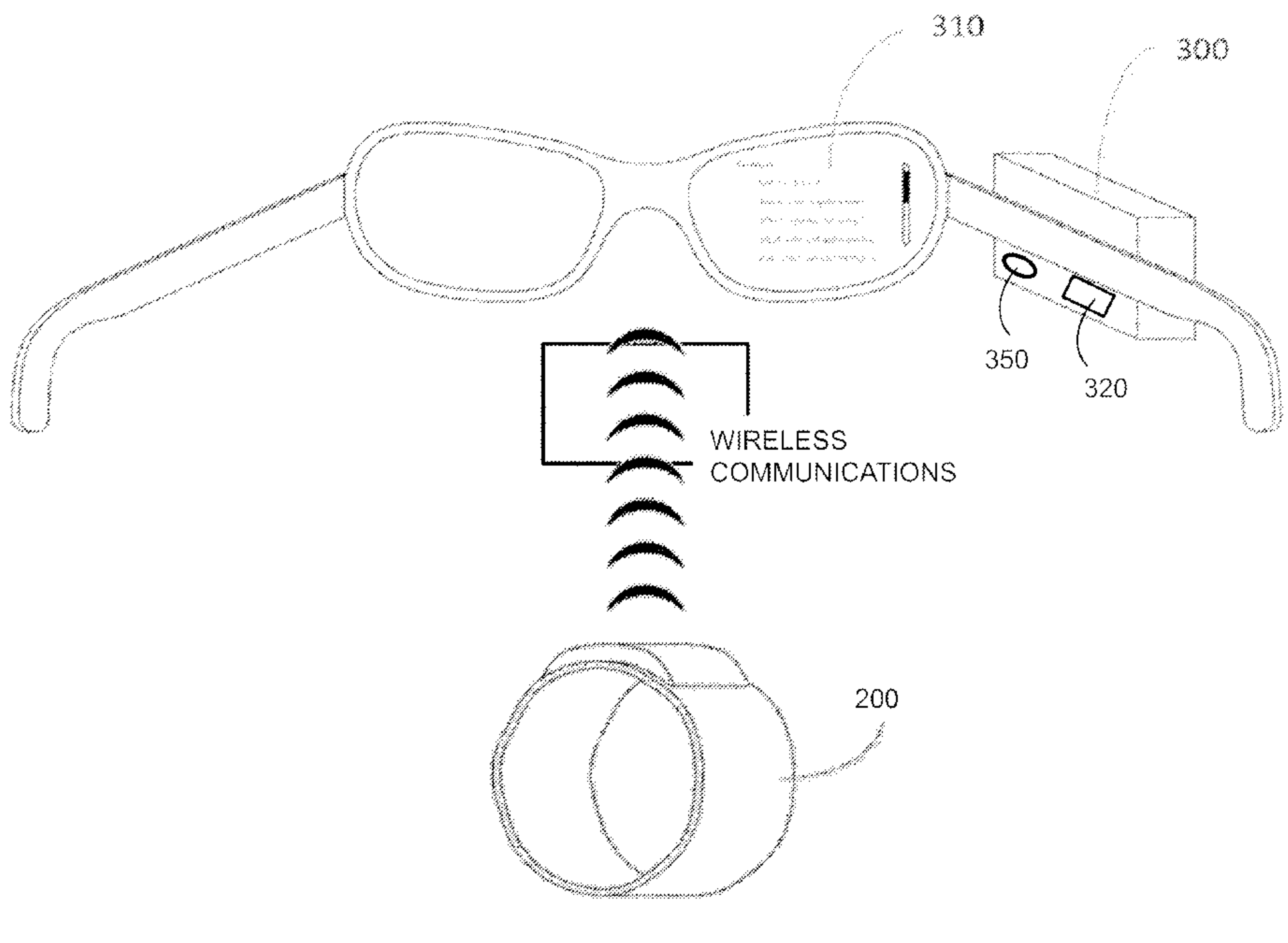

FIG. 3

(57) Abrégé/Abstract:
There is disclosed a wearable electronic device for use with controllable connected devices. The wearable electronic device includes a band worn on, for example, the forearm of a user, and the band carries at least one muscle activity sensor, at least one inertial sensor, and a processor communicatively coupled to the sensors. The on-board processor is operable to identify, a plurality of gestures made by a user, based on muscle activity detected by the muscle activity sensor(s) and motion detected by the inertial sensor(s). In response to identifying a gesture, the wearable electronic device wirelessly transmits one or more signal(s) in order to interact with a controllable connected device.

ABSTRACT OF THE DISCLOSURE

There is disclosed a wearable electronic device for use with controllable connected devices. The wearable electronic device includes a band worn on, for example, the forearm of a user, and the band carries at least one muscle activity sensor, at least one inertial sensor, and a processor communicatively coupled to the sensors. The on-board processor is operable to identify, a plurality of gestures made by a user, based on muscle activity detected by the muscle activity sensor(s) and motion detected by the inertial sensor(s). In response to identifying a gesture, the wearable electronic device wirelessly transmits one or more signal(s) in order to interact with a controllable connected device.

METHODS AND DEVICES THAT COMBINE MUSCLE ACTIVITY SENSOR SIGNALS AND INERTIAL SENSOR SIGNALS FOR GESTURE-BASED CONTROL

BACKGROUND

Technical Field

The present methods and devices relate generally to human-electronics interfaces, and more specifically to wearable electronic devices that combine muscle activity sensor signals and inertial sensor signals to provide gesture-based control of electronic devices.

Description of the Related Art

WEARABLE ELECTRONIC DEVICES

Electronic devices are commonplace throughout most of the world today. Advancements in integrated circuit technology have enabled the development of electronic devices that are sufficiently small and lightweight to be carried by the user. Such "portable" electronic devices may include on-board power supplies (such as batteries or other power storage systems) and may be designed to operate without any wire-connections to other electronic systems; however, a small and lightweight electronic device may still be considered portable even if it includes a wire-connection to another electronic system. For example, a microphone may be considered a portable electronic device whether it is operated wirelessly or through a wire-connection.

The convenience afforded by the portability of electronic devices has fostered a huge industry. Smartphones, audio players, laptop computers, tablet computers, and ebook readers are all examples of portable electronic devices. However, the convenience of being able to carry a portable electronic device has also introduced the inconvenience of having one's hand(s) encumbered by the device itself. This problem is addressed by making an electronic device not only portable, but wearable.

A wearable electronic device is any portable electronic device that a user can carry without physically grasping, clutching, or otherwise holding onto the device with their hands. For example, a wearable electronic device may be attached or coupled to the user by a strap or straps, a band or bands, a clip or clips, an adhesive, a pin and clasp, an article of clothing, tension or elastic support, an interference fit, an ergonomic form, etc. Examples of wearable electronic devices include digital wristwatches, electronic armbands, electronic rings, electronic ankle-bracelets or "anklets," head-mounted electronic display units, hearing aids, and so on.

ELECTROMYOGRAPHY DEVICES

Electromyography ("EMG") is a process for detecting and processing the electrical signals generated by muscle activity. EMG devices employ EMG sensors that are responsive to the range of electrical potentials (typically μV – mV) involved in muscle activity. EMG signals may be used in a wide variety of applications, including: medical monitoring and diagnosis, muscle rehabilitation, exercise and training, prosthetic control, and even in controlling functions of electronic devices.

HUMAN-ELECTRONICS INTERFACES

A wearable electronic device may provide direct functionality for a user (such as audio playback, data display, computing functions, etc.) or it may provide electronics to realize a human-electronics interface that enables a user to interact with, receive information from, or control another electronic device. Throughout this specification and the appended claims, a human-computer interface ("HCI") is used as an example of a human-electronics interface. The present methods and devices may be applied to HCIs, but may also be applied to any other form of human-electronics interface.

In recent years, there has been an increasing need for human-computer interfaces, or HCIs, for use in various control applications. An example of a technology for HCIs that has received some attention is the sensing of muscle activity through the surface of the skin, called sEMG (surface electromyography), to detect hand and/or arm gestures performed by a user. For example, a device that contains EMG sensors may be worn on the wrist or forearm of a user and used to detect electrical signals generated by muscle activity. Pattern recognition algorithms are used to analyze the electrical data to identify the physical gesture that the user has performed. There is a comprehensive overview of this technology and its limitations in US Patent No. 8,170,656.

In order for gesture sensing devices to be commercially viable, the devices must have a very high gesture detection rate with a relatively low build cost. One limitation is that sEMG-based sensors are very susceptible to variations in operating conditions, and signals generated by sEMG sensors may be affected by such variables as skin perspiration, amount of hair, and fat content in the skin. Because of this, it is very difficult to achieve high gesture recognition rates using just sEMG sensors alone.

Therefore, what is needed is an effective HCI device which overcomes these limitations in the prior art.

BRIEF SUMMARY

The present disclosure relates to human-computer interface devices, and more specifically to a wearable muscle control sensor based human-computer interface (HCI).

In an embodiment, the wearable muscle control device is worn on the forearm of the user, and includes a plurality of capacitive electromyography (cEMG) sensors. Advantageously, the cEMG sensors do not require direct contact with the skin of the user, and therefore are not susceptible to the signal variations that are characteristic to surface electromyography (sEMG) sensors used in the prior art. The muscle control device further includes an inertial measurement unit (IMU) which has an accelerometer to measure the acceleration of the user's arm. The muscle control device may further contain a filtering module to filter and process the acquired signals from the sensors, an analog to digital converter to convert an analog signal to digital, and a processing unit configured to recognize the gestures the user is making from the processed cEMG and IMU signals.

In an embodiment, the device may be connected by wire to a connected device which receives control inputs from the muscle control device. Alternatively, the muscle control device contains one or more batteries and a wireless transceiver module for wireless connection to the connected device.

Preferably, the device takes the form of an expandable band that is able to stay in position on a user's forearm. The device may also contain a vibratory motor which may be used for providing haptic feedback to a user to confirm an event, or to request an input.

In another embodiment, various other types of sensors may be used in combination with cEMG sensors to detect gestures made by a user. This may include, for example, mechanomyography (MMG) sensors to detect vibrations made by muscles during contraction.

In another embodiment, the muscle interface device includes a calibration module with a routine for calibrating the muscle interface device for use with a connected device or HCI.

A wearable electronic device may be summarized as including a band that, in use, is worn by a user; at least one muscle activity sensor carried by the band, the at least one muscle activity sensor to, in use, detect muscle activity in response to the user performing a physical gesture and provide at least one signal in response to the detected muscle activity; at least one inertial sensor carried by the band, the at least one inertial sensor to, in use, detect motion in response to the user performing a physical gesture and provide at least one signal in response to the detected motion; and a processor carried by the band, the processor communicatively coupled to the at least one muscle activity sensor and to the at least one inertial sensor and the processor to, in use, identify a physical gesture performed by the user based on either or both of: at least one signal provided by the at least one muscle activity sensor; and at least one signal provided by the at least one inertial sensor. The wearable electronic device may further include a non-transitory computer-readable storage medium carried by the band and communicatively coupled to the processor, wherein the non-transitory computer-readable storage medium stores processor executable instructions that, when executed by the processor, cause the processor to identify a physical gesture performed by the user based on either or both of: at least one signal provided by the at least one muscle activity sensor; and at least one signal provided by the at least one inertial sensor. The non-transitory computer-readable storage medium may store processor executable instructions that, when executed by the processor, cause the processor to perform a machine intelligence method to identify a physical gesture performed by the user based on either or both of: at least one signal provided by the at least one muscle activity sensor; and at least one signal provided by the at least one inertial sensor. The processor executable instructions stored in the non-transitory computer-readable storage medium may include processor executable instructions that, when executed by the processor, cause the processor to implement at least one of: a classifier, a Hidden Markov Model, and/or a Long Short Term Neural Net.

The wearable electronic device may further include a wireless transmitter carried by the band, the wireless transmitter communicatively coupled to the processor to, in use, wirelessly transmit at least one signal in response to the processor identifying a physical gesture performed by the user. The at least one muscle activity sensor may include at least one muscle activity sensor selected from the group consisting of: an electromyography (EMG) sensor and a mechanomyography (MMG) sensor. The at least one muscle activity sensor may include a plurality of electromyography (EMG) sensors.

The wearable electronic device may further include a haptic feedback module carried by the band, the haptic feedback module to, in use, provide haptic feedback to the user. The haptic feedback module may include a vibratory motor.

The band of the wearable electronic device may be expandable.

The wearable electronic device may further include at least one additional component carried by the band, the at least one additional component selected from the group consisting of: an amplification circuit communicatively coupled to the at least one muscle activity sensor, a filtering circuit communicatively coupled to the at least one muscle activity sensor, an analog-to-digital conversion circuit communicatively coupled to the at least one muscle activity sensor, and a battery electrically coupled to the processor. The at least one inertial sensor may include at least one inertial sensor selected from the group consisting of: an accelerometer, a gyroscope, and an inertial measurement unit (IMU).

A method of operating a wearable electronic device, wherein the wearable electronic device includes a band worn by a user, at least one muscle activity sensor carried by the band, at least one inertial sensor carried by the band, and a processor carried by the band, the processor communicatively coupled to the at least one muscle activity sensor and to the at least one inertial sensor, may be summarized as including: detecting, by at least one muscle activity sensor carried by the band of the wearable electronic device, muscle activity in response to the user performing a physical gesture; providing at least one signal from at least one muscle activity sensor to the processor in response to the detected muscle activity; detecting, by at least one inertial sensor carried by the band of the wearable electronic device, motion in response to the user performing a physical gesture; providing at least one signal from at least one inertial sensor to the processor in response to the detected motion; processing, by the processor carried by the band of the wearable electronic device, the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor; and identifying, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user based on at least one of: the at least one signal provided by at least one muscle activity sensor; and the at least one signal provided by at least one inertial sensor.

Identifying, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user may include identifying, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user based on both the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor. Identifying, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user may include: identifying, by the processor carried by the band of the wearable electronic device, a first physical gesture performed by the user based on the at least one signal provided by at least one muscle activity sensor; and identifying, by the processor carried by the band of the wearable electronic device, a second physical gesture performed by the user based on the at least one signal provided by at least one inertial sensor.

Processing, by the processor carried by the band of the wearable electronic device, the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor may include utilizing one or more of a classifier, a Hidden Markov Model, a Long-Short Term Neural Net, or another machine intelligence method to process the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor.

The wearable electronic device may further includes a wireless transmitter carried by the band and communicatively coupled to the processor, and the method may further include wirelessly transmitting at least one signal in response to the processor identifying a physical gesture performed by the user.

The wearable electronic device may further include an amplification circuit carried by the band and communicatively coupled to at least one muscle activity sensor, and the method may further include: amplifying, by the amplification circuit, the at least one signal from at least one muscle activity sensor before providing the at least one signal from at least one muscle activity sensor to the processor.

