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(54) **FORCE GROUNDING WRISTBAND FOR HAPTIC GLOVE**

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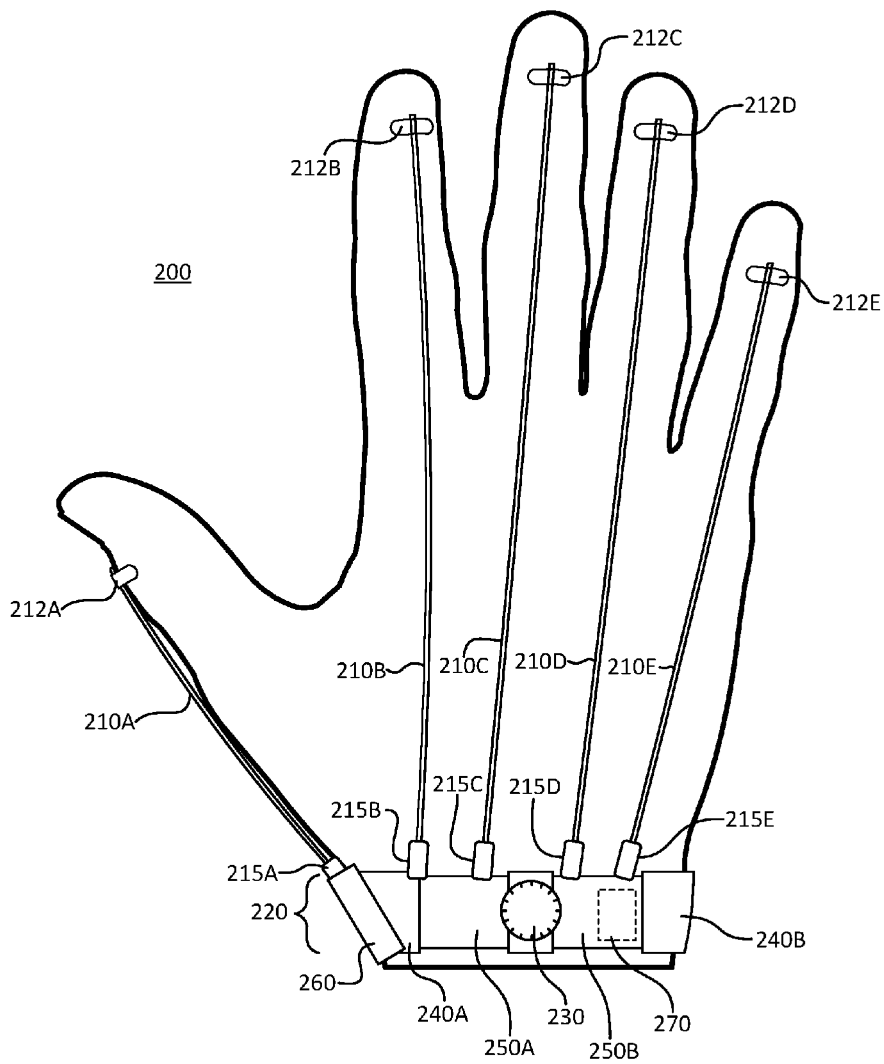
(57) **ABSTRACT**

Disclosed is a force ground device (e.g., a glove) including one or more tendons coupled to actuators for providing haptic feedback when worn by a user. The force ground device includes a wristband that couples to the tendons or to the actuators. The wristband grounds forces from the compressed tendons to the wrist of the user. The wristband may include two force grounding segments adjacent to the ulnar and radial sides of the wrist. The wristband may also include a tension adjustment mechanism (e.g., a ratchet) to adjust the tension of the wristband.



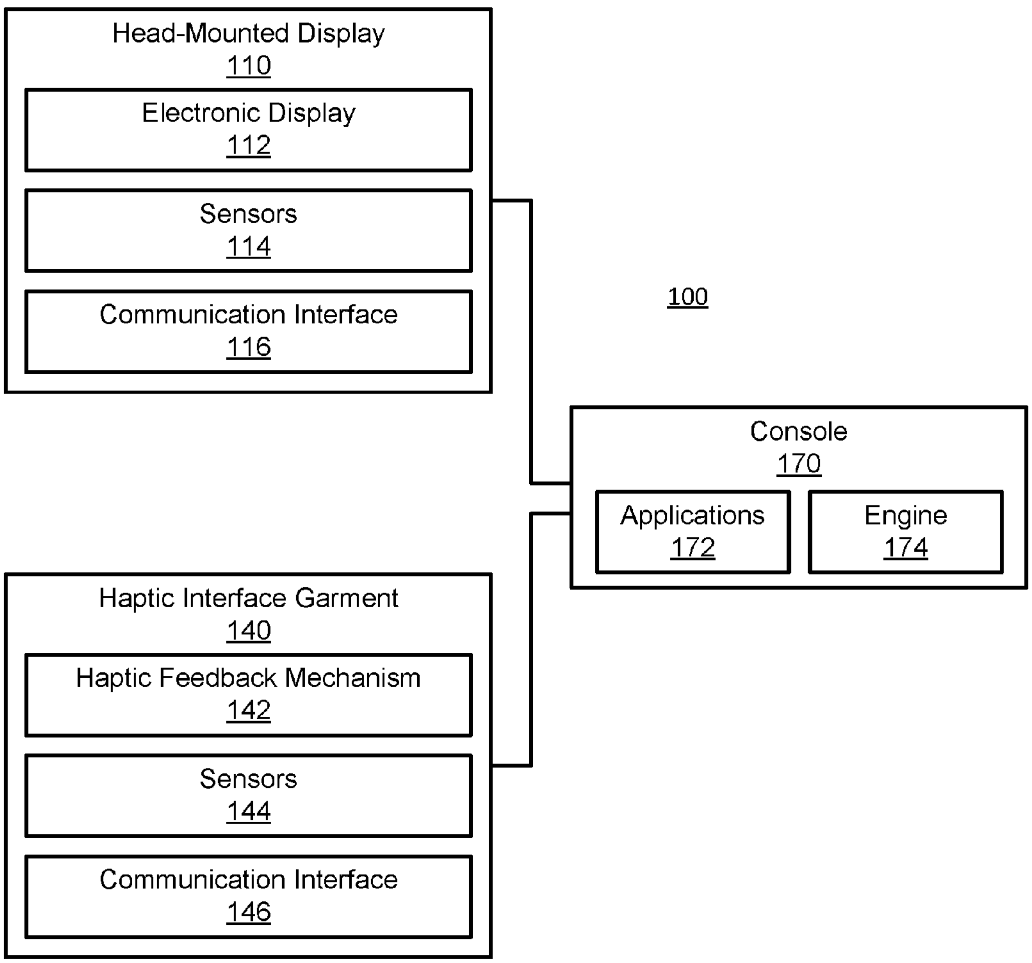

Head-Mounted Display
110
Electronic Display
112
Sensors
114
Communication Interface
116
100
Console
170
Applications
172
Engine
174
Haptic Interface Garment
140
Haptic Feedback Mechanism
142
Sensors
144
Communication Interface
146