The wearable electronic device may further include a filtering circuit carried by the band and communicatively coupled to at least one muscle activity sensor, and the method may further include filtering, by the filtering circuit, the at least one signal from at least one muscle activity sensor before providing the at least one signal from at least one muscle activity sensor to the processor.

The wearable electronic device may further include an analog-to-digital conversion circuit carried by the band and communicatively coupled to at least one muscle activity sensor, and the method may further include converting, by the analog-to-digital conversion circuit, the at least one signal from at least one muscle activity sensor from an analog signal to a digital signal before providing the at least one signal from at least one muscle activity sensor to the processor.

The at least one muscle activity sensor may include a plurality of electromyography (EMG) sensors, and: detecting, by at least one muscle activity sensor carried by the band of the wearable electronic device, muscle activity in response to the user performing a physical gesture may include detecting, by at least one EMG sensor in the plurality of EMG sensors carried by the band of the wearable electronic device, muscle activity in response to the user performing a physical gesture; and providing at least one signal from at least one muscle activity sensor to the processor in response to the detected muscle activity may include providing at least one signal from at least one EMG sensor in the plurality of EMG sensors to the processor in response to the detected muscle activity.

The wearable electronic device may further include a haptic feedback module carried by the band, the haptic feedback module including a vibratory motor that is communicatively coupled to the processor, and the method may further include providing haptic feedback to the user by the vibratory motor in response to the processor identifying a physical gesture performed by the user.

Other features and advantages of the present methods and devices will become apparent from the following detailed description and accompanying drawings. It should be understood, however, that the detailed description and specific examples are given by way of illustration and not limitation. Many modifications and changes within the scope of the present methods and devices may be made without departing from the spirit thereof, and the present methods and devices include all such modifications.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

In the drawings, identical reference numbers identify similar elements or acts. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various elements and angles are not drawn to scale, and some of these elements are arbitrarily enlarged and positioned to improve drawing legibility. Further, the particular shapes of the elements as drawn are not intended to convey any information regarding the actual shape of the particular elements, and have been solely selected for ease of recognition in the drawings.

FIG. 1 illustrates a user wearing a connected device and a wearable electronic device in accordance with the present methods and devices.

FIG. 2A illustrates a detailed view of a wearable electronic device in accordance with the present methods and devices.

FIG. 2B illustrates a data graph corresponding to an electrical signal detected by an EMG sensor.

FIG. 3 illustrates wireless communication between a connected device and a wearable electronic device in accordance with the present methods and devices.

FIG. 4 illustrates a user's hand and wrist gesture processed as a control signal by the wearable electronic device for interacting with content displayed on the connected device.

FIG. 5 illustrates a schematic system architecture of a wearable electronic device in accordance with the present methods and devices.

FIG. 6 illustrates a gesture training module utilizing samples having a sliding window with an overlap in accordance with the present methods and devices.

FIG. 7 illustrates a pattern recognition system with a hierarchical decision tree with each node representing a different classifier in accordance with the present methods and devices.

FIG. 8 illustrates monitoring a signal channel for an RMS value that exceeds a certain threshold to initiate gesture recognition.

FIG. 9 illustrates a schematic flow chart of a method of operating a wearable electronic device in accordance with the present methods and devices.

FIG. 10 is a flow-diagram showing another method of operating a wearable electronic device in accordance with the present methods and devices.

In the drawings, embodiments of the present methods and devices are illustrated by way of example. It is to be expressly understood that the description and drawings are only for the purpose of illustration and as an aid to understanding, and are not intended as a definition of the limits of the present methods and devices.

DETAILED DESCRIPTION

In the following description, certain specific details are set forth in order to provide a thorough understanding of various disclosed embodiments. However, one skilled in the relevant art will recognize that embodiments may be practiced without one or more of these specific details, or with other methods, components, materials, etc. In other instances, well-known structures associated with electronic devices, and in particular portable electronic devices such as wearable electronic devices, have not been shown or described in detail to avoid unnecessarily obscuring descriptions of the embodiments.

Unless the context requires otherwise, throughout the specification and claims which follow, the word “comprise” and variations thereof, such as, “comprises” and “comprising” are to be construed in an open, inclusive sense, that is as “including, but not limited to.”

Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

As used in this specification and the appended claims, the singular forms “a,” “an,” and “the” include plural referents unless the content clearly dictates otherwise. It should also be noted that the term “or” is generally employed in its broadest sense, that is as meaning “and/or” unless the content clearly dictates otherwise.

The headings and Abstract of the Disclosure provided herein are for convenience only and do not interpret the scope or meaning of the embodiments.

The present methods and devices relate generally to human-computer interface devices, and more specifically to a wearable electronic device that combines signals from on-board muscle activity sensors and on-board inertial sensors in order to provide a gesture-based human-computer interface (HCI).

Throughout this specification and the appended claims, the term “gesture” is used to generally refer to a physical action (e.g., a movement, a stretch, a flex, a pose) performed or otherwise effected by a user. Any physical action performed or otherwise effected by a user that involves detectable muscle activity (detectable, e.g., by at least one appropriately positioned EMG sensor) and/or detectable motion (detectable, e.g., by at least one appropriately positioned inertial sensor, such as an accelerometer and/or a gyroscope) may constitute a gesture in the present methods and devices.

The wearable electronic device includes a band that is worn on the arm (e.g., the forearm) of the user. The band carries a plurality of muscle activity sensors, such as the electromyography (EMG) sensors[TM1] described in US Provisional Patent Application Serial No. 61/771,500, US Provisional Patent Application Serial No. 61/903,238, and/or US Provisional Patent Application Serial No. 61/909,786, each of which is incorporated by reference herein in its entirety.

An EMG signal is an oscillating waveform that varies in both frequency and amplitude, and a majority of signal information may be contained within, for example, the 5Hz to 250Hz frequency band. Advantageously, the EMG sensors used in the wearable electronic devices described herein are active, in that they have an amplification circuit providing an amplification stage located on the sensor board itself. The signal from the EMG sensor may thus be amplified before it is sent to the main logic board (i.e., to the processor) of the wearable electronic device to minimize transmission line interference.

In some applications, cEMG sensors (i.e., capacitive EMG sensors) may sense muscle activity by capacitively coupling to the muscle activity which induces a charge in the cEMG electrode, thereby obviating the need for a direct electrical connection with the skin. Therefore, by avoiding a direct electrical connection, the signal is less susceptible to variations resulting from a direct connection.

In addition to one or more muscle activity sensor(s), the wearable electronic devices described herein also include one or more inertial sensor(s) (which may include, for example, an accelerometer) to measure motions (e.g., accelerations) of the user's arm. The inertial sensor(s) may include one or a set of accelerometers which sense accelerations in three degrees of freedom (x, y, z directions), and may sense the location of the wearable electronic device on the body of a user (e.g. the forearm). The signal(s) provided by the inertial sensor(s) may be combined with the signal(s) provided by the muscle activity sensors in order to improve the quality and/or quantity of gestures identifiable by the wearable electronic device.

The wearable electronic devices described herein may further include a filtering circuit to filter and process the signals provided by the muscle activity sensors and/or by the inertial sensors, and/or an analog-to-digital conversion circuit to convert analog signals provided by the muscle activity sensors and/or inertial sensors into digital signals. The wearable electronic devices described herein include a processor to process the signals provided by the muscle activity sensors and inertial sensors and to identify the physical gestures performed by the user based on either or both of at least one signal provided by at least one muscle activity sensor and at least one signal provided by at least one inertial sensor.

The wearable electronic devices described herein may be connected by wire to a connected device which receives control inputs therefrom (i.e., based on the physical gesture(s) performed by the user and identified by the wearable electronic device), and/or the wearable electronic devices described herein may include one or more batteries and a wireless transceiver module (e.g., a wireless transmitter) for wireless connection to the connected device.

In addition to or instead of EMG sensors, the muscle activity sensors employed in the wearable electronic devices described herein may include mechanomyography (MMG) sensors.

As previously described, methods and devices that employ muscle activity sensors to achieve gesture-based control in an HCI have been described in the art (e.g., in the aforementioned US Patent 8,170,656). However, muscle activity sensors have significant limitations and drawbacks if used alone for the purpose of gesture detection and identification. In accordance with the present methods and devices, gesture-based control in an HCI may be enhanced by implementing wearable electronic devices that combine signals from at least one on-board muscle activity sensor with signals from at least one on-board inertial sensor in order to capture more complete and/or more distinguishable information about the physical gesture(s) being performed by the user. Some of the limitations and drawbacks of muscle activity sensors are now described,

For example, surface electromyographic (sEMG) sensors may be used to measure forearm muscle activity. A sEMG sensor typically requires direct contact with the skin of the user in order to measure the electrical activity conducted from the underlying muscles through the fat and skin, or in order to be sufficiently proximate the underlying muscles in order to capacitively couple thereto. There are some inherent limitations with sEMG, as the quality of the acquired signal is directly related to the skin conditions such as impedance, perspiration, amount of arm hair, fat content, and a number of other attributes. The effects of variations in skin conditions can be mitigated by the use of moisturizing and conductive gels, shaving the skin, or other skin preparation practices to get a reliable and repeatable signal from this type of sensor, but such is undesirable in wearable electronic devices for use by typical consumers.

The various embodiments described herein provide that, in order to accommodate the limitations of muscle activity sensors without invoking impractical solutions such as shaving and conductive gels, one or more inertial sensors (e.g., one or more accelerometer sensors) may be included in the wearable electronic device and used to provide signals representative of, for example, larger gestures made by a user, for example involving the elbow or even the shoulders of a user. When used together with muscle activity sensors for detecting more subtle gestures (e.g. made by the hand and/or wrist for example), information from the inertial sensor(s) can significantly improve the accuracy of gesture identification algorithms and/or expand the number of gestures that a wearable electronic device is able to identify. For example, inertial sensors can provide relative velocity and orientation data in combination with the muscle activity data from muscle activity sensors to increase the quantity and variety of data associated with any particular gesture.

Systems and methods that combine signals provided by muscle activity sensors and signals provided by inertial sensors in order to achieve improved gesture identification have been proposed in the art, as in for example, Xiong et al., "A Novel HCI Based on EMG and IMU," Proceedings of the 2011 IEEE International Conference on Robotics and Biomimetics, December 2011. However, all such proposals involve combining signals from physically disparate sensor systems (e.g., one or more EMG sensors in a first apparatus worn at a first location on the user's body and one or more accelerometers in a second apparatus worn at a second location on the user's body, where the first apparatus and the second apparatus are physically and communicatively decoupled from one another) that separately provide signals to a common off-board computing system (i.e., a computing system that is not wearable or worn by the user) for processing. As a consequence of at least the many separate wire connections to off-board systems and the off-board processing provided by a physically disparate computing system, such proposals suffer from the drawbacks of being bulky and impractical for use by general consumers for general human-electronics interfaces, as well as being severely limited in the variety of electronic/computing devices that they are operable to control. The present methods and devices overcome these drawbacks by incorporating muscle activity sensors, inertial sensors, and a processor all into a single wearable electronic device that detects, processes, and identifies gestures all on-board the device itself.

An illustrative example of a wearable electronic device that incorporates the teachings of the present methods and devices will now be described with reference to the drawings.

Shown in FIG. 1 is an illustrative user 100 wearing a connected device 310 with connected device control 300, and a wearable electronic device 200 in accordance with the present methods and devices. In this illustrative example, wearable electronic device 200 includes a flexible, stretchable, and/or elastic (i.e., "expandable") band that may be worn on the forearm of user 100 as shown. The band carries (i.e., physically couples to) the other components of wearable electronic device 200.

FIG. 2A illustrates a detailed view of the wearable electronic device 200 of FIG. 1 in accordance with the present methods and devices. As shown, wearable electronic device 200 includes an expandable band 201 that carries: a central processing unit (i.e., a "processor") 210, one or more batteries 220, which may be rechargeable, and which may be utilized concurrently or sequentially in conventional manner, muscle activity sensor(s) 230 which, when more than one sensor 230 is included, may be positioned radially around the circumference of band 201 such that the muscle activity sensor(s) 230 can detect muscle activity in response to physical gestures performed by user 100, at least one inertial sensor 260, and a wireless transmitter 250. Muscle activity sensor(s) 230, inertial sensor 260, and wireless transmitter 250 are all communicatively coupled to processor 210 on-board wearable electronic device 200. Wearable electronic device 200 may further include a haptic feedback mechanism, such as a vibratory motor or actuator 240 to provide haptic feedback as described further below.

Processor 210 may be any type of processor, including but not limited to: a digital microprocessor or microcontroller, an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), a digital signal processor (DSP), a graphics processing unit (GPU), a programmable gate array (PGA), a programmable logic unit (PLU), or the like.

Further features and details that may be included in the wearable electronic devices of the present methods and devices (of which wearable electronic device 200 is an illustrative example) are described in, at least: US Provisional Patent Application Serial No. 61/857,105; US Provisional Patent Application Serial No. 61/860,063; US Provisional Patent Application Serial No. 61/822,740; US Provisional Patent Application Serial No. 61/866,960; US Provisional Patent Application Serial No. 61/869,526; US Provisional Patent Application Serial No. 61/874,846; US Provisional Patent Application Serial No. 61/881,064; US Provisional Patent Application Serial No. 61/894,263; US Provisional Patent Application Serial No. 61/915,338; and/or US Provisional

Patent Application Serial No. 61/940,048, each of which is incorporated by reference herein in its entirety.

In some applications, for simplicity, the wearable electronic device 200 may be marked to be worn in the appropriate position and orientation on the arm. For example, a marking on the wearable electronic device 200 may show the top center of the forearm and the direction in which the wearable electronic device 200 should be worn. In other applications, the wearable electronic device 200 may perform a calibration routine when first worn, prior to operation for gesture identification, such that the positioning of the muscle activity sensors 230 is identified and does not need to depend on the location of particular muscles in the forearm.

As an example, muscle activity sensors 230 may include at least one or more capacitive EMG (cEMG) sensors adapted to detect electrical signals in the forearm of user 100 for generating a control signal. cEMG typically does not require direct contact with the skin as with other sEMG sensors described earlier. Rather, cEMG sensors are capacitively coupled to the electrical signals generated by contracting muscles, and may operate at a distance of up to 3mm from the skin. By way of example, the cEMG signal can be an oscillating waveform that varies in both frequency and amplitude, and the majority of signal information may be contained within, for example, the 5Hz to 250Hz frequency band. An illustrative example of a cEMG signal is shown in FIG. 2B.

As another example, muscle activity sensors 230 may include one or more MMG sensors comprising piezoelectric sensors to measure the vibrations at the surface of the skin produced by the underlying muscles when contracted. By way of example, the MMG signal generated may be an oscillating waveform that varies in both frequency and amplitude, and a majority of signal information may be contained within, for example, the 5Hz to 250Hz frequency band. Because the MMG signal is acquired via mechanical means, electrical variations like skin impedance do not have an effect on the signal.

The MMG signal is very similar to the illustrative example of the cEMG signal shown in FIG. 2B.

In some applications, cEMG or MMG may either or both provide a reliable control signal that can be obtained over the duration of a full day, as skin perspiration and moisturization changes do not typically affect the signal.

Inertial sensor 260 may include one or more accelerometer sensors and/or one or more gyroscope sensors for detecting additional aspects of gestures made by user 100 in three degrees of freedom. The inertial sensor signal may consist of three digital channels of data, each representing the acceleration in either the x, y, or z direction. The inertial sensor 260 may be subject to all of the accelerations that the user's arm is subject to, and may further incorporate motion of the body as a whole. As an example, inertial sensors 260 may include an inertial measurement unit (IMU) such as an MPU-9150 Nine-Axis MEMS MotionTracking™ Device from InvenSense that comprises multiple inertial sensors, including multiple accelerometer(s) and multiple gyroscopes.

Now referring to FIG. 3, shown is an illustration of wireless communication (e.g. Bluetooth) between wearable electronic device 200 and a connected device 310 and connected device control 300. The illustrative connected device in this example is a wearable heads-up display. However, it will be appreciated that the connected device may be one of any number of devices that may receive a control input, including but not limited to a general purpose computer, a robot, an electronic consumer device, a mobile phone, etc.

This wireless communication is utilized to transmit at least one signal from wearable electronic device 200 to connected device control 300 in response to the processor 210 of wearable electronic device 200 identifying a physical gesture performed by the user 100. This is illustrated by way of example in FIG. 4, in which user 100's hand and wrist gesture is detected by muscle activity sensors 230 and/or by inertial sensor 260, each or both of which provide at least one signal that is processed by processor 210 to identify the gesture performed by the user, and, in response to identifying the gesture, at least one signal is wirelessly transmitted by transmitter 250 for interacting with content displayed on the connected device 310.

In this particular example, a physical gesture 410 performed by the user 100 involves extending an index finger, which is detected by muscle activity sensors 230 of wearable electronic device 200, and making a wrist flexion motion 420, which is detected by inertial sensor 260 of wearable electronic device 200. In response to the detected muscle activity and the detected motion, muscle activity sensors 230 and inertial sensor 260, respectively, provide signals to on-board processor 210 of wearable electronic device 200. Processor 210 processes both of the signals, identifies the physical gesture performed by the user 100 based on both of the signals, and provides at least one control signal to wireless transmitter 250, which transmits the control signal to connected device 310 for causing a menu appearing on display 310 to scroll downwards.

As another example, a similar gesture performed by user 100 may involve extending the index finger, which is detected by muscle activity sensors 230 of wearable electronic device 200, and making a wrist extension motion, which is detected by inertial sensor 260 of wearable electronic device 200. In response to the detected muscle activity and the detected motion, muscle activity sensors 230 and inertial sensor 260, respectively, provide signals to on-board processor 210 of wearable electronic device 200. Processor 210 processes both of the signals, identifies the physical gesture performed by the user 100 based on both of the signals, and provides at least one control signal to wireless transmitter 250, which transmits the control signal to connected device 310 for causing a menu appearing on display 310 to scroll upwards.

As yet another example, another gesture performed by user 100 may involve extending the index finger, which is detected by muscle activity sensors 230 of wearable electronic device 200, and making a poking motion involving a slight movement of the elbow and shoulder, which is detected by inertial sensor 260 of wearable electronic device 200. In response to the detected muscle activity and the detected motion, muscle activity sensors 230 and inertial sensor 260, respectively, provide signals to processor 210 of wearable electronic device 200. Processor 210 processes both of the signals, identifies the physical gesture performed by the user 100 based on both of the signals, and provides at least one control signal to wireless transmitter 250, which transmits the control signal to connected device 310 for causing a highlighted menu item appearing on display 310 to be selected.

In each of the three examples described above, at least one signal provided by at least one muscle activity sensor 230 and at least one signal provided by at least one inertial sensor 260 are both processed simultaneously by processor 210 in order to identify the physical gesture performed by user 100. In each case, at least one muscle activity sensor 230 detects the extension of user 100's index finger and at least one inertial sensor 260 detects a unique motion: wrist flexion, wrist extension, and poking. The extension of user 100's index finger and the motion (i.e., the wrist flexion, wrist extension, or poking action) may be processed as multiple components of a single physical gesture or as two separate gestures. As an alternative to simultaneously processing, by processor 210, both the at least one signal from muscle activity sensors 230 and the at least one signal from inertial sensor 260, the signals may be processed in sequence or in series. For example, the at least one signal from muscle activity sensors 230 may first be processed by processor 210 to identify that user 100 has performed a first gesture (i.e., extending the index finger) and then the at least one signal from inertial sensor 260 may be processed by processor 210 to identify that user 100 has performed a second gesture (i.e., a wrist flexion, a wrist extension, or a poking action). In this case, when processor 210 identifies (based on at least one signal from muscle activity sensors 230) that user 100 has performed an extension of their index finger, a first signal may be transmitted from transmitter 250 to, for example, indicate to connected device 310 that a menu navigation command is forthcoming. Then, when processor 210 identifies (based on at least one signal from inertial sensor 260) that user 100 has performed a second gesture characterized by a motion (i.e., a wrist flexion, a wrist extension, or a poking action), a corresponding second signal may be transmitted from transmitter 250 to effect a corresponding menu navigation action.

If the user extends a different finger other than the index finger, muscle activity sensors 230 will detect this and will cause a different gesture to be identified by processor 210, which may cause a different control signal to be generated. For example, extending the pinky finger instead of the index finger may cause wearable electronic device 200 to interpret the user's gestures with functions analogous to clicking a right mouse button rather than a left mouse button in a conventional mouse user interface. Extending both the index and pinky fingers at the same time may cause wearable electronic device 200 to interpret the user's gestures with yet other functions analogous to clicking a third mouse button in a conventional mouse user interface.

In accordance with the present methods and devices, wearable electronic device 200 incorporates both muscle activity sensors 230 and inertial sensors 260 to recognize a wider range of user gestures (and/or to provide enhanced accuracy in recognizing gestures) than is typically achievable using muscle activity sensors alone.

Advantageously, wearable electronic device 200 is itself adapted to identify gestures from the detected signals as described. However, in an alternative implementation, the detected signals may be transmitted to the connected device 310 and connected device control 300 to be interpreted as gestures at the connected device control 300. Whether the detected signals are interpreted at the device 200 or at the connected device control 300, the detected signal is first interpreted as a recognized gesture in order to interact with content displayed on the display 310.

In some implementations, upon interpretation of a gesture, wearable electronic device 200 may include a haptic feedback module to provide feedback to user 100 when a gesture has been recognized. This haptic feedback provides a user with confirmation that the user's gesture has been recognized and successfully converted to a control signal to interact with, for example, content displayed on display 310. The haptic feedback module may comprise, for example, a vibrating mechanism such as a vibratory motor 240 or actuator built into the wearable electronic device 200.

Alternatively, rather than haptic feedback provided by the wearable electronic device 200, confirmation of recognition of a gesture may be provided by auditory feedback, either generated by a speaker on the wearable electronic device, or operatively connected to the connected device 310.

In still another example, confirmation of recognition of a gesture may also be provided visually on the display 310 itself. If there is more than one possible gesture that may be interpreted from the detected signals, rather than providing a possibly erroneous signal, the wearable electronic device 200 and/or the connected device control 300 may provide a selection of two or more possible gestures as possible interpretation, and the user may be prompted to select (e.g., by performing a selection gesture) from one of them to confirm the intended gesture and corresponding control.

Now referring to FIG. 5, shown is an illustrative schematic system architecture 500 of a wearable electronic device (e.g., wearable electronic device 200) in accordance with the present methods and devices. As shown, system architecture 500 includes a CPU or “processor” 502, a non-transitory computer-readable storage medium or memory 504, a system clock 506, a wireless communication module 508 (e.g. Bluetooth™, ZigBee™, etc.), and a direct memory access (DMA) controller 510. As shown, DMA controller 510 is adapted to receive inputs from various sensors including one or more EMG (i.e., muscle activity) sensors 520, MMG sensors 530 and accelerometer (i.e., inertial) sensors 540.

In the example of architecture 500, detected analog signals from one or more EMG sensors 520 are processed through signal filtering circuit 522. The signal(s) may be band-passed between, for example, 10Hz to 500Hz, and amplified by an amplification circuit by a total of, for example, about 1000 to 4000 times. However, this filtering and amplification can be altered by software and/or by hardware to whatever is required based on the analog signal generated by the EMG sensors 520. A notch filter at 60Hz, or at any other relevant frequency, may also be used to remove powerline noise.

The signal(s) may be converted from analog to digital signals by analog-to-digital conversion circuit (ADC) 524, for example at 12-bit resolution, and then clocked into onboard memory 504 by the DMA controller 510 to later be processed by the CPU/processor 502. Once data has accumulated, the CPU/processor 502 wakes up and processes this data stored in memory 504. The number of data points that accumulate before the CPU 502 wakes up is adjustable, and is referred to herein as the feature window size.

If one or more MMG sensors 530 are also used, then the detected signals from the MMG sensors 530 are processed through signal filter 532 and converted from analog to digital signals by ADC 534. Digital signals from one or more accelerometer sensors 540 may also be processed through signal filter 542 and received by DMA controller 510.

Gesture Training

In some applications, wearable electronic device 200 may be provided with a set of pre-defined gestures already stored in the memory thereof, with device 200 being operable to identify when the user performs a gesture from the set of pre-defined gestures. Either instead of or in addition to pre-defined gestures, wearable electronic device 200 may be trained to recognize a variety of user-defined gestures. For example, the user may first input a name for a gesture that the user wants the device 200 to be able to recognize, and when the device 200 is ready to record the gesture, the device 200 will prompt the user to make the gesture. The muscle activity sensor(s) and/or the inertial sensor(s) are then used to acquire data channels sampled on the band (e.g. at 1000Hz) over a sufficient length of time to cover the duration of the gesture being performed.

The acquired data may then be segmented into windows with a predetermined length, where each window overlaps the previous window by a predetermined length (including a predetermined length of zero). Features of the muscle activity signal(s) and/or inertial sensor signal(s) are then calculated from each window on each channel of data. These features are chosen to extract the most relevant information from the raw sensor data to classify the gesture. For example, if there are eight cEMG channels, and the window size is 100 samples, then the raw window vector is 100x8 in size. If, for example, 15 features are chosen to represent the raw cEMG data, then the resultant feature vector calculated from that window would be 1x (8 x 15), or 1 x 120.

In an illustrative example, 100 samples may be used for the window size and the gesture training module may utilize a sliding window with an overlap (e.g. 50%). This is illustrated by example in FIG. 6, where W_1 represents a window size, W_2 represents a second window of the same size, and there is an overlap between the two.

Thus, the vector acquisition frequency may be, for example, sampleFreq / windowSize. The features may include, but are not limited to, wavelet decomposition coefficients, RMS value, slope sign changes, wave length autoregressive coefficients, etc.

In addition to data acquired from EMG sensors, data acquired from an IMU (accelerometer) may also be segmented into windows that may, for example, correspond to the EMG data of the same instants in time. The features extracted from IMU data may include, but are not limited to, the RMS value, the mean and the standard deviation of the signal.

To train the pattern recognition system, the gesture training module may use two sets of data, including example inputs to the system, and the corresponding outputs from the system. The inputs to the gesture training and pattern recognition system are the features that have been calculated from the windows segmented from the raw EMG data, as well as the IMU (accelerometer) data. The outputs from this system are the detected gestures.

While the user is in the gesture training phase of the system, the user is telling the system what gesture he is performing. This user-defined gesture is what will become the output of the system when it enters the real time classification mode. While the system now knows which segments of data correspond to what gesture (since the user defined it), the system does not yet know within that segment of data where the gesture begins and ends (as the user is not always going to start and finish the gesture at the same instant of time every iteration). Therefore, the beginning and end of the gesture must be identified and distinguished from when the user is not performing the gesture.

As an example, the beginning and end of a gesture may be determined through EMG data. Assuming that a user has already performed an "on" gesture to turn on the wearable electronic device 200, then the system may monitor a signal channel with an RMS value that exceeds a certain threshold, as illustrated by example in FIG. 8. Once that threshold has been exceeded, then the system begins to calculate the features from the data windows and attempts to classify the gestures.

As an example, features may be calculated by analyzing the RMS value of the EMG and/or IMU data signals. More specifically, when the RMS value of any of the channels of, for example, EMG data becomes greater than the average of the channel when no gesture is being performed, plus three times the standard deviation of the data when no gesture is being performed, then the system may identify that a gesture is being performed. A separate label vector may be created in synchronization with the data that is being recorded for the gesture. This label vector may contain the data that tells the machine learning algorithms when the feature vectors represent a gesture and what gesture that is, and when the feature vectors represent no input. This information is useful for a supervised learning of the pattern recognition algorithm in the next stage described below.

Pattern Recognition Engine

Once the user has finished recording a number of iterations of each gesture, for however many gestures they want to recognize, the wearable electronic device begins the pattern recognition phase. As an example, the wearable electronic device may gather all the recorded feature vectors and their corresponding label vectors into a large matrix representing all of the gestures and all of their iterations.

As shown in FIG. 7, in an illustrative example, the hierarchy of the pattern recognition system may comprise a classifier (e.g., a decision tree) 700 with each node representing a different classifier. The result from each classifier will determine which branch to traverse down to get to the next node.

As an example, the first node of the classifier 700 may determine if the gesture is static or dynamic. This may be determined from the standard deviation of the accelerometer signal.

The second node of the classifier 700 may determine whether the gesture is a long or short duration gesture. This may be determined by the length of the activated segment of the RMS value of the EMG signals. For example, a finger snap gesture or a flick gesture may be a short gesture that is almost instantaneous. A long gesture may be a gesture that takes longer than a short instance to complete.

The third node of the classifier 700 may determine the orientation of the hand gesture from the mean value of the IMU, including, for example, data from the three axes of the accelerometers.

The last node of the classifier 700 may use any one of either a Hidden Markov Model, Long-Short Term Neural Net, or other machine intelligence method to classify between the remaining gestures.

The training data may be used to train each of the nodes of this classifier 700 such that the wearable electronic device will be able to correctly identify unknown gesture data that is detected by the sensors thereof.

Real Time Classification

Once the wearable electronic device has been trained, and a pattern recognition engine has been established, the device is configured for real time classification and recognition of a gesture it has been trained to recognize.