FIG. 1

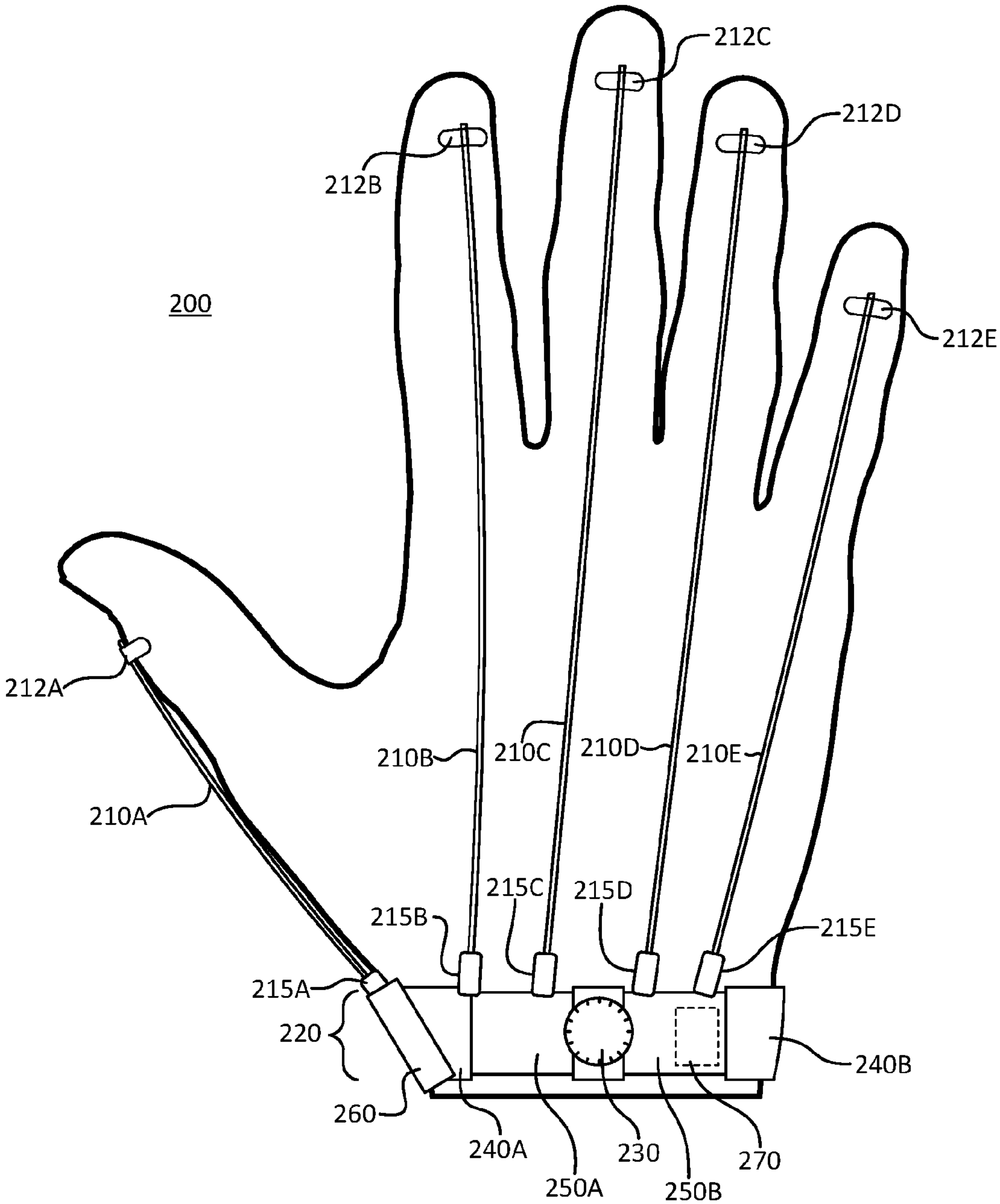

212C
212D
212B
200
212E
212A
210B
210C
210D
210E
210A
215C
215D
215B
215E
215A
220
240B
260
240A
230
270
250A
250B

FIG. 2

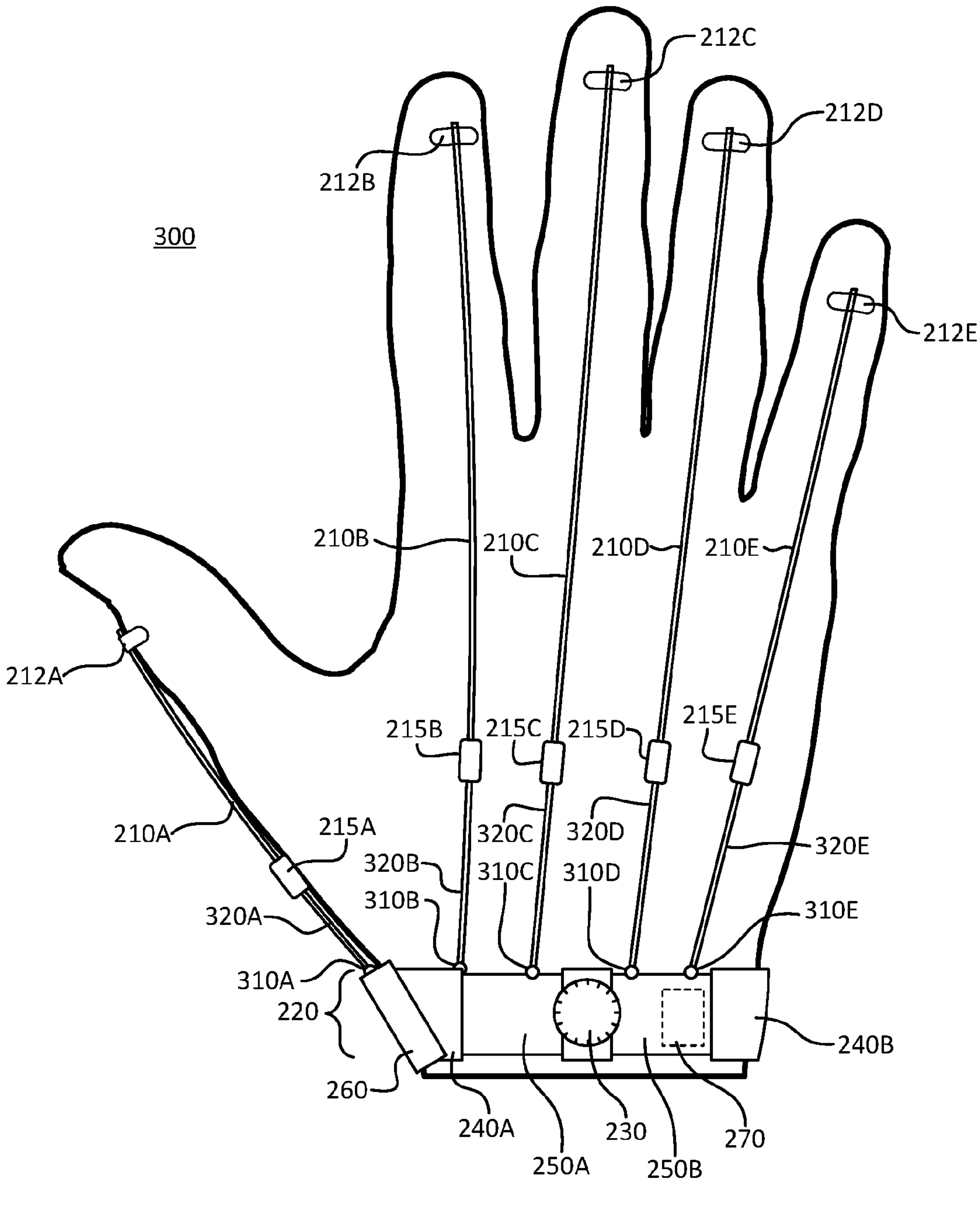

300
212A
212B
212C
212D
212E
210A
210B
210C
210D
210E
215A
215B
215C
215D
215E
320A
320B
320C
320D
320E
310A
310B
310C
310D
310E
220
260
240A
240B
250A
250B
230
270