As an example, data is collected from the muscle activity sensor(s) and inertial sensor(s) in the wearable electronic device and stored in the device's on-board non-transitory computer-readable memory. The device may wait (i.e., continue to collect data without attempting to identify the gesture performed by the user) until a predetermined number of samples has been recorded as per the feature window size. When the predetermined number of samples has been reached, the processor in the wearable electronic device calculates all of the features from that block of data, and passes a vector containing the features to the classifier.

Data may be passed through the different nodes of the decision tree as described above, and then on to a final classifier where the gesture is recognized/identified. Once the gesture has been recognized, the gesture and its attributed data are sent to a transceiver module (e.g., a wireless transmitter) to be sent to a connected device.

If the recognized gesture is determined to be one that utilizes the accelerations of the arm as a positional control input, then the velocity of the arm may also be calculated from the accelerations detected by the IMU, and that data is also sent out over the transceiver to the connected device.

Upon successful recognition of a gesture, the vibration motor/actuator in the wearable electronic device can be triggered to vibrate for a duration of time to indicate to the user that a gesture has been successfully recognized/identified. The vibratory motor can be used in other ways to convey information to the user. For example, subtle vibration may be activated during the course of a dynamic gesture, vibration may be used to indicate the device has been woken up, vibration may be used to indicate the device needs to be recalibrated or there is an issue, etc.

Illustrative Methods

Now referring to FIG. 9, shown is a schematic flow chart of an illustrative method 900 of operating a wearable electronic device (e.g., wearable electronic device 200) in accordance with the present methods and devices.

As shown, method 900 begins at block 902, where method 900 begins by acquiring signals (e.g. a window of data) from a plurality of muscle activity (e.g., EMG) sensors and at least one inertial (e.g., IMU) sensor.

Next, at decision block 904, method 900 determines if the RMS of the signals is above a predetermined threshold, to determine if the user has performed or is performing a physical gesture. If no, method 900 returns to block 902. If yes, method 900 then proceeds to block 906, where method 900 calculates the features from acquired data. Method 900 then proceeds to block 908, where method 900 performs pattern recognition on the feature vectors to determine the gesture performed or being performed.

In this example, method 900 then proceeds to decision block 910, where method 900 determines if a connected device requires positional data. If yes, method 900 proceeds to block 912, where method 900 sends an identified gesture together with positional IMU data (e.g. relative velocity and/or orientation) to the connected device. If no, method 900 proceeds to block 914, where method 900 sends the identified gesture to the connected device without positional IMU data. The identified gesture and positional IMU data may be sent over a wired connection to the connected device, or alternatively over a wireless communication protocol.

Method 900 illustrated in FIG. 9 is an example of a method in accordance with the present methods and devices. Another example is provided in FIG. 10.

FIG. 10 is a flow-diagram showing a method 1000 of operating a wearable electronic device in accordance with the present methods and devices. The wearable electronic device (e.g., 200) includes a band (e.g., 201) worn by a user, at least one muscle activity sensor (e.g., 230) carried by the band (e.g., 201), at least one inertial sensor (e.g., 260) carried by the band (e.g., 201), and a processor (e.g., 210) carried by the band (e.g., 201), the processor communicatively coupled to the at least one muscle activity sensor (e.g., 230) and to the at least one inertial sensor (e.g., 260). Method 1000 includes four acts 1001, 1002, 1003, and 1004, with acts 1001 and 1002 both being broken down into two parallel parts: 1001a/b and 1002ab/s, respectively. Those of skill in the art will appreciate, however, that in alternative embodiments certain acts may be omitted and/or additional acts may be added. Those of skill in the art will also appreciate that the illustrated order of the acts is shown for exemplary purposes only and may change in alternative embodiments. To exemplify the relationship between the acts of method 1000 and the elements of the wearable electronic devices described herein, reference to elements of device 200 from FIG 2A are included in parentheses throughout the description of method 1000. However, a person of skill in the art will appreciate that method 1000 may similarly be implemented using hardware that differs from device 200.

At 1001a, muscle activity of a user (e.g., of the arm of a user) is detected by at least one muscle activity sensor (230) carried by the band (201) of the wearable electronic device (200) in response to the user performing a physical gesture. The at least one muscle activity sensor (230) may include a plurality of EMG sensors and any number of EMG sensors in the plurality of EMG sensors may detect the muscle activity depending on the position of each particular EMG sensor relative to the muscle(s) that are active in performing the gesture.

At 1002a, at least one signal is provided from at least one muscle activity sensor (230) to the processor (210) carried by the band (201) of the wearable electronic device (200) in response to the detected muscle activity. The communication path in between the at least one muscle activity sensor (230) and the processor (210) may include any or all of: a filtering circuit to filer the at least one signal provided to the processor (210), an amplification circuit to amplify the at least one signal provided to the processor (210), and/or an analog-to-digital conversion circuit to convert the at least one signal provided to the processor (210) from an analog signal to a digital signal.

Acts 1001b and 1002b may be carried out substantially in parallel with acts 1001a and 1002a, respectively, either at least approximately simultaneously with acts 1001a and 1002a, respectively or staggered/offset from acts 1001a and 1002a.

At 1001b, motion of the user (e.g., of the arm of the user) is detected by at least one inertial sensor (260) carried by the band (201) of the wearable electronic device (200) in response to the user performing a physical gesture. The at least one inertial sensor (260) may include at least one accelerometer and/or at least one gyroscope, which may be packaged in an IMU. As discussed in more detail below, the physical gesture involving motion detected by at least one inertial sensor (260) at 1001b may be the same physical gesture involving muscle activity detected by at least one muscle activity sensor (230) at 1001a or the physical gesture involving motion detected by at least one inertial sensor (260) at 1001b may be a different physical gesture from the physical gesture involving muscle activity detected by at least one muscle activity sensor (230) at 1001a.

At 1002b, at least one signal is provided from at least one inertial sensor (260) to the processor (210) carried by the band (201) of the wearable electronic device (200) in response to the detected motion. The communication path in between the at least one inertial sensor (260) and the processor (210) may include any or all of: a filtering circuit to filer the at least one signal provided to the processor (210), an amplification circuit to amplify the at least one signal provided to the processor (210), and/or an analog-to-digital conversion circuit to convert the at least one signal provided to the processor (210) from an analog signal to a digital signal.

At 1003, the at least one signal provided by at least one muscle activity sensor (230) at 1002a and the at least one signal provided by at least one inertial sensor (260) at 1002b are both processed by the processor (210) carried by the band (201) of the wearable electronic device (200). Depending on the application and whether the at least one signal provided by at least one muscle activity sensor (230) and the at least one signal provided by at least one inertial sensor (260) are in response to the same physical gesture or different physical gestures, the at least one signal provided by at least one muscle activity sensor (230) at 1002a and the at least one signal provided by at least one inertial sensor (260) at 1002b may be processed in sequence/series by the processor (210) or they may be processed simultaneously, either in combination or in parallel, by the processor (210). For example, if the at least one signal provided by at least one muscle activity sensor (230) and the at least one signal provided by at least one inertial sensor (260) are both provided substantially simultaneously in response to a single physical gesture, then the at least one signal provided by at least one muscle activity sensor (230) at 1002a and the at least one signal provided by at least one inertial sensor (260) at 1002b may be processed together in combination by the processor (210) in order to identify the physical gesture. Alternatively, if the at least one signal provided by at least one muscle activity sensor (230) and the at least one signal provided by at least one inertial sensor (260) are each provided separately in response to two separate physical gestures (e.g., performed in series), then the at least one signal provided by at least one muscle activity sensor (230) at 1002a and the at least one signal provided by at least one inertial sensor (260) at 1002b may be processed in series by the processor (210) in order to identify the two separate gestures.

At 1004, a physical gesture performed by the user is identified by the processor (210) carried by the band (201) of the wearable electronic device (200) based on at least one of: i) the at least one signal provided by at least one muscle activity sensor (230); and ii) the at least one signal provided by at least one inertial sensor (260). Returning to the example of a gesture that comprises an index finger extension and a wrist flexion motion in order to control a navigation of a virtual menu (i.e., previously described in the context of FIG. 4), the index finger extension may involve muscle activity that is detected by muscle activity sensors (230) per act 1001a and a corresponding signal may be provided to the on-board processor (210) per act 1002a. Either simultaneously or shortly thereafter (depending on how the user performs the gesture), the wrist flexion may involve motion that is detected by inertial sensor(s) (260) per act 1001b and a corresponding signal may be provided to the on-board processor (210) per act 1002b. The signal(s) from the muscle activity sensors (230) and the signal(s) from the inertial sensor(s) (260) are both processed by the processor (210) per act 1003. Depending on the particular implementation, the physical gesture may be defined as a single gesture comprising an index finger extension and a wrist flexion motion, in which case the gesture may be identified, per act 1004, based on both the signal(s) from the muscle activity sensor(s) (230) and the signal(s) from the inertial sensor(s) 260, or the physical gesture may be defined as having two components that are identified separately: a first gesture comprising an index finger extension that is identified by the processor (210) per act 1004 based on the signal(s) provided by at least one muscle activity sensor (230); and a second gesture comprising a wrist flexion that is identified by the processor (210) per act 1004 based on the signal(s) provided by at least one inertial sensor (260). In either case, in response to identifying the gesture(s) performed by the user, one or more signals (e.g., control signals) may be provided by the processor (210) to a wireless transmitter (250) carried by the band (201) of the wearable electronic device (200) and wirelessly transmitted to any other electronic device in order to effect an action of, function of, control of, or interaction with the other electronic device. In this way, the wearable electronic device (200) provides a general-purpose human-electronics interface.

While a wearable heads-up display device has been used as an illustrative example of a connected device, as will be appreciated, the wearable electronic devices and methods of the present disclosure may be used for interaction with many other types of connected devices in virtually any application in which connected devices are contemplated.

Thus as [TM2]an exemplary aspect, there is provided an apparatus for detecting and analyzing signals for gesture control, comprising: a plurality of capacitive electromyography (cEMG) sensors configured to detect a gesture by measuring in each cEMG sensor an electrical signal produced by an electrical charge induced in an electrode of the cEMG sensors by muscle activity; and a processor configured to receive the one or more electrical signals from the plurality of cEMG sensors as acquired data, process the acquired data by calculating a feature vector representative of a window of acquired data, and detect the gesture by analyzing a resulting feature vector to recognize a pattern.

In this example, the apparatus further comprises one or more inertial measurement unit (IMU) sensors configured to detect motion and orientation of a gesture by measuring relative velocity and orientation of the apparatus; and wherein, the processor is further configured to receive acquired data from the IMU, process the acquired IMU data to determine the position and orientation of the apparatus, and detect the gesture by analyzing the relative velocity and orientation of the apparatus together with the analyzed feature vector.

In this example, the processor may be further configured to utilize one or more of a Hidden Markov Model, Long-Short Term Neural Net, or another machine intelligence method to classify the gestures.

In this example, the processor may be further configured to detect a static gesture or a dynamic gesture in dependence upon analyzing the acquired IMU data together with the analyzed feature vectors.

In this example, the processor may be further configured to determine whether the gesture is a long or short duration gesture by measuring the length of an activated segment of an RMS value of the cEMG signals.

In this example, the processor may be further configured to record one or more user defined gestures by recording the resulting feature vectors, and the position and orientation of the apparatus during the gesture.

In this example, the apparatus may further include one or more mechanomyography (MMG) sensors configured to detect muscle activity produced by a gesture by measuring in each MMG sensor an electrical signal produced by the muscle activity.

In this example, the apparatus may further include a haptic feedback module for providing feedback to a user.

In this example, the haptic feedback module may provide confirmation of recognition of a gesture.

In this example, the haptic feedback module may comprise a vibratory motor and/or actuator.

In another exemplary aspect, there is provided a method for detecting and analyzing signals for gesture control, comprising: providing a plurality of capacitive electromyography (cEMG) sensors on an apparatus configured to detect muscle activity produced by a gesture by measuring in each cEMG sensor an electrical signal produced by an electrical charge induced in an electrode of the cEMG sensor; receiving the one or more electrical signals from the plurality of cEMG sensors as acquired data; processing the acquired data by calculating a feature vector representative of a window of acquired data; and detecting the gesture by analyzing a resulting feature vector to recognize a pattern.

In this example, the method further comprises: receiving acquired data from one or more inertial measurement unit (IMU) sensors; processing the acquired IMU data to determine the relative velocity and orientation of the apparatus; and detecting the gesture by analyzing the position and orientation of the apparatus together with the analyzed feature vector.

In this example, the method may further comprise utilizing one or more of a Hidden Markov Model, Long-Short Term Neural Net, or another machine intelligence method to classify the gestures.

In this example, the method may further comprise detecting a static gesture or a dynamic gesture in dependence upon analyzing the acquired IMU data together with the analyzed feature vectors.

In this example, the method may further comprise determining whether the gesture is a long or short duration gesture by measuring the length of an activated segment of an RMS value of the cEMG signals.

In this example, the method may further comprise recording one or more user defined gestures by recording the resulting feature vectors, and the position and orientation of the apparatus during the gesture.

In this example, the method may further comprise providing one or more mechanomyography (MMG) sensors configured to detect muscle activity produced by a gesture by measuring in each MMG sensor an electrical signal produced by the muscle activity.

In this example, the method may further comprise providing a haptic feedback module for providing feedback to a user.

In this example, the haptic feedback may provide confirmation of recognition of a gesture.

In this example, the haptic feedback may comprises a vibratory feedback provided by a vibratory motor and/or actuator.

Throughout this specification and the appended claims the term “communicative” as in “communicative pathway,” “communicative coupling,” and in variants such as “communicatively coupled,” is generally used to refer to any arrangement for transferring and/or exchanging information. Exemplary communicative pathways include, but are not limited to, electrically conductive pathways (e.g., electrically conductive wires, electrically conductive traces), magnetic pathways (e.g., magnetic media), and/or optical pathways (e.g., optical fiber), and exemplary communicative couplings include, but are not limited to, electrical couplings, magnetic couplings, and/or optical couplings.

Throughout this specification and the appended claims, the term “provide” and variants such as “provided” and “providing” are frequently used in the context of signals. For example, a muscle activity sensor is described as “providing at least one signal” and an inertial sensor is described as “providing at least one signal.” Unless the specific context requires otherwise, the term “provide” is used in a most general sense to cover any form of providing a signal, including but not limited to: relaying a signal, outputting a signal, generating a signal, routing a signal, creating a signal, transducing a signal, and so on. For example, a surface EMG sensor may include at least one electrode that resistively or capacitively couples to electrical signals from muscle activity. This coupling induces a change in a charge or electrical potential of the at least one electrode which is then relayed through the sensor circuitry and output, or "provided," by the sensor. Thus, the surface EMG sensor may "provide" an electrical signal by relaying an electrical signal from a muscle (or muscles) to an output (or outputs). In contrast, an inertial sensor may include components (e.g., piezoelectric, piezoresistive, capacitive, etc.) that are used to convert physical motion into electrical signals. The inertial sensor may "provide" an electrical signal by detecting motion and generating an electrical signal in response to the motion.