FIG. 3

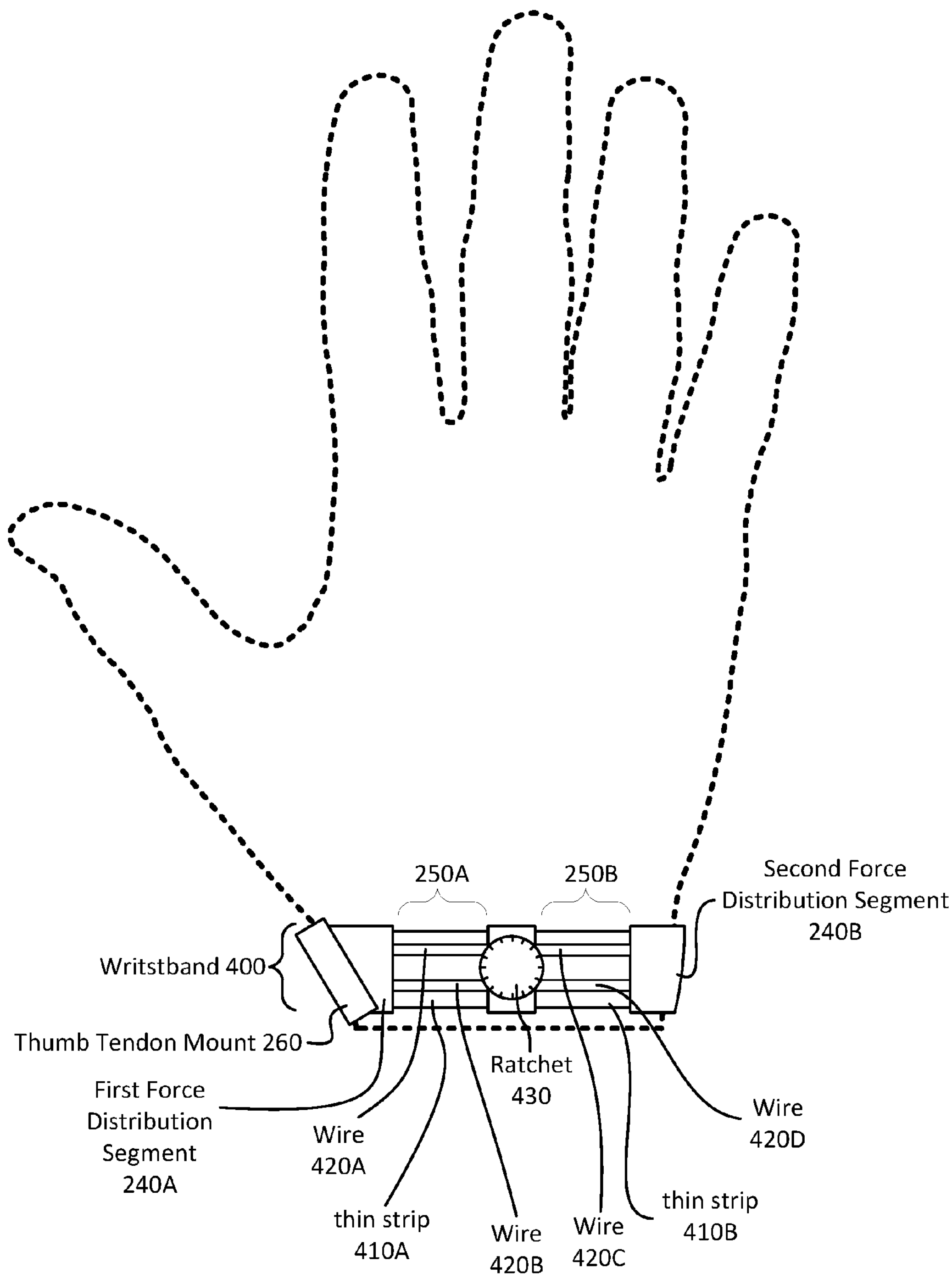
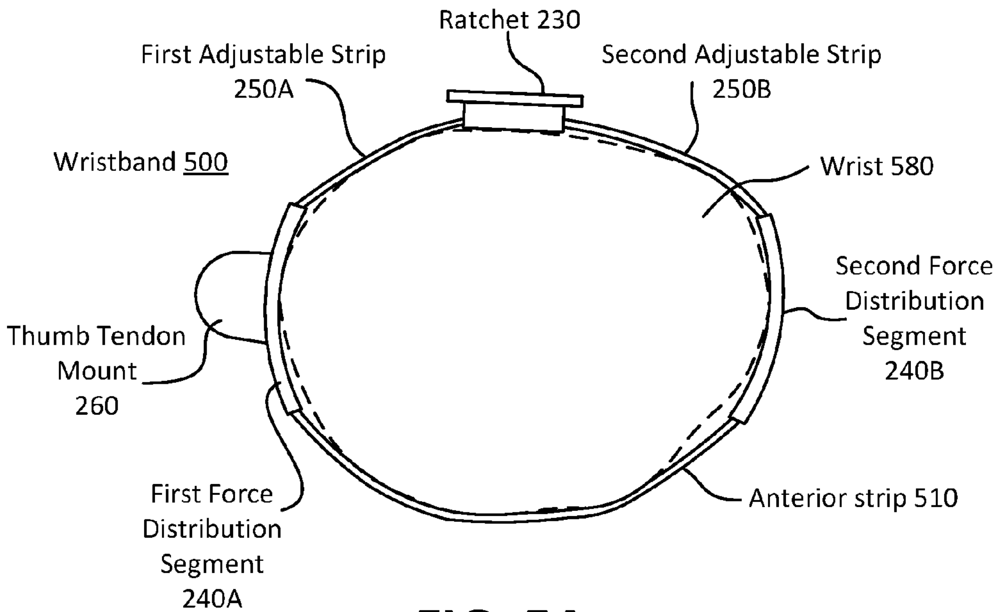
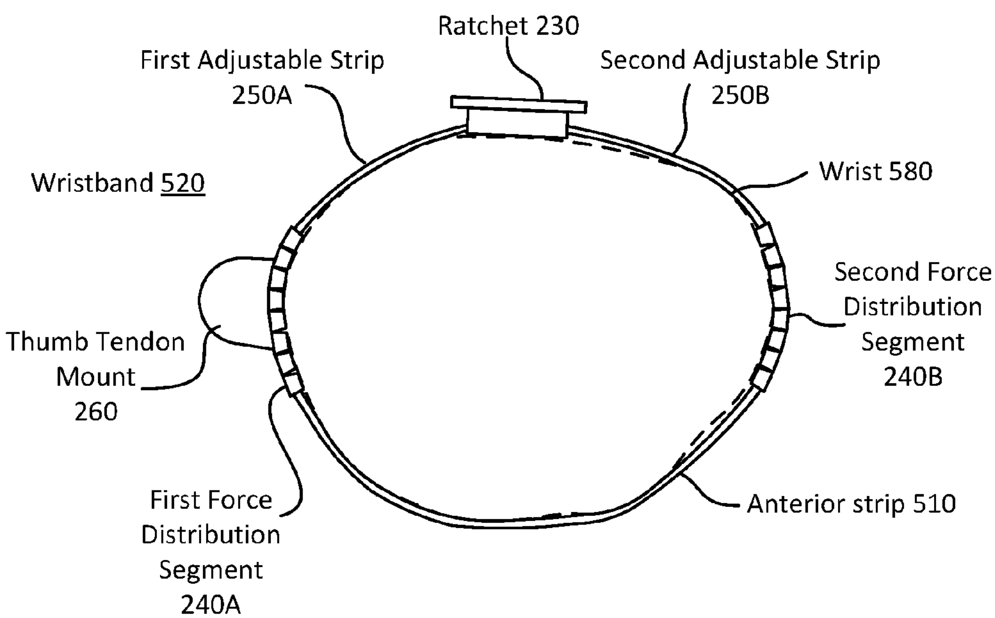

250A
250B
Second Force Distribution Segment 240B
Writstband 400
Thumb Tendon Mount 260
Ratchet 430
First Force Distribution Segment 240A
Wire 420A
thin strip 410A
Wire 420B
Wire 420C
thin strip 410B
Wire 420D

FIG. 4



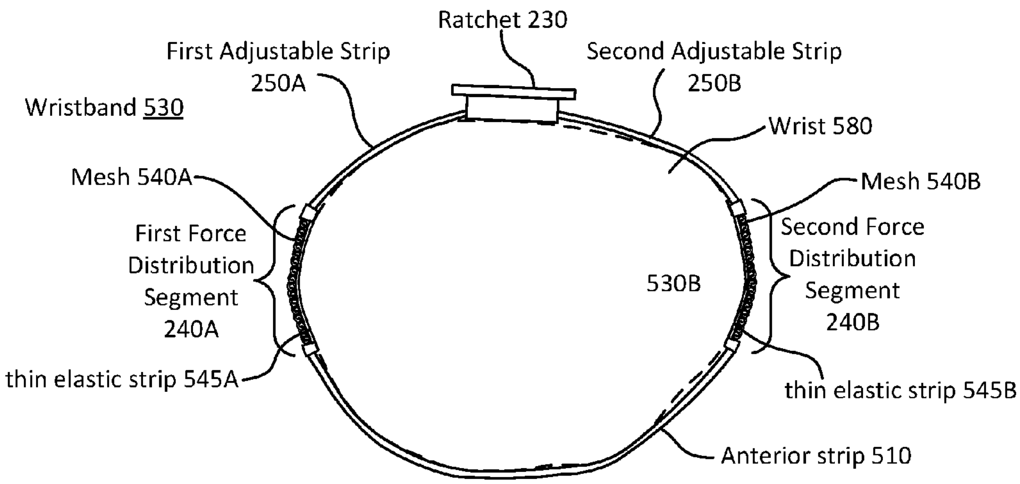
Ratchet 230
First Adjustable Strip 250A
Second Adjustable Strip 250B
Wristband 500
Wrist 580
Thumb Tendon Mount 260
Second Force Distribution Segment 240B
First Force Distribution Segment 240A
Anterior strip 510

FIG. 5A



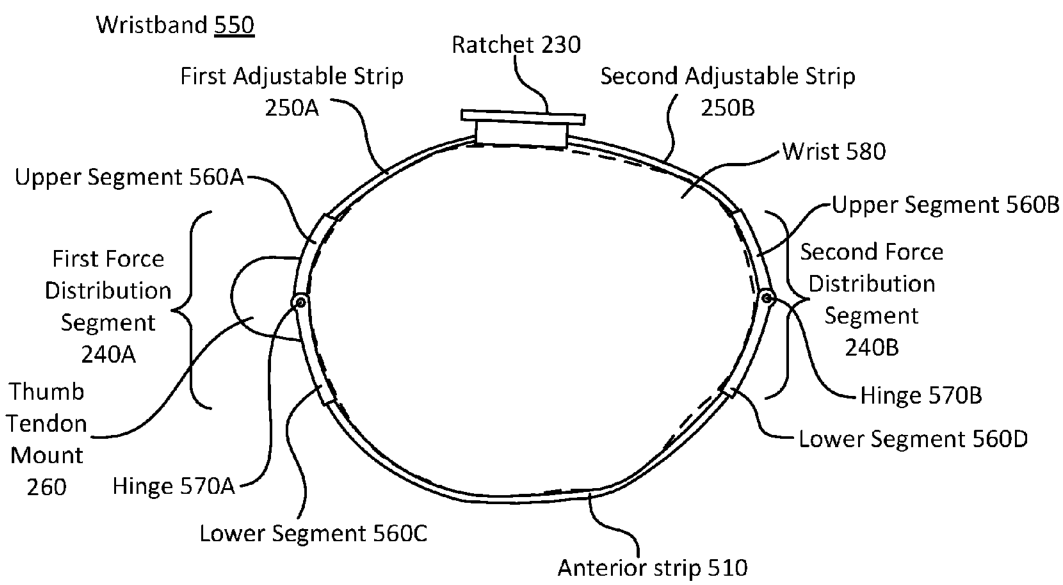
Ratchet 230
First Adjustable Strip 250A
Second Adjustable Strip 250B
Wristband 520
Wrist 580
Thumb Tendon Mount 260
Second Force Distribution Segment 240B
First Force Distribution Segment 240A
Anterior strip 510

FIG. 5B



Ratchet 230
First Adjustable Strip 250A
Second Adjustable Strip 250B
Wristband 530
Wrist 580
Mesh 540A
Mesh 540B
First Force Distribution Segment 240A
Second Force Distribution Segment 240B
530B
thin elastic strip 545A
thin elastic strip 545B
Anterior strip 510

FIG. 5C



Wristband 550
Ratchet 230
First Adjustable Strip 250A
Second Adjustable Strip 250B
Wrist 580
Upper Segment 560A
Upper Segment 560B
First Force Distribution Segment 240A
Second Force Distribution Segment 240B
Thumb Tendon Mount 260
Hinge 570A
Hinge 570B
Lower Segment 560D
Lower Segment 560C
Anterior strip 510

FIG. 5D

FORCE GROUNDING WRISTBAND FOR HAPTIC GLOVE

BACKGROUND

[0001] The present disclosure generally relates to virtual reality systems, and specifically relates to a wristband for grounding forces generated by a haptic glove.

[0002] Virtual reality (VR) systems typically provide multiple forms of sensory output, such as a head-mounted display and headphones, which operate together to create the illusion that a user is immersed in a virtual world. A VR system can also include an input device such as a haptic glove that can be used to detect the position, acceleration, orientation, or some combination thereof of the user's hand and uses the information as input. The input can then be used to move a corresponding item in the virtual world (e.g., a hand or other appendage belonging to a character in the virtual world) when the VR system detects movement of the haptic glove in the real world. A haptic glove can also be used to facilitate interactions with other objects in the virtual world. For example, the VR system can allow the user to use the haptic glove to manipulate virtual objects by touching them, picking them up, and moving them.

[0003] Similarly, a haptic glove may be used in a mixed reality (MR) system. A MR system combines virtual elements with elements from physical world (e.g., a live video feed). For example, a MR system may be an augmented reality (AR) system. An example of an AR system is a display which overlays virtual objects on a live video feed. Virtual elements displayed in the AR may correspond to physical phenomena detected by the AR system (e.g., a virtual representation a magnetic field). The haptic glove may be used to interact with virtual objects or physical objects in an AR system.

SUMMARY

[0004] A force ground device glove is described. In some embodiments, the force ground device is part of a haptic glove. The force ground device includes one or more finger sheaths, one or more tendons, and one or more actuators. The one or more finger sheaths are configured to enclose a finger of a user of the force grounding device. The one or more tendons connect to respective finger sheaths, and each tendon may have a first end and a second end where the first end couples to the respective finger sheath. The one or more actuators are coupled to the second end of respective tendons, and are configured to produce tension in the respective tendons.

[0005] The force ground device may also include a wristband coupled to the one or more actuators. The wrist band is configured to ground forces from the one or more actuators to a wrist of the user. The wristband may include one or more force distribution segments, one or more adjustable strips, one or more tension adjustment mechanism, or some combination thereof.

[0006] In some embodiment, the wristband may include one or more force distribution segments that are inflexible in directions parallel to a surface of a wrist. The first force distribution band may distribute forces on the wristband from the one or more actuators to a side of the wrist. For example, a first force distribution segment may be adjacent to an ulna bone of the wrist and a second force distribution segment may be adjacent to a radius bone of the wrist.

[0007] In some embodiments, the wristband may also include one or more adjustable strips. The adjustable strips may be coupled to the one or more force distribution segments. The one or more tension adjustment mechanisms may couple to the adjustable strips. Each tension adjustment mechanisms may be configured to adjust tension in and/or the length of adjustable strips to which it is coupled. For example, a tension adjustment mechanism adjacent to the posterior of the user's wrist may couple to two adjustable strips which each couple to a respective force distribution segment. In some embodiments, the wristband further comprises an anterior band, which may couple between two force distribution segments.

[0008] The one or more adjustable strips may each include one or more wristband tendons. The wristband tendons may couple between one of the force distribution segments and one of the tension adjustment mechanisms. A tension adjustment mechanism may be configured to increase the tension in an adjustable strip by partially withdrawing the one or more tendons corresponding to the adjustable strip into itself. The tension adjustment mechanism allows a user to manually adjust the tension in the wristband by operating as a ratcheting mechanism.

[0009] In some embodiments, each of the one or more force distribution segments may include a plurality of interconnected rigid links. In alternate embodiments, each of the one or more force distribution segments includes a mesh and an elastic strip. The elastic strip is positioned between the wrist and the mesh. The elastic strip may be composed of neoprene and the mesh may be a Milanese mesh. In some embodiments, the one or more force distribution segments are flexible in a first direction perpendicular to the surface of the wrist.

[0010] The one or more finger sheaths may include a thumb sheath that encloses the thumb of a user. The thumb sheath may couples to thumb tendon, which, in turn, couples to a thumb tendon. A thumb tension adjustment mechanism on the wristband may be configured to allow a user to adjust the default tension in the thumb tendon.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a block diagram of a system environment, in accordance with an embodiment.

[0012] FIG. **2** illustrates a plan view of a haptic glove, in accordance with an embodiment.

[0013] FIG. **3** illustrates a plan view of a haptic glove with an alternate tendon configuration, in accordance with an embodiment.

[0014] FIG. **4** illustrates a plan view of a wristband with wires for tension adjustment, in accordance with an embodiment.

[0015] FIG. **5**A illustrates a cross-section of a wristband with force distribution segments that are each continuous elements, according to an embodiment.