Throughout this specification and the appended claims, infinitive verb forms are often used. Examples include, without limitation: "to detect," "to provide," "to transmit," "to communicate," "to process," "to route," and the like. Unless the specific context requires otherwise, such infinitive verb forms are used in an open, inclusive sense, that is as "to, at least, detect," to, at least, provide," "to, at least, transmit," and so on.

The above description of illustrated embodiments, including what is described in the Abstract, is not intended to be exhaustive or to limit the embodiments to the precise forms disclosed. Although specific embodiments of and examples are described herein for illustrative purposes, various equivalent modifications can be made without departing from the spirit and scope of the disclosure, as will be recognized by those skilled in the relevant art. The teachings provided herein of the various embodiments can be applied to other portable and/or wearable electronic devices, not necessarily the exemplary wearable electronic devices generally described above.

For instance, the foregoing detailed description has set forth various embodiments of the devices and/or processes via the use of block diagrams, schematics, and examples. Insofar as such block diagrams, schematics, and examples contain one or more functions and/or operations, it will be understood by those skilled in the art that each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In one embodiment, the present subject matter may be implemented via Application Specific Integrated Circuits (ASICs). However, those skilled in the art will recognize that the embodiments disclosed herein, in whole or in part, can be equivalently implemented in standard integrated circuits, as one or more computer programs executed by one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs executed by on one or more controllers (e.g., microcontrollers) as one or more programs executed by one or more processors (e.g., microprocessors, central processing units, graphical processing units), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of ordinary skill in the art in light of the teachings of this disclosure.

When logic is implemented as software and stored in memory, logic or information can be stored on any computer-readable medium for use by or in connection with any processor-related system or method. In the context of this disclosure, a memory is a computer-readable medium that is an electronic, magnetic, optical, or other physical device or means that contains or stores a computer and/or processor program. Logic and/or the information can be embodied in any computer-readable medium for use by or in connection with an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that can fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions associated with logic and/or information.

In the context of this specification, a “non-transitory computer-readable medium” can be any element that can store the program associated with logic and/or information for use by or in connection with the instruction execution system, apparatus, and/or device. The computer-readable medium can be, for example, but is not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus or device. More specific examples (a non-exhaustive list) of the computer readable medium would include the following: a portable computer diskette (magnetic, compact flash card, secure digital, or the like), a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM, EEPROM, or Flash memory), a portable compact disc read-only memory (CDROM), digital tape, and other non-transitory media.

The various embodiments described above can be combined to provide further embodiments. To the extent that they are not inconsistent with the specific teachings and definitions herein, all of the U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, including but not limited to US Provisional Patent Application Serial No. 61/768,322, filed February 22, 2013, US Provisional Patent Application Serial No. 61/771,500, US Provisional Patent Application Serial No. 61/903,238, US Provisional Patent Application Serial No. 61/909,786, US Provisional Patent Application Serial No. 61/857,105; US Provisional Patent Application Serial No. 61/860,063; US Provisional Patent Application Serial No. 61/822,740; US Provisional Patent Application Serial No. 61/866,960; US Provisional Patent Application Serial No. 61/869,526; US Provisional Patent Application Serial No. 61/874,846; US Provisional Patent Application Serial No. 61/881,064; US Provisional Patent Application Serial No. 61/894,263; US Provisional Patent Application Serial No. 61/915,338; and/or US Provisional Patent Application Serial No. 61/940,048, are incorporated herein by reference, in their entirety. Aspects of the embodiments can be modified, if necessary, to employ systems, circuits and concepts of the various patents, applications and publications to provide yet further embodiments.

These and other changes can be made to the embodiments in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the claims to the specific embodiments disclosed in the specification and the claims, but should be construed to include all possible embodiments along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

While various embodiments and illustrative examples have been described above, it will be appreciated that these embodiments and illustrative examples are not limiting, and the scope of the invention is defined by the following claims.

CLAIMS

1. A wearable electronic device comprising:

a band that, in use, is worn by a user;

at least one muscle activity sensor carried by the band, the at least one muscle activity sensor to, in use, detect muscle activity in response to the user performing a physical gesture and provide at least one signal in response to the detected muscle activity;

at least one inertial sensor carried by the band, the at least one inertial sensor to, in use, detect motion in response to the user performing a physical gesture and provide at least one signal in response to the detected motion; and

a processor carried by the band, the processor communicatively coupled to the at least one muscle activity sensor and to the at least one inertial sensor and the processor to, in use, identify a physical gesture performed by the user based on either or both of:

at least one signal provided by the at least one muscle activity sensor; and

at least one signal provided by the at least one inertial sensor.

2. The wearable electronic device of claim 1, further comprising a non-transitory computer-readable storage medium carried by the band and communicatively coupled to the processor, wherein the non-transitory computer-readable storage medium stores processor executable instructions that, when executed by the processor, cause the processor to identify a physical gesture performed by the user based on either or both of:

at least one signal provided by the at least one muscle activity sensor; and

at least one signal provided by the at least one inertial sensor.

3. The wearable electronic device of claim 2 wherein the non-transitory computer-readable storage medium stores processor executable instructions that, when executed by the processor, cause the processor to perform a machine intelligence method to identify a physical gesture performed by the user based on either or both of:

at least one signal provided by the at least one muscle activity sensor; and

at least one signal provided by the at least one inertial sensor.

4. The wearable electronic device of claim 3 wherein the processor executable instructions stored in the non-transitory computer-readable storage medium include processor executable instructions that, when executed by the processor, cause the processor to implement at least one of: a classifier, a Hidden Markov Model, and/or a Long Short Term Neural Net.

5. The wearable electronic device of claim 1, further comprising a wireless transmitter carried by the band, the wireless transmitter communicatively coupled to the processor to, in use, wirelessly transmit at least one signal in response to the processor identifying a physical gesture performed by the user.

6. The wearable electronic device of claim 1 wherein the at least one muscle activity sensor includes at least one muscle activity sensor selected from the group consisting of: an electromyography (EMG) sensor and a mechanomyography (MMG) sensor.

7. The wearable electronic device of claim 1 wherein the at least one muscle activity sensor includes a plurality of electromyography (EMG) sensors.

8. The wearable electronic device of claim 1, further comprising a haptic feedback module carried by the band, the haptic feedback module to, in use, provide haptic feedback to the user.

9. The wearable electronic device of claim 8 wherein the haptic feedback module includes a vibratory motor.

10. The wearable electronic device of claim 1 wherein the band is expandable.

11. The wearable electronic device of claim 1, further comprising at least one additional component carried by the band, the at least one additional component selected from the group consisting of: an amplification circuit communicatively coupled to the at least one muscle activity sensor, a filtering circuit communicatively coupled to the at least one muscle activity sensor, an analog-to-digital conversion circuit communicatively coupled to the at least one muscle activity sensor, and a battery electrically coupled to the processor.

12. The wearable electronic device of claim 1 wherein the at least one inertial sensor includes at least one inertial sensor selected from the group consisting of: an accelerometer, a gyroscope, and an inertial measurement unit (IMU).

13. A method of operating a wearable electronic device, wherein the wearable electronic device includes a band worn by a user, at least one muscle activity sensor carried by the band, at least one inertial sensor carried by the band, and a processor carried by the band, the processor communicatively coupled to the at least one muscle activity sensor and to the at least one inertial sensor, the method comprising:

detecting, by at least one muscle activity sensor carried by the band of the wearable electronic device, muscle activity in response to the user performing a physical gesture;

providing at least one signal from at least one muscle activity sensor to the processor in response to the detected muscle activity;

detecting, by at least one inertial sensor carried by the band of the wearable electronic device, motion in response to the user performing a physical gesture;

providing at least one signal from at least one inertial sensor to the processor in response to the detected motion;

processing, by the processor carried by the band of the wearable electronic device, the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor; and

identifying, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user based on at least one of:

the at least one signal provided by at least one muscle activity sensor; and

the at least one signal provided by at least one inertial sensor.

14. The method of claim 13 wherein identifying, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user includes identifying, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user based on both the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor.

15. The method of claim 13 wherein identifying, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user includes:

identifying, by the processor carried by the band of the wearable electronic device, a first physical gesture performed by the user based on the at least one signal provided by at least one muscle activity sensor; and

identifying, by the processor carried by the band of the wearable electronic device, a second physical gesture performed by the user based on the at least one signal provided by at least one inertial sensor.

16. The method of claim 13 wherein processing, by the processor carried by the band of the wearable electronic device, the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor includes utilizing one or more of a classifier, a Hidden Markov Model, a Long-Short Term Neural Net, or another machine intelligence method to process the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor.

17. The method of claim 13 wherein the wearable electronic device further includes a wireless transmitter carried by the band and communicatively coupled to the processor, the method further comprising:

wirelessly transmitting at least one signal in response to the processor identifying a physical gesture performed by the user.

18. The method of claim 13 wherein the wearable electronic device further includes an amplification circuit carried by the band and communicatively coupled to at least one muscle activity sensor, the method further comprising:

amplifying, by the amplification circuit, the at least one signal from at least one muscle activity sensor before providing the at least one signal from at least one muscle activity sensor to the processor.

19. The method of claim 13 wherein the wearable electronic device further includes a filtering circuit carried by the band and communicatively coupled to at least one muscle activity sensor, the method further comprising:

filtering, by the filtering circuit, the at least one signal from at least one muscle activity sensor before providing the at least one signal from at least one muscle activity sensor to the processor.

20. The method of claim 13 wherein the wearable electronic device further includes an analog-to-digital conversion circuit carried by the band and communicatively coupled to at least one muscle activity sensor, the method further comprising:

converting, by the analog-to-digital conversion circuit, the at least one signal from at least one muscle activity sensor from an analog signal to a digital signal before providing the at least one signal from at least one muscle activity sensor to the processor.

21. The method of claim 13 wherein the at least one muscle activity sensor includes a plurality of electromyography (EMG) sensors, and wherein:

detecting, by at least one muscle activity sensor carried by the band of the wearable electronic device, muscle activity in response to the user performing a physical gesture includes detecting, by at least one EMG sensor in the plurality of EMG sensors carried by the band of the wearable electronic device, muscle activity in response to the user performing a physical gesture; and providing at least one signal from at least one muscle activity sensor to the processor in response to the detected muscle activity includes providing at least one signal from at least one EMG sensor in the plurality of EMG sensors to the processor in response to the detected muscle activity.

22. The method of claim 13 wherein the wearable electronic device further includes a haptic feedback module carried by the band, the haptic feedback module including a vibratory motor that is communicatively coupled to the processor, the method further comprising: providing haptic feedback to the user by the vibratory motor in response to the processor identifying a physical gesture performed by the user.