[0016] FIG. **5**B illustrates a cross-section of a wristband including series of links, according to an embodiment.

[0017] FIG. **5**C illustrates a cross-section of a wristband including meshes, according to an embodiment.

[0018] FIG. **5**D illustrates a cross-section of a wristband including hinged segments, according to an embodiment.

[0019] The figures depict embodiments of the present disclosure for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles, or benefits touted, of the disclosure described herein.

DETAILED DESCRIPTION

[0020] To provide a more immersive experience in a VR, MR, or AR system, a haptic glove may apply force to a user's hand to simulate a user's interaction with a virtual object. For example, the system may detect that a user has reached out to grab a virtual object. This may be detected by sensors integrated into a haptic glove, sensors external to a haptic glove, or some combination thereof. As the user closes her hand to grasp the virtual object, the glove may generate an opposing force that resists the closing of the hand. In this way, the haptic glove simulates the experience of grasping the virtual object. The haptic glove may also produce force feedback corresponding to a real-world machine controlled by the user. For example, the forces generated by the haptic glove may correspond to forces and/or torques applied by a motor or system of motors in, for example, heavy machinery (e.g., an excavator), a robotic surgery system, a telerobotic system, or some combination thereof.

[0021] The haptic glove may apply forces to the user's hand via one or more tendons adjacent to the back of the user's hand (i.e., the posterior side of the hand). A tendon may connect to an anchor point and to the posterior side of a user's finger. By modulating tension in this tendon by an actuator, the tendon may produce a force resisting the closing of the user's hand, thereby simulating the normal forces of a virtual object grasped by the user.

[0022] Depending on how an anchor point is attached to the glove, forces on the anchor point may cause the haptic glove to deform, shift its position on the user's hand, or produce uncomfortable, irritating forces on the user's hand. For example, if the anchor is attached to compliant fabric on the haptic glove, a tension in the tendon may produce an undesirable deformation of the fabric around the anchor point.

[0023] Deformation of the haptic glove is undesirable because, as tension in a tendon is repeatedly applied and released, the glove may repeatedly deform and shift along the surface of the user's hand. Friction produced by this repeated movement may irritate the user's hand. Furthermore, if tension in the tendon causes the anchor point's position on the user's hand to shift significantly, in order to produce sufficient tension, the tendon may need to be shortened further than it would if the anchor point's position was invariant. Accordingly, it is advantageous for an anchor point of a tendon system to, as close as practicable, remain fixed to the user's hand and/or wrist. That is, the anchor point should not move relative to the user's hand or deform the haptic glove when a force is applied. Such an anchor point is referred to herein as a "grounded" anchor.

[0024] A haptic glove that grounds the forces from tensioned tendons to a wristband may resolve the aforementioned problems. The wristband distributes the forces from the tendons to the ulnar and radial sides of the wrist (i.e., the bony portions on the side of the wrist). The interface between the sides of the wrist and wristband may provide lateral stiffness so that wristband remains fixed to the wrist. Tension in the wristband produces compressive force between the wristband and the sides of the user's wrist. This compressive force increases the lateral stiffness between the sides of the user's wrist and the wristband of the haptic glove.

System Overview

[0025] FIG. **1** is a block diagram of a system environment **100** in which a haptic interface garment **140** operates. The system environment **100** may be, for example, a VR, MR, or AR system. In some embodiments, the system environment **100** is capable of alternating between operating as a VR, an MR, and an AR system, or some subset thereof. The system environment **100** shown in FIG. **1** comprises a head-mounted display (HMD) **110** and a haptic interface garment **140** that are both coupled to a console **170**. While FIG. **1** shows an example system environment **100** including one HMD **110** and one haptic interface garment **140**, in other embodiments any number of these components may be included in the system environment **100**. For example, the system environment **100** may include two haptic interface garments **140** (e.g., one haptic glove for each hand) that are worn by the same user. As another example, the system environment **100** may include multiple haptic interface garments **140** intended to be worn by multiple users, with each haptic interface garment **140** or each pair of haptic interface garments **140** associated with a different HMD **110**. In alternative configurations, different or additional components may be included in the system environment **100**.

[0026] The HMD **110** is a head-mounted display that presents media to a user. Examples of media presented by the HMD **110** include images, video, audio, or some combination thereof. In some embodiments, audio is presented via an external device (e.g., speakers or headphones) that receives audio information from the HMD **110**, the console **170**, or both, and presents audio data based on the audio information. In some embodiments, the HMD **110** may also act as an AR and/or MR headset. In these embodiments, the HMD **110** augments views of a physical, real-world environment with computer-generated elements (e.g., images, video, sound, etc.).

[0027] The HMD **110** includes an electronic display **112**, sensors **114**, and a communication interface **116**. Some embodiments of the HMD **110** have different components than those described here. Similarly, the functions can be distributed among the components in a different manner than is described here.

[0028] The electronic display **112** displays images to the user in accordance with data received from the console **170**. In various embodiments, the electronic display **112** may comprise a single electronic display **112** or multiple electronic displays **112** (e.g., one display for each eye of a user).

[0029] The sensors **114** include one or more hardware devices that detect spatial and motion information about the HMD **110**. Spatial and motion information can include information about the position, orientation, velocity, rotation, and acceleration of the HMD **110**. For example, the sensors **114** may include a gyroscope that detects rotation of the user's head while the user is wearing the HMD **110**. This rotation information can then be used (e.g., by the engine **174**) to adjust the images displayed on the electronic display **112**.

[0030] The communication interface **116** enables input and output to the console **170**. In some embodiments, the communication interface **116** is a bus, such as High-Definition Multimedia Interface (HDMI), Universal Serial Bus

(USB), Video Graphics Array (VGA), Digital Visual Interface (DVI), DisplayPort™, or some combination thereof. In other embodiments, the communication interface **116** includes several distinct communication buses operating together or independently. In one embodiment, the communication interface **116** includes wireless connections for sending data collected by the sensors **114** from the HMD **110** to the console **170** but also includes a wired connection (e.g., an HDMI or DVI connection) that receives audio/visual data to be rendered on the electronic display **112**.

[0031] The haptic interface garment **140** is a wearable device for receiving haptic input or producing haptic output. The haptic interface garment **140** may be configured to be worn on a portion of a user's body, such as the user's hand (e.g., a glove). The haptic interface garment **140** may collect information about the portion of the user's body that can be used as input for virtual reality applications **172** executing on the console **170**. The haptic interface garment **140** includes a haptic feedback mechanism **142**, sensors **144**, and a communication interface **146**. Some embodiments of the haptic interface garment **140** have different components than those described here, e.g., the haptic interface garment **140** may include additional components that are not shown in FIG. **1**, such as a power source (e.g., an integrated battery, a connection to an external power source, a container containing compressed air, or some combination thereof). Similarly, the functions can be distributed among the components in a different manner than is described here.

[0032] The haptic feedback mechanism **142** provides haptic feedback to the user by directing the portion of the user's body to move in a particular way or in a particular direction or preventing the portion of the user's body from moving in certain directions or in certain ways. The haptic feedback mechanism **142** includes a tendon system to apply force to the haptic interface garment **140**. Transducers of the tendon system may apply forces on portions of the user's body. By applying forces to the user's body, the tendon system may move a portion of the user's body apply torque to a joint of a user's body, or produce tactile sensation for the user. Various embodiments of the haptic feedback mechanism **142** are described in conjunction with FIGS. **2**-**5**D.

[0033] The sensors **144** include one or more hardware devices that detect spatial information for the haptic interface garment **140**. The spatial information may include information about position, orientation, velocity, rotation, and acceleration, or some combination thereof. The spatial information may refer to the entire haptic interface garment **140**, subdivisions of the haptic interface garment **140**, or both. For example, if the haptic interface garment **140** is a haptic glove, sensors **144** may identify positions and orientations of various portions of the glove, such as the fingers, fingertips, knuckles, palm, or wrist. The sensors **144** may also detect forces applied by the user to the haptic interface garment **140**.