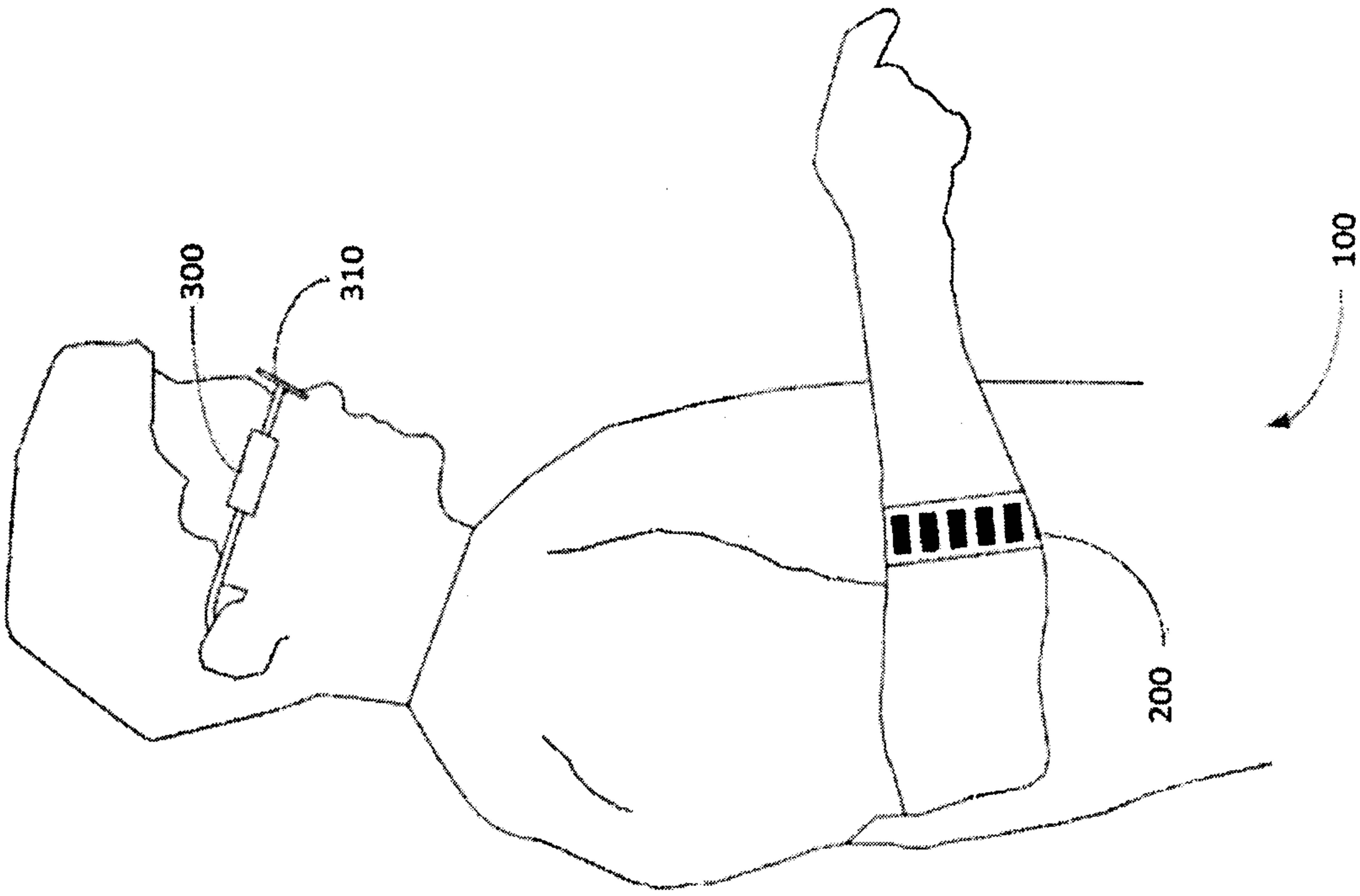

FIG. 1

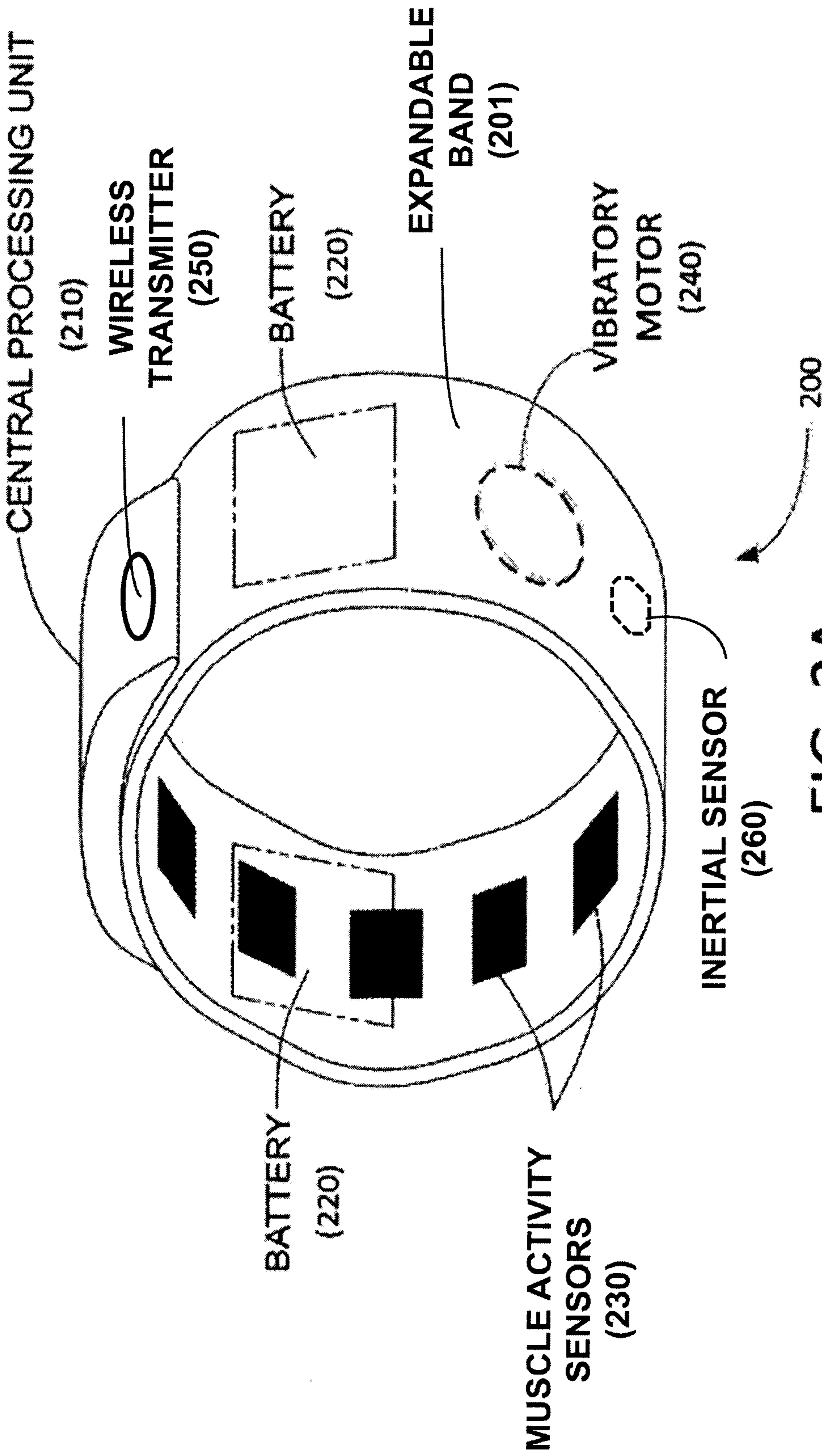
CENTRAL PROCESSING UNIT (210)
WIRELESS TRANSMITTER (250)
BATTERY (220)
EXPANDABLE BAND (201)
VIBRATORY MOTOR (240)
200
INERTIAL SENSOR (260)
MUSCLE ACTIVITY SENSORS (230)
BATTERY (220)

FIG. 2A

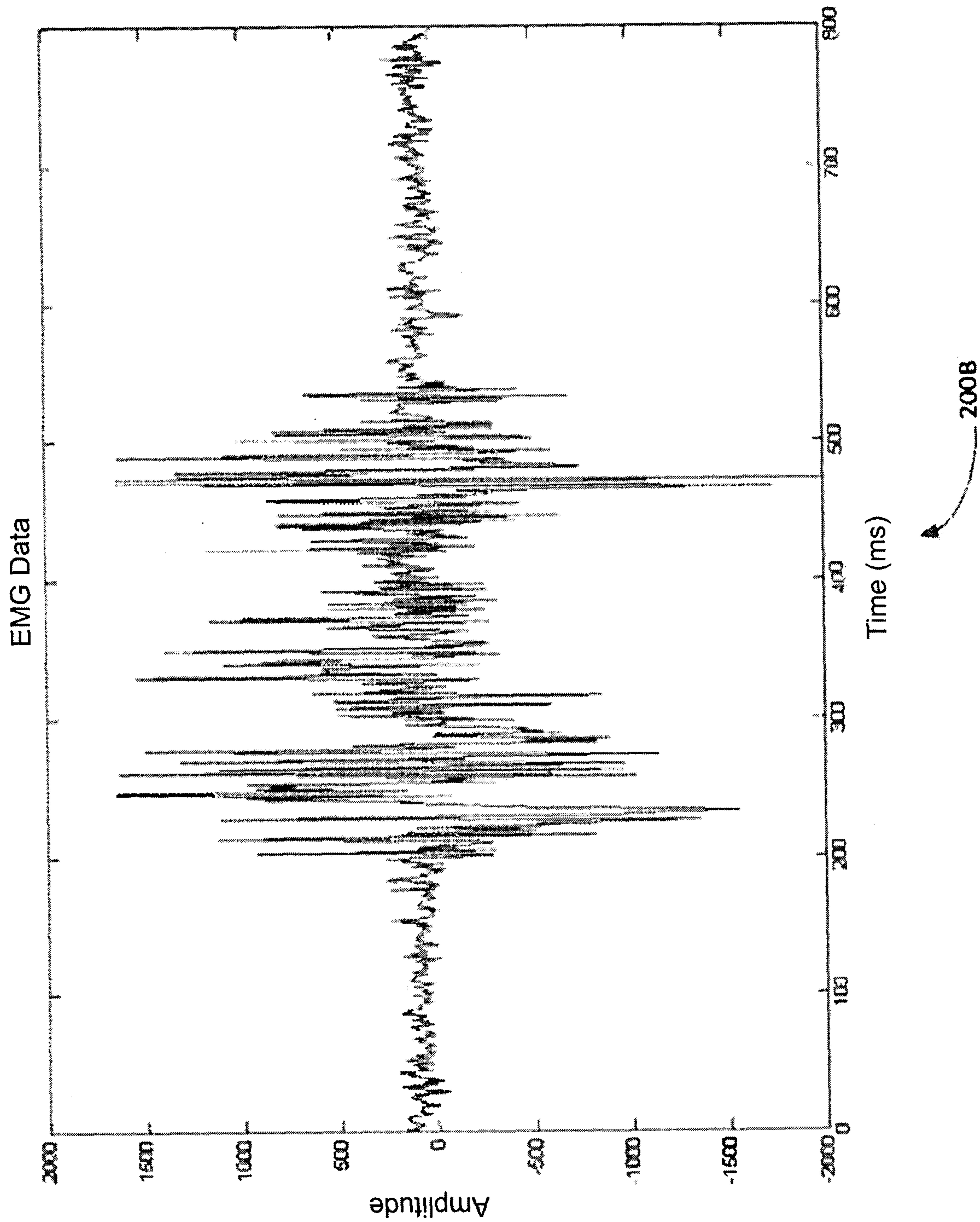

FIG. 2B

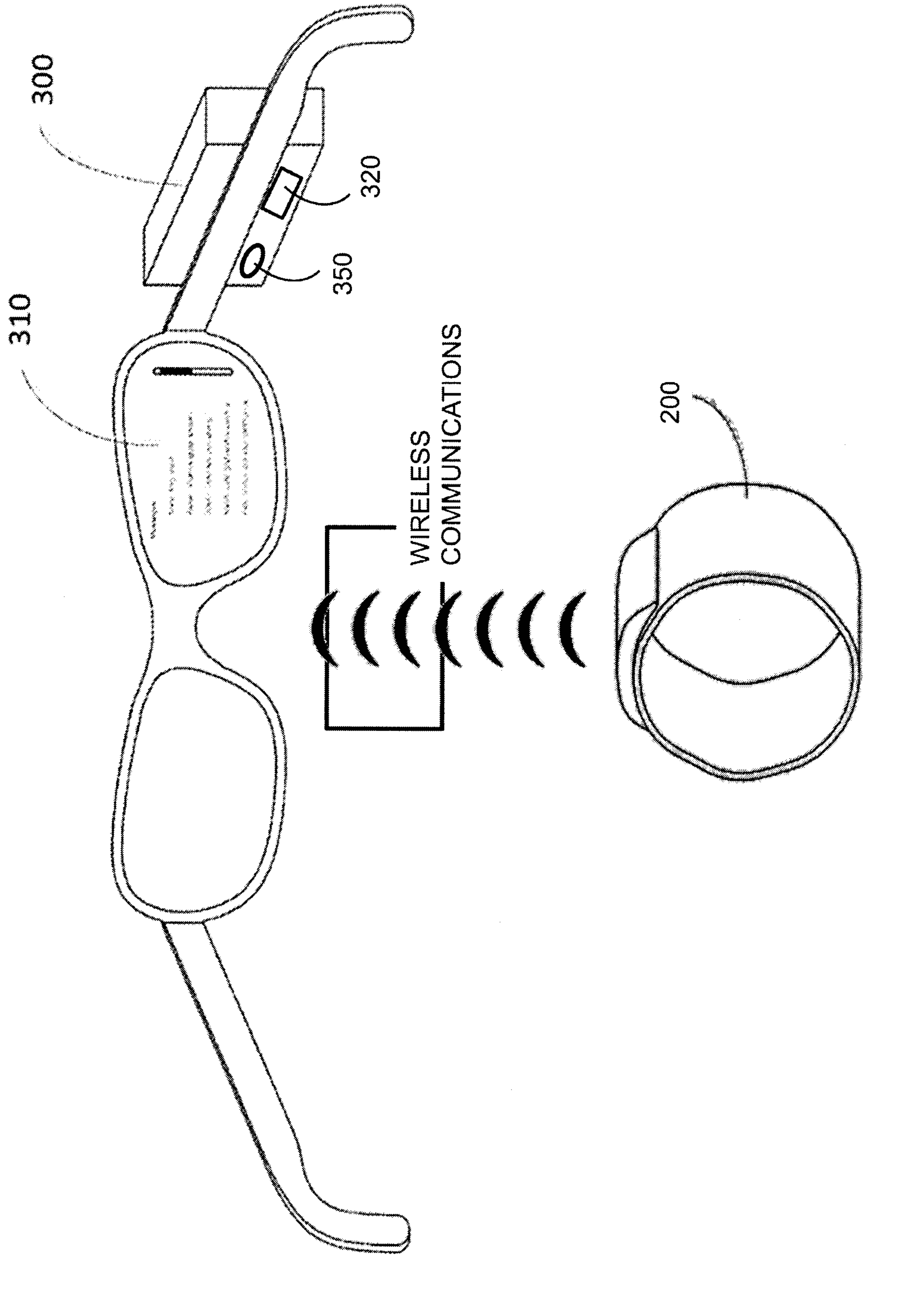

FIG. 3

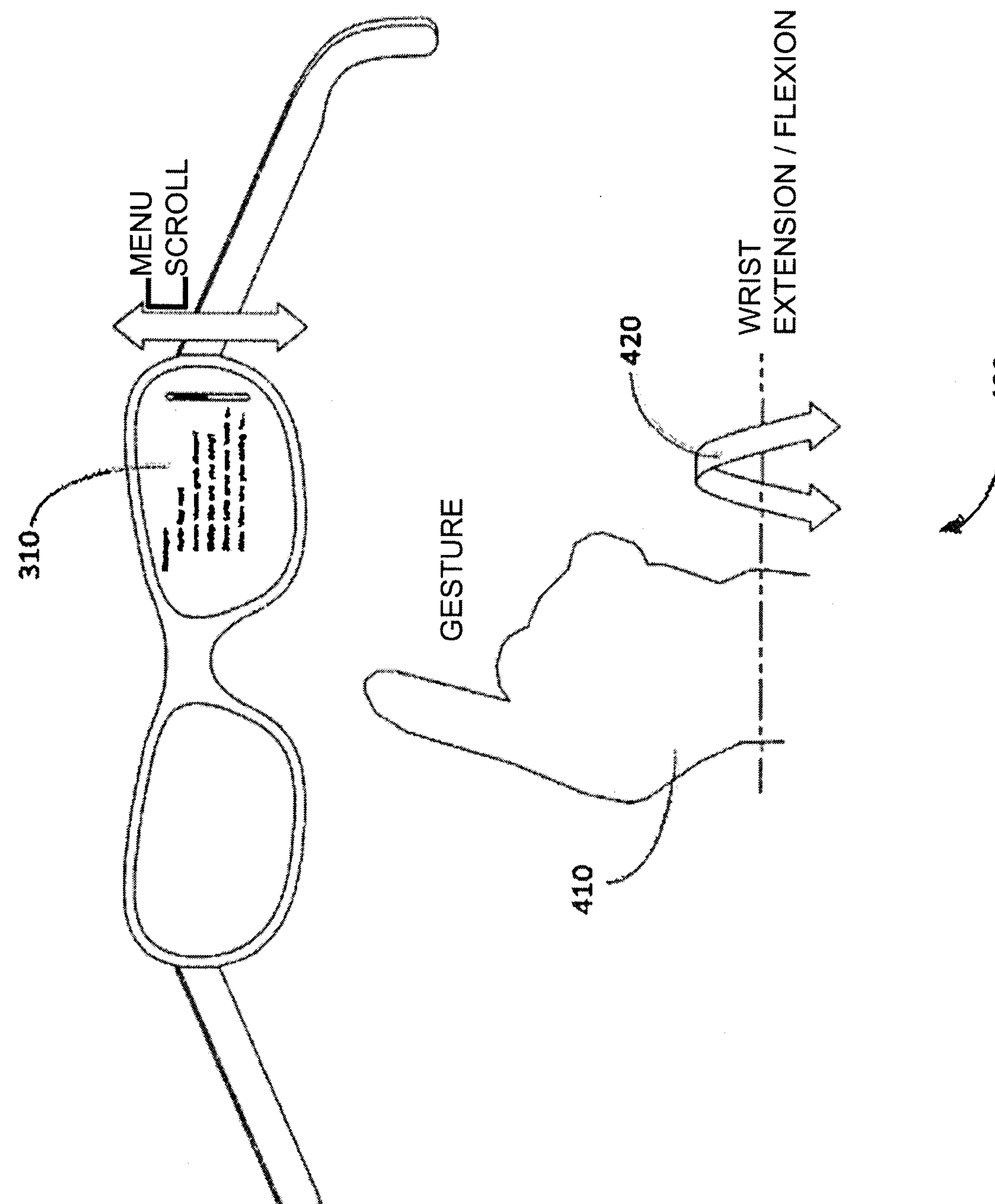
310
MENU
SCROLL
GESTURE
420
WRIST
EXTENSION / FLEXION
410
400