[0034] The communication interface **146** enables input from and output to the console **170**. In some embodiments, the communication interface **146** may be a single communication bus, such as USB. In other embodiments, the communication interface **146** includes several distinct communication buses operating together or independently. For example, the communication interface **146** may include separate communication buses for receiving control signals for the haptic feedback mechanism **142** and sending data from the sensors **144** to the console **170**. The one or more communication buses of the communication interface **146** may be implemented as wired connections, wireless connections, or some combination thereof.

[0035] The console **170** is a computing device that executes virtual reality applications, augmented reality applications, mixed reality applications, or some combination thereof, to process input data from the sensors **114** and **144** on the HMD **110** and the haptic interface garment **140** and provide output data for the electronic display **112** on the HMD **110** and the haptic feedback mechanism **142** on the haptic interface garment **140**. The console **170**, or portions thereof, may be integrated with the HMD **110**, the haptic interface garment **140**, or both the HMD **110** and the haptic interface garment **140**. The console **170** can be implemented as any kind of computing device, such as an integrated system-on-a-chip, a microcontroller, a desktop or laptop computer, a server computer, a tablet, a smart phone, or other mobile device. Thus, the console **170** may include components common to typical computing devices, such as a processor, random access memory (RAM), a storage device, a network interface, an I/O interface, and the like.

[0036] The processor may be or include one or more graphics processing units (GPUs), microprocessors, or application specific integrated circuits (ASICs). The memory may be or include RAM, ROM, DRAM, SRAM, and MRAM, and may include firmware, such as static data or fixed instructions, BIOS, system functions, configuration data, and other routines used during the operation of the computing device and the processor. The memory also provides a storage area for data and instructions associated with applications and data handled by the processor.

[0037] The storage device provides non-volatile, bulk, or long term storage of data or instructions in the computing device. The storage device may take the form of a magnetic or solid state disk, tape, CD, DVD, or other reasonably high capacity addressable or serial storage medium. Multiple storage devices may be provided or be available to the computing device. Some of these storage devices may be external to the computing device, such as network storage or cloud-based storage. The network interface includes an interface to a network and can be implemented as either a wired or wireless interface. The I/O interface interfaces the processor to peripherals (not shown) such as, depending upon the computing device, sensors, displays, cameras, color sensors, microphones, keyboards and USB devices.

[0038] In the example shown in FIG. **1**, the console **170** further includes applications **172** and an engine **174**. An application **172** running on the engine **174** may generate a VR environment, an AR environment, an MR environment, or some combination thereof. In some embodiments, the applications **172** and the engine **174** are implemented as software modules that are stored on the storage device and executed by the processor. Some embodiments of the console **170** include additional or different components than those described in conjunction with FIG. **1**. Similarly, the functions further described below may be distributed among components of the console **170** in a different manner than is described here.

[0039] Each application **172** is a group of instructions that, when executed by a processor, generates virtual reality content for presentation to the user. An application **172** may generate content (e.g., VR, MR, or AR content) in response to inputs received from the user via movement of the HMD **110** or the haptic interface garment **140**. Examples of applications **172** include gaming applications, conferencing applications, video playback applications, augmented reality application, telerobotic applications, or other suitable applications.

[0040] The engine **174** is a software module that allows the applications **172** to operate in conjunction with the HMD **110** and the haptic interface garment **140**. In some embodiments, the engine **174** receives information from sensors **114** on the HMD **110** and provides the information to an application **172**. Based on the received information, the engine **174** determines media content to provide to the HMD **110** for presentation to the user via the electronic display **112** or haptic feedback to provide to the haptic interface garment **140** to provide to the user via the haptic feedback mechanism. For example, if the engine **174** receives information from the sensors **114** on the HMD **110** indicating that the user has looked to the left, the engine **174** generates content for the HMD **110** that mirrors the user's movement in a virtual environment.

[0041] Similarly, in some embodiments the engine **174** receives information from the sensors **144** on the haptic interface garment **140** and provides the information to an application **172**. The application **172** can use the information to perform an action within the virtual world of the application **172**. For example, if the engine **174** receives information from the sensors **144** that the user has closed her fingers around a position corresponding to a coffee mug in the virtual environment and raised her hand, a simulated hand in the application **172** picks up the virtual coffee mug and lifts it to a corresponding height.

[0042] The engine **174** may also provide feedback to the user that the action was performed. The provided feedback may be visual via the electronic display **112** in the HMD **110** (e.g., displaying the simulated hand as it picks up and lifts the virtual coffee mug) or haptic feedback via the haptic feedback mechanism **142** in the haptic interface garment **140** (e.g., resisting movement of a user's fingers from curling past a certain point to simulate the sensation of touching a solid coffee mug). The haptic feedback may also be force feedback from some machine being controlled by the user.

Force Grounding Wristband

[0043] FIG. **2** illustrates a plan view of a haptic glove **200**, in accordance with an embodiment. The haptic glove **200** includes one or more tendons **210**A-**210**E, one or more actuators **215**A-**215**E, one or more finger-tendon anchors **212**A-**212**E, a controller **270**, and a wristband **220**. In the embodiment of FIG. **2**, each of the five finger sheaths of the glove **200** corresponds to a respective tendon **210**A-**210**E, a respective actuator **215**A-**215**E, and a respective finger-tendon anchor **212**A-**212**E. In FIG. **2**, the haptic glove **200** is shown in an orientation corresponding to posterior view of a user's right hand (i.e., a plan view of the back of the user's hand).

[0044] The tendons **210**A-**210**E are thin elements that each translate force from a respective actuator **215**A-**215**E to a respective finger. For example, a tendon **210**A-**210**E may be a wire, string, rod, chord, chain, wire cable, or elastic structure. As depicted in FIG. **2**, each of the non-thumb tendons **210**B-**210**E runs along the back of the haptic glove **200** (i.e., the side of the haptic glove **200** corresponding to the posterior side of the user's hand) and along the posterior side of its respective finger sheath. The tendon **210**A corresponding to the thumb may runs along the side of the thumb.

[0045] The actuators **215**A-**215**E are motors that each tension a respective tendon **210**A-**210**-**210**E. Each actuators **215**A-**215**E may include an electromagnetic mechanism (e.g., one or more solenoids), a hydraulic mechanism, a pneumatic mechanism, a piezoelectric mechanism, or a combination thereof. When an electrical signal is delivered to an actuator **215**A-**215**E, the actuator **215**A-**215**E may apply a force to its respective tendon **210**A-**210**E causing the tendon **210**A-**210**E to be tensioned. By modulating the tension in the tendons **210**A-**210**E via the actuators **215**A-**215**E, the haptic glove **200** can apply a force to the fingers of the user's hand. In this way, the haptic glove **200** resists flexion of one or more of the user's fingers or causes extension of the fingers. Resistance to flexion from the haptic glove **200** may be used in conjunction with the display of a virtual object in the HMD **110** to simulate the grasping of the virtual object.

[0046] Each of the finger-tendon anchors **212**A-**212**E is a coupling between a respective tendon **210**A-**210**E and a respective finger sheath of the haptic glove **200**. In some embodiments, the finger-tendon anchors **212**A-**212**E are located on different portions of the finger sheaths that is depicted in FIG. **2**. For example, some or all of the finger-tendon anchors **212**A-**212**E could be adjacent to the distal interphalangeal joints of the fingers, the proximal interphalangeal joints, or both. In some embodiments, more than one finger-tendon anchor **212**A-**212**E couples between each tendon **210**A-**210**E and the respective finger sheath. In addition, alternate embodiments use different types of finger-tendon anchors **212**A-**212**E than those illustrated in FIG. **2**.

[0047] Each tendon **210**A-**210**E mechanically couples at a respective first end to a respective finger sheath via a respective finger-tendon anchor **212**A-**212**E. The first tendon **210**A couples at the first end to the finger sheath corresponding to the user's thumb (i.e., the "thumb sheath"). The other four tendons **210**B-**210**E (i.e., the "finger tendons") couple at respective first ends to finger sheaths corresponding to the user's index, middle, ring, and "pinky" fingers, respectively. Each tendon **210**A-**210**E mechanically couples at a respective second end to a respective actuator **215**A-**215**E. The five actuators **215**A-**215**E each couple to the wristband **220**. The actuators **215**A-**215**E may be rigidly anchored to the wristband **220**. The first actuator **215**A couples to the thumb tendon mount **260**. The second actuator **215**B couples to the first force distribution segment **240**A. The third actuator **215**C couples to the first adjustable strip **250**A and the fourth and fifth actuators **215**D-**215**E couple to the second adjustable strip **215**E. One or more of the actuators **215**A-**215**E may couple to a respective tension adjustment mechanism, and in some embodiments all of the actuators **215**A-**215**E may couple to a respective tension adjustment mechanism. These tension adjustment mechanisms may allow the user to configure the tension on each tendon **210**A-**210**E by adjusting its length to accommodate the shape of the user's hand (e.g., the length of the user's fingers).

[0048] In an alternate embodiment, the actuators **215**B-**215**E not corresponding to the thumb all couple at the same part of the wristband **220**. For example, the four finger actuators **215**B-**215**E may couple to the first or second adjustable strip **250**A, the first or second force distribution segments **240**A-**240**B, or the ratchet **230**. In another embodiment, the two actuators **215**B-**215**C corresponding to the index and middle fingers couple to the first adjustable strip

250A and the two actuators 215D-215E corresponding to the ring and pinky fingers couple the second adjustable strip 250B. In some embodiments, one or more of the finger actuators 215B-215E are omitted and one or more of the finger tendons 210B-210E are coupled to the same actuator. For example, the four finger tendons 210B-210E may be coupled to a single actuator. Other coupling configurations for the actuators 215A-215E and tendons 210A-210E are also possible.

[0049] The controller 270 is an electronic device the controls each of the actuators 215A-215E. The controller 270 may receive input the console 170 that may determine setpoint position for each actuator, a force to apply to each actuator, or some combination thereof. The controller 270 may include a digital-to-analog converter for converting input from the console 170 to an electrical signal for controlling the actuators 215A-215E. The controller 270 may control the actuators 215A-215E individually or control a set of the actuators 215A-215E as a unit. A unit of actuators (e.g., every other actuator, all the actuators, or any other combination of actuators) may be controlled together, so that each actuator in the unit is tensioned or de-tensioned together. In some embodiments, the controller 270 is located at a different location on the haptic glove 200. In alternate embodiments, the functions of the controller 270, as described herein, are implemented by a device external to but communicatively coupled to the haptic glove 200 (e.g., the console 170).

[0050] The wristband 220 is a band that may encircle a user's wrist. The wristband 220 may ground forces generated by the actuators 215A-215E. The wristband 220 may ground these forces by distributing the forces from the actuators 215A-215E to the ulnar and radial sides of the wrist (i.e., the bony portions on the side of the wrist). The wristband 220 includes a ratchet 230, one or more force distribution segments 240A-240B, one or more adjustable strips 250A-250B, and a thumb tendon mount 260. In the embodiments shown in FIG. 2, the wristband includes two adjustable strips 250A-250B and two force distribution segments 240A-240B.

[0051] The ratchet 230 is a tension adjustment mechanism with which a user can manually adjust the tension in the wristband 220. The ratchet 230 of the wristband 220 couples at a first end to a first adjustable strip 250A and couples to a second adjustable strip 250B at a second opposite end. The ratchet 230 may include a rotatable knob for adjusting tension. The ratchet 230 may include a locking mechanism so that in a locked position the knob can rotate in a first direction to tension the wristband, but cannot be rotated in the opposite direction to provide slack to the wristband. In an unlocked position, the ratchet 230 releases tension in the wristband. Lifting the knob up may set the ratchet 230 to the unlocked position and pressing the knob down may set it to the locked position (or vice versa).

[0052] The adjustable strips 250A-250B are strips that couple to the ratchet 230. The adjustable strips 250A-250B may be adjusted in length by the ratchet 230 to produce tension in the wristband 220. The first and second adjustable strips 250A, 250B couple to first and second force distribution segments 240A-240B, respectively. In alternate embodiments, the ratchet 230 and adjustable strips 250A-250B are omitted in favor of an alternate tension adjustment mechanism, a linear ratchet mechanism (e.g., a ratchet strap), such as a ratchetable buckle strap system, a releasable pawl and gear rack system, a threaded buckle, a ladderlock strap system, or a fabric hook and fastener strap system.

[0053] The first and second force distribution segments 240A-240B are components of the wristband 220 that may ground forces to the bony portions of the user's wrist. The first and second force distribution segments 240A-240B adjacent to the radial side and ulnar side, respectively, of the user's wrist. The first force distribution segment 240A is adjacent to the radial side (i.e., the "thumb side") of the user's wrist, and the second force distribution segment 240B is adjacent to the ulnar side (i.e., the "pinky side") of the wrist. The force distribution segments 240A-240B may rigidly couple to the wrist of the user. Tension in the wristband 220 is distributed along the sides of the wrist to ground the forces caused by tendons 210A-210E anchored to the wristband 220. The force distribution segments 240A-240B may be inflexible in directions parallel to the surface of the wrist. That is, forces parallel to the wrist's surface produce relatively little deformation of the force distribution segments 240A-240B. The first and second force distribution segments 240A-240B may be coupled together. An anterior band (not shown) couples between the first and second force distribution segments 240A-240B in some embodiments. In alternate embodiments, the first and second force distribution segments 240A-240B may be portions of a single continuous element. The wristband 220 also includes a thumb tendon mount 260 that couples to the first force distribution segment 240A.

[0054] The force distribution segments 240A-240B may be curved in the same direction as the surface of the wrist to which they are adjacent. In some embodiments, the force distribution segments 240A-240B are flexible (e.g., susceptible to bending) in the direction perpendicular to the surface of the wrist. Thus, a tension in the wristband 220 may cause the force distribution segments 240A-240B to bend towards the curvature of the wrist. As a result, tension in the wristband 220 causes the force distribution segments 240A-240B to conform to the curvature of the wrist. By conforming to the sides of the wrist, the wristband 220 may distribute the force from tendons 210A-210E over a larger area. Thus, the force distribution segments 240A-240B allow the wristband 220 to effectively ground the forces produced by the tendons 210A-210E and actuators 215A-215E. Several embodiments of force distribution segments 240A-240B are discussed below in conjunction with FIGS. 5A-5B.

[0055] The thumb tendon mount 260 is a rigid component that is coupled to the actuator 215A corresponding to the thumb. Because the thumb tendon 210A runs along the side of the thumb, the thumb tendon mount 260 may extend from the side of the first force distribution segment 240A. The actuator 215A, the thumb tendon mount 260, and the first force distribution segment 240A may be rigidly coupled together. The thumb tendon mount 260 may be a continuous piece of the first force distribution segment 240A and may protrude therefrom. The actuator 215A may be coupled to the thumb tendon mount 260 or may be integrated within the thumb tendon mount 260. The thumb tendon mount 260 may include a tension adjustment mechanism for adjusting the default tension in the thumb tendon 210A. By adjusting the thumb tension mount, the user can adjust the length of the tendon 210A to accommodate the length of his or her thumb.

[0056] The haptic glove 200 may be a full-fingered glove wearable on the user's hand. The haptic glove 200 may cover the user's hand with a textile, but it may also include other materials such as rubber, processed animal hide (e.g., leather), cloth, wool, a polymer (e.g., nylon, polyester, or latex), or some combination thereof. The haptic glove **200** may include multiple layers. For example, the tendons **210**A-**210**E and the actuators **215**A-**215**E may be enclosed between two layers of the haptic glove **200**. The haptic glove **200** may include five finger sheaths, each of which may entirely cover a respective finger or cover a portion of the finger (e.g., as in a fingerless glove). The haptic glove **200** may alternately be a mitten, or a gauntlet.

[0057] FIG. **3** illustrates a plan view of a haptic glove **300** with an alternate tendon configuration, according to an embodiment. The embodiment of the haptic glove **300** illustrated in FIG. **3** has a different tendon configuration than the haptic glove **200** illustrated in FIG. **2**. Whereas, the actuators **215**A-**215**E of the haptic glove **300** in FIG. **2** were directly coupled to the wristband **220**, the actuators **215**A-**215**E of the haptic glove **300** in FIG. **3** are each coupled to a respective second tendon **320**A-**320**E which couples to the wristband **220** at a respective coupling point **310**A-**310**E. The coupling points **310**A-**310**E may be rigid anchors to the wristband **220**. The actuators **215**A-**215**E may be directly coupled to the fabric of the haptic glove **300**. The actuators **215**A-**215**E may alternately be free-floating with respect to the fabric of the haptic glove **300**.