FIG. 4

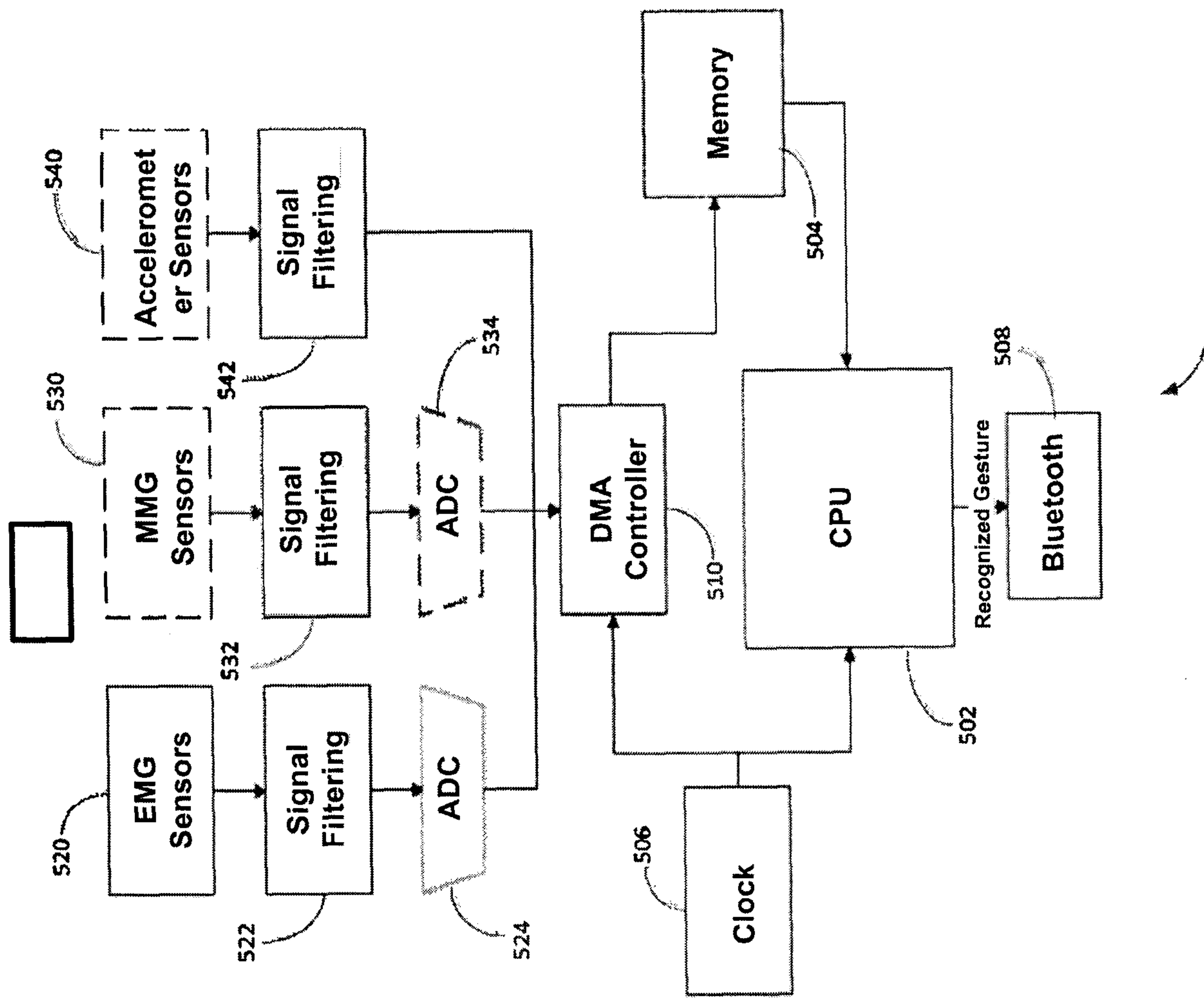
Accelerometer Sensors
540
Signal Filtering
542
MMG Sensors
530
Signal Filtering
532
ADC
534
EMG Sensors
520
Signal Filtering
522
ADC
524
Memory
504
DMA Controller
510
CPU
502
Clock
506
Recognized Gesture
Bluetooth
508
500

FIG. 5

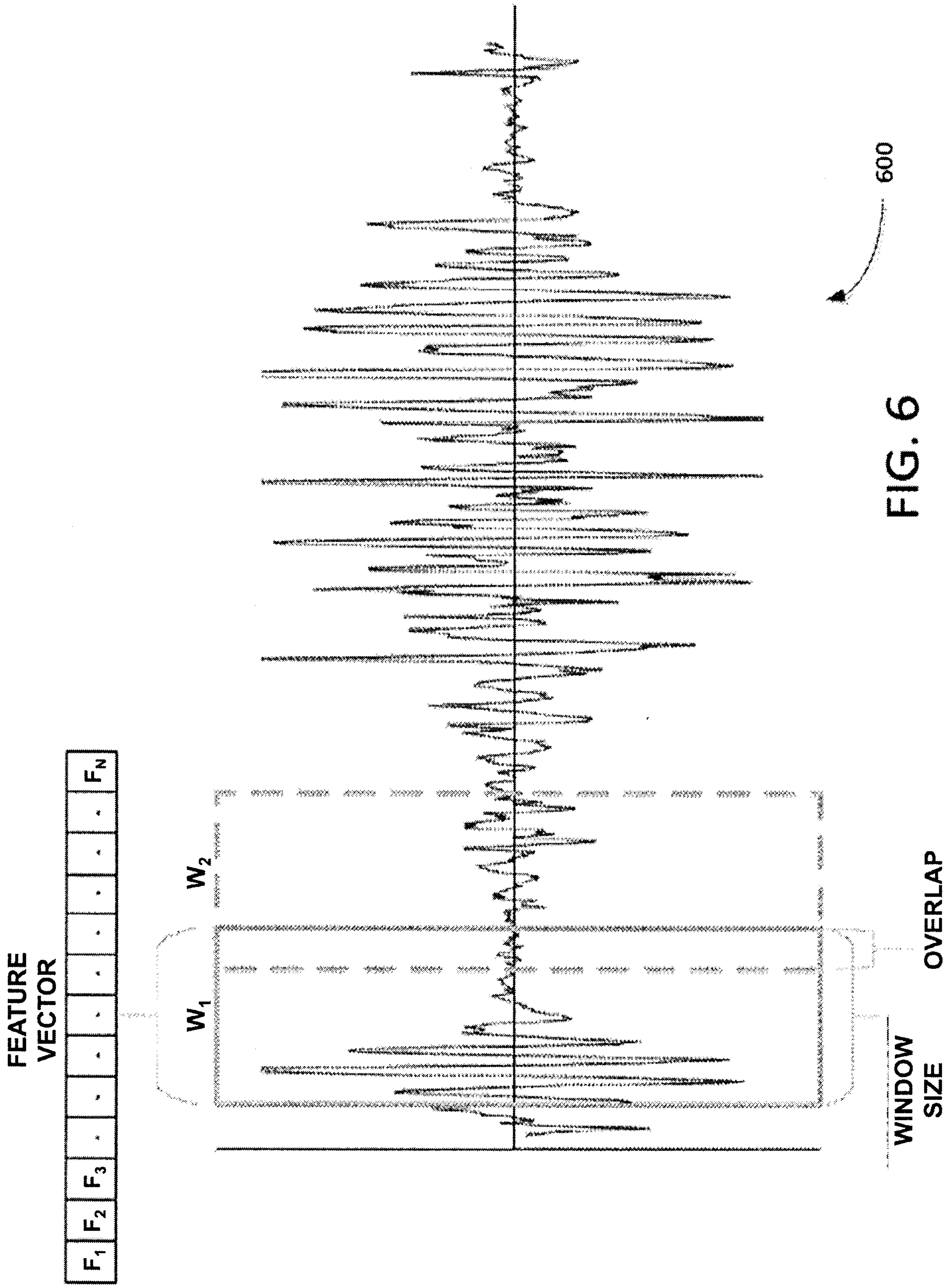

FIG. 6

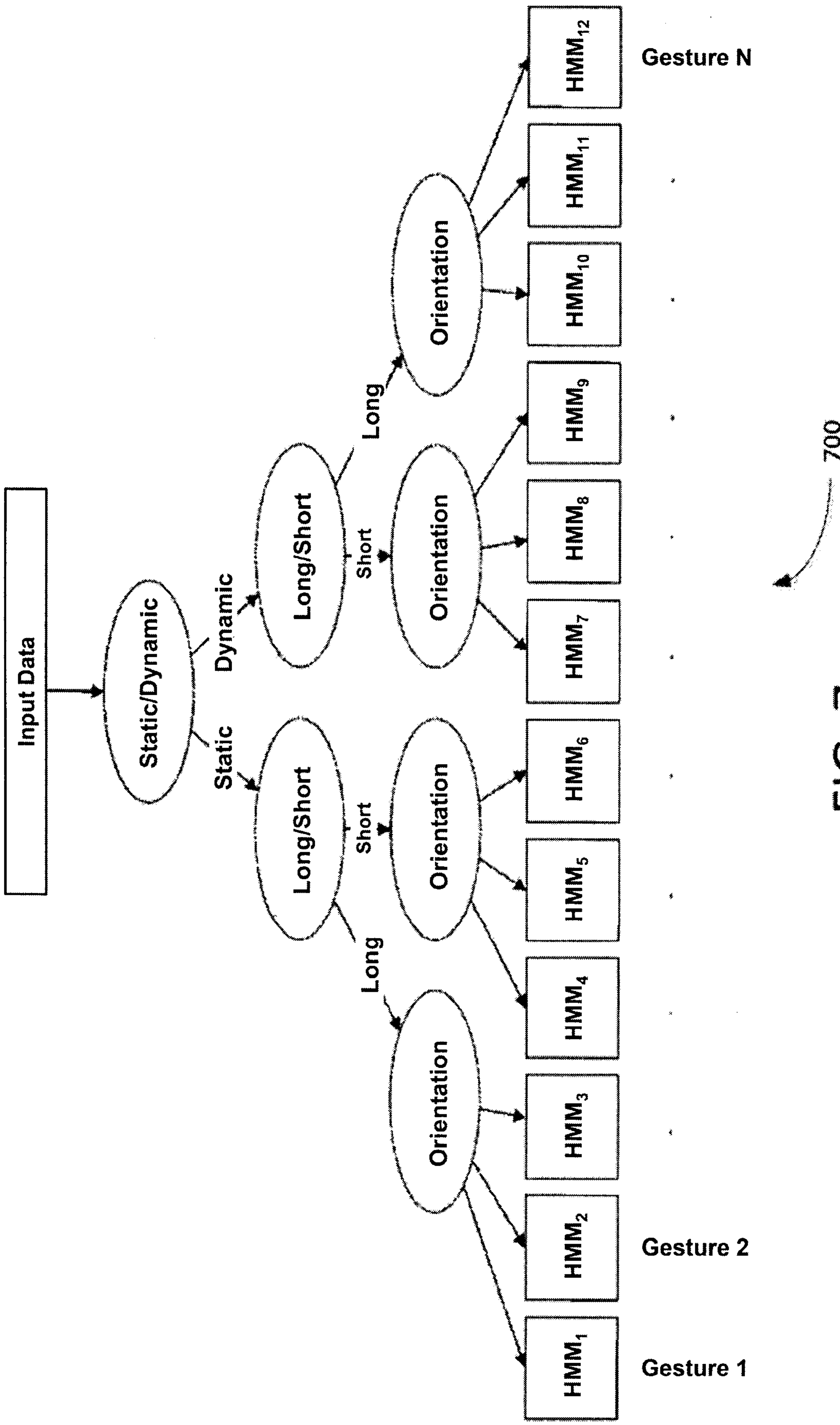
Input Data
Static/Dynamic
Static
Dynamic
Long/Short
Long/Short
Long
Short
Short
Long
Orientation
Orientation
Orientation
Orientation
HMM_1
HMM_2
HMM_3
HMM_4
HMM_5
HMM_6
HMM_7
HMM_8
HMM_9
HMM_{10}
HMM_{11}
HMM_{12}
Gesture 1
Gesture 2
Gesture N
700

FIG. 7

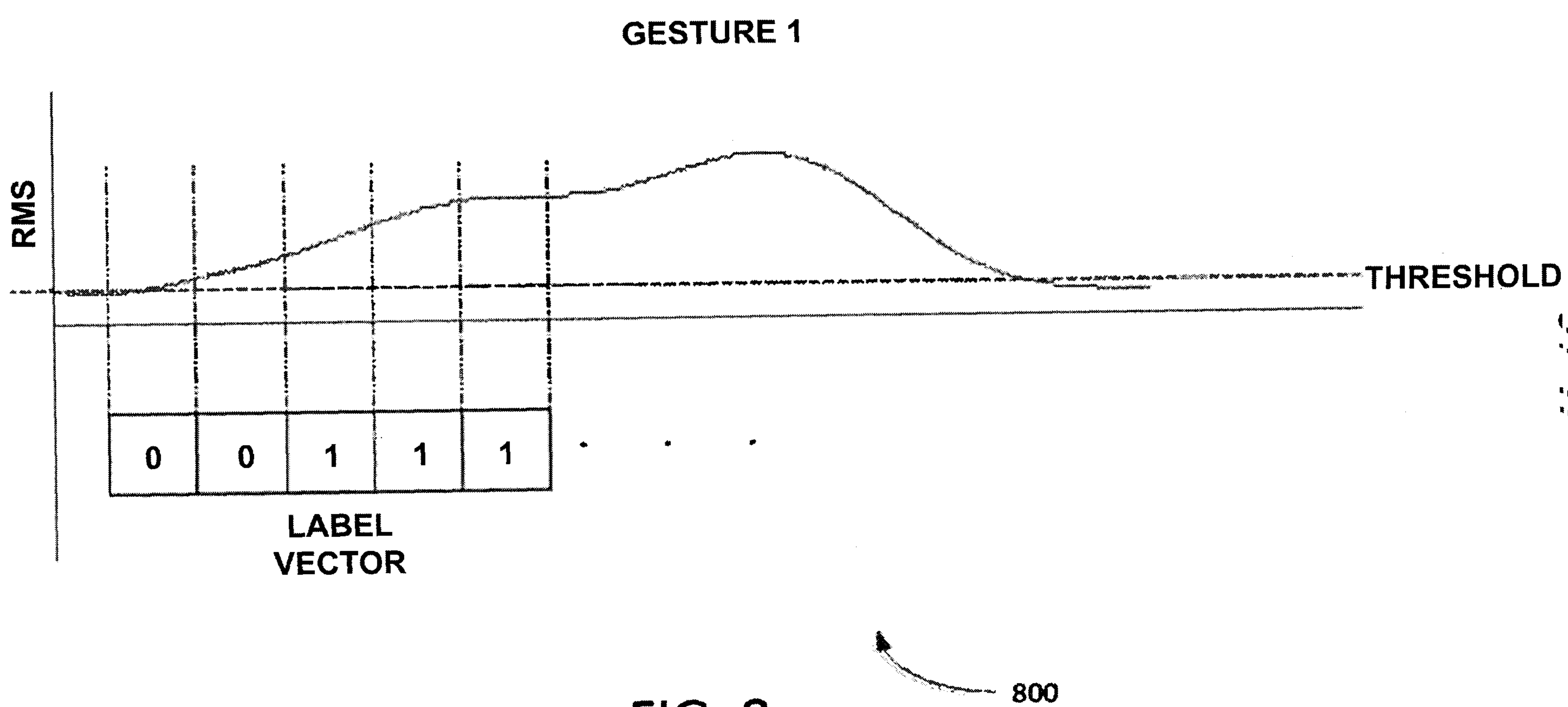

FIG. 8

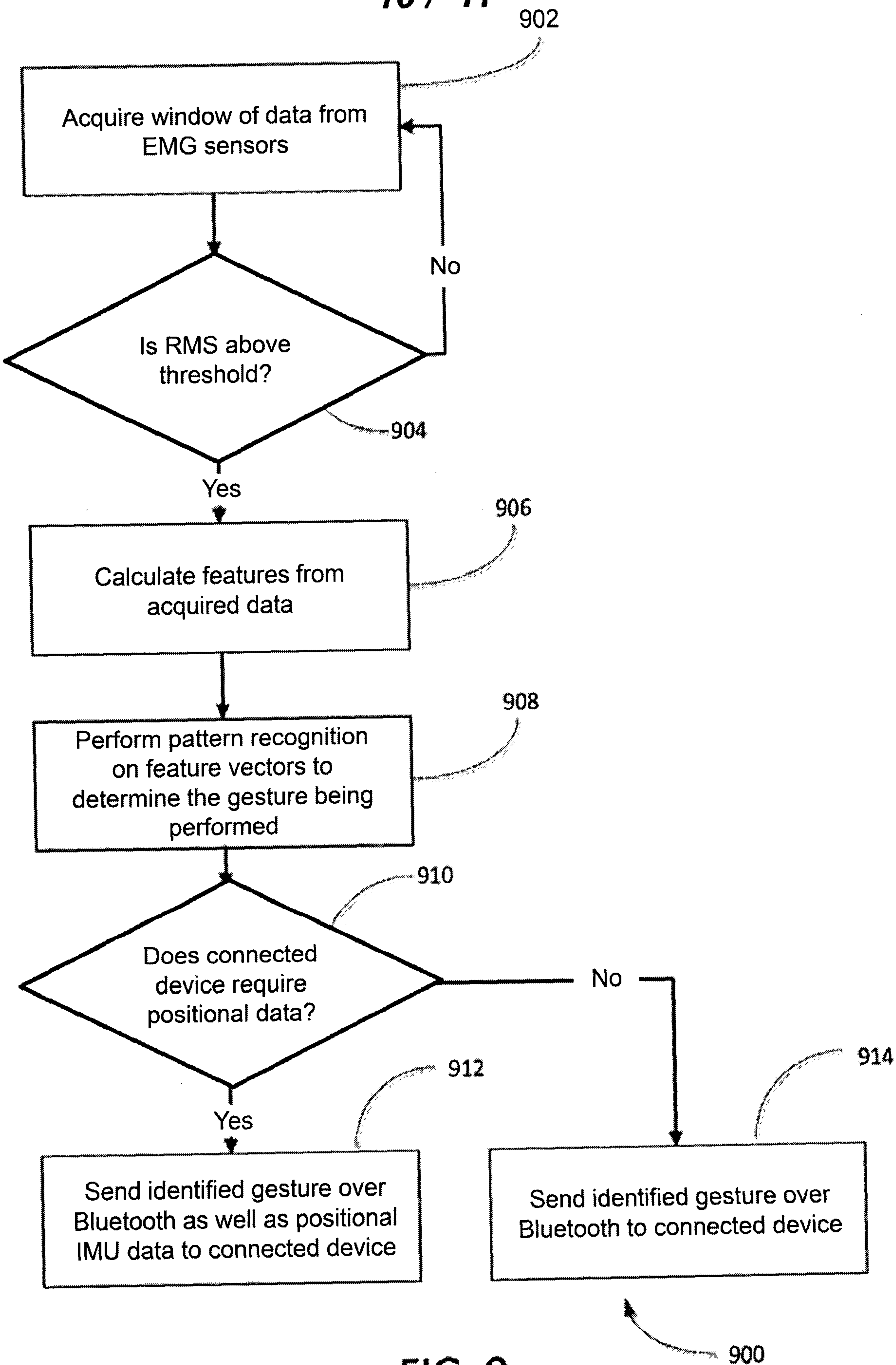
902
Acquire window of data from EMG sensors
No
Is RMS above threshold?
904
Yes
906
Calculate features from acquired data
908
Perform pattern recognition on feature vectors to determine the gesture being performed
910
Does connected device require positional data?
No
912
Yes
Send identified gesture over Bluetooth as well as positional IMU data to connected device
914
Send identified gesture over Bluetooth to connected device
900

FIG. 9

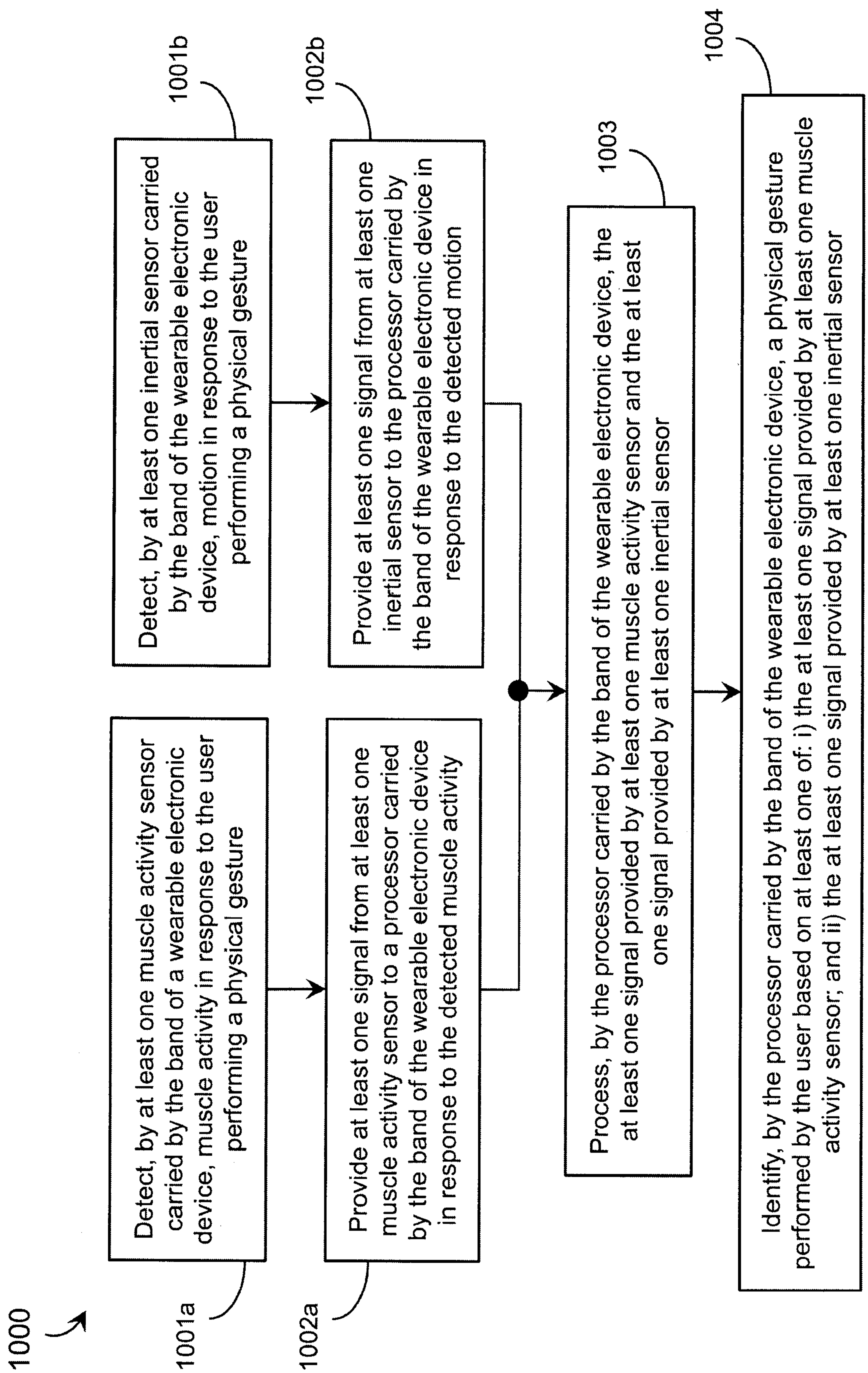
1000
1001a
Detect, by at least one muscle activity sensor carried by the band of a wearable electronic device, muscle activity in response to the user performing a physical gesture
1001b
Detect, by at least one inertial sensor carried by the band of the wearable electronic device, motion in response to the user performing a physical gesture
1002a
Provide at least one signal from at least one muscle activity sensor to a processor carried by the band of the wearable electronic device in response to the detected muscle activity
1002b
Provide at least one signal from at least one inertial sensor to the processor carried by the band of the wearable electronic device in response to the detected motion
1003
Process, by the processor carried by the band of the wearable electronic device, the at least one signal provided by at least one muscle activity sensor and the at least one signal provided by at least one inertial sensor
1004
Identify, by the processor carried by the band of the wearable electronic device, a physical gesture performed by the user based on at least one of: i) the at least one signal provided by at least one muscle activity sensor; and ii) the at least one signal provided by at least one inertial sensor

FIG. 10

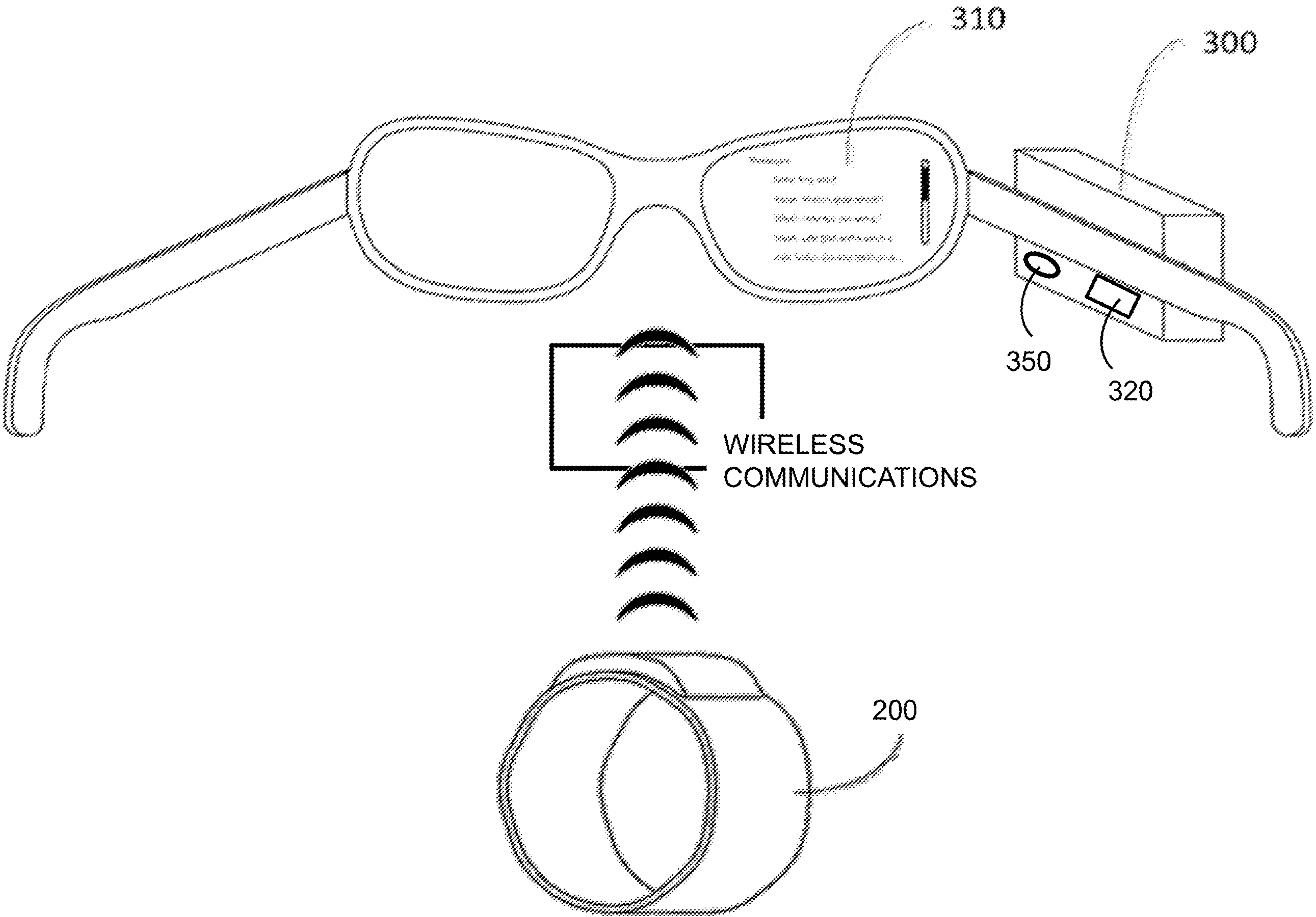

FIG. 3