[0058] Each actuator **215**A-**215**E may be controlled by the controller **270** to contract a respective first tendon **210**A-**210**E while the length of the respective second tendon **320**A-**320**E remains relatively invariant. In an alternate embodiment, each actuator **215**A-**215**E may contract the second tendon **320**A-**320**E to produce tension, while the length of the respective first tendon **210**A-**210**E remains relatively invariant. In a third alternate embodiment, the actuators **215**A-**215**E may exert tension by contracting both the first tendons **210**A-**210**E and the second tendons **320**A-**320**E.

[0059] FIG. **4** illustrates a plan view of a wristband **400** with wires **420**A-**420**D for tension adjustment, in accordance with an embodiment. The wristband **400** may be an embodiment of the wristband **220** illustrated in FIGS. **2-3**. The wristband **400** includes one or more adjustable strips (e.g., adjustable strips **250**A-**250**B), each of which includes one or more wires **420**A-**420**D over a thin strip **410**A-**410**B. For example, the wristband **400** illustrated in FIG. **4** includes two adjustable strips **250**A-**250**B, each of which includes two wires **420**A-**420**D over a thin strip **410**A-**410**B.

[0060] The wires **420**A-**420**D couple between the ratchet **230** and the force distribution segments **240**A-**240**B. Instead of wires **420**A-**420**D, any type of tendon may alternately be used, such as, strings, rods, chords, chains, or elastic structures. In alternate embodiments, the wristband **400** includes a different number of wires than shown in FIG. **4**. The wristband **400** may also include a layer of material (e.g., fabric) over the wires **420**A-**420**D or sheaths that enclose the wires **420**A-**420**D.

[0061] The thin strips **410**A-**410**B are layers of material beneath the wires **420**A-**420**D. The thin strips **410**A-**410**B may be composed of elastic material (e.g., neoprene), inelastic fabric, or some combination thereof. In some embodiments, the thin strips **410**A-**410**B are omitted entirely.

[0062] The ratchet **430** is an embodiment of the ratchet **230** of FIGS. **2-3**. The ratchet **430** may comprise one or more reels about which the wires **420**A-**420**D are wound. The one or more reels retract the wires **420**A-**420**D into the ratchet **430** when rotated in a first direction and provide slack when rotated in the opposite direction. The ratchet **430** may include a locking mechanism so that in a locked position the one or more reels can rotate in the first direction to retract the wires **420**A-**420**D, but cannot rotate in the opposite direction to provide slack to the wires **420**A-**420**D. That is, the one or more reels are ratchetable. In an unlocked position, the one or more reels of the ratchet **430** may be free to rotate in either direction, thereby allowing the user to reduce the tension in the wristband **400**. In some embodiments, the ratchet **430** comprises a knob configured to rotate the one or more reels. Lifting the knob up may set the ratchet **430** to the unlocked position and pressing the knob down may set it to the locked position (or vice versa). In some embodiments, when the ratchet **430** is in a locked position the knob and the one or more reels are rotationally coupled, but the knob and the one or more reels are disengaged in the unlocked position. In some embodiments, the ratchet **430** is unlocked by disengaging a pawl from a gear rotationally coupled to the knob, the one or more reels, or both.

Force Distribution Segments

[0063] FIG. **5**A illustrates a cross-section of a wristband **500** with force distribution segments **240**A-**240**B that are each continuous elements, according to an embodiment. The wristband **500** may be part of a haptic glove (e.g., haptic glove **200**). The wristband **500** includes two adjustable strips **250**A-**250**B, two force distribution segments **240**A-**240**B, a thumb tendon mount **260**, a ratchet **230**, and an anterior strip **510**. For context FIG. **5**A shows a cross-section of a user's wrist **580**, that the wristband **500** encircles. The user's wrist **580** is illustrated as a dotted outline.

[0064] Each the force distribution segments **240**A-**240**B may be a continuous, curved solid element. The force distribution segments **240**A-**240**B may be curved in the same direction as the surface of the wrist to which they are adjacent. The force distribution segments **240**A-**240**B may be a segment of an oblong annular cylinder. In some embodiments, the force distribution segments **240**A-**240**B are flexible in the direction perpendicular to the surface of the wrist. Thus, a tension in the wristband **220** may cause the force distribution segments **240**A-**240**B to bend towards the curvature of the wrist. As a result, tension in the wristband **220** may cause the force distribution segments **240**A-**240**B to conform to the wrist's curvature.

[0065] FIG. **5**A also shows an anterior strip **510**, which couples between the first and second force distribution segments **240**A-**240**B. The anterior strip **510** may be an elastic strip (e.g., rubber) or an inelastic flexible strip (e.g., fabric). In some embodiments, the anterior strip **510** comprises a thin elastic strip under one or more wires, wherein each wire couples between the force distribution segments **240**A-**240**B. Instead of wires, any type of tendon may be used, such as, strings, rods, chords, chains, or elastic structures. The wires may bear most of the tension in the anterior strip **510**.

[0066] In some embodiments, elements of the anterior strip **510** are coupled to one or both of the adjustable strips **250**A-**250**B. For example, the anterior strip **510** may comprise one or more wires (e.g., wires **420**A,**420**B) that are also part of the first adjustable strip **250**A. These one or more wires may run through or over the force distribution segment **240**A. In this way, when the ratchet **230** retracts these wires, the length of the first adjustable strip **250**A and the length of the anterior strip **510** may both be shortened. Similarly, the anterior strip **510** may comprise one or more wires (e.g., **420**C, **420**D) that are also part of the second adjustable strip **250**B. In this way, one or more continuous wires may be part of the first and second adjustable strips **250**A, **250**B and the anterior strip **510**. For example, wire **420**A of the first adjustable strip **250**A and the wire **420**C of the second adjustable strip **250**B may be portions of the same continuous wire. These one or more wires may encircle the wrist, running from one end of the ratchet **230** to the opposite end of the ratchet **230**. In alternate embodiments, the anterior strip **510** is replaced by a tension adjustment mechanism similar to that on the posterior side of the wrist (e.g., two adjustable strips coupled to ratchet configured to adjust the length of the adjustable strips). Alternately, the anterior strip **510** may include a ratchetable buckle strap system, a releasable pawl and gear rack system, a ladderlock strap system, or a fabric hook and fastener strap system. In some embodiments, the anterior strip **510**A is omitted. In such embodiments, the force distribution segments **240**A, **240**B may directly couple to each other with one or more hinges. Alternately, the force distribution segments **240**A, **240**B may be constituent portions of a single continuous element.

[0067] FIG. **5**B illustrates a cross-section of a wristband **520** including series of links, according to an embodiment. The wristband **520** may part of a haptic glove (e.g., haptic glove **200**). The wristband may include force distribution segments **240**A-**240**B that each comprise a series of links. These links may be rigid elements (e.g., plastic, metal, or ceramic) connected to each other by hinges, which permit the links to rotate relative to each other. The hinges may be configured to allow rotation along an axis parallel to the surface of the user's wrist thereby allowing the force distribution segments **240**A, **240**B to conform to the curvature of the user's wrist.

[0068] FIG. **5**C illustrates a cross-section of a wristband **530** including meshes, according to some embodiments. The wristband **530** may be part of a haptic glove (e.g., haptic glove **200**). The wristband **530** may include force distribution segments **240**A, **240**B. Force distribution segment **240**A includes a mesh **540**A over a thin elastic strop **540**A, and force distribution segment **240**B includes a mesh **540**B over a thin elastic strip **540**B. Each mesh **540**A, **540**B may consist of interconnected links, such as metal rings. The mesh **540**A, **540**B may be, for example, a Milanese mesh. The meshes **540**A,**540**B may be compliant in a direction perpendicular to the surface of the user's wrist **580**, but relatively stiff to forces parallel to the surface of the user's wrist **580**.

[0069] FIG. **5**C does not depict a thumb tendon mount **260**. In some embodiments, the wristband **530** does not include a thumb tendon mount **260**, and a thumb tendon (e.g., tendon **215**A) couples to an alternate part of the wristband **530** (e.g., the mesh **540**A). In alternate embodiments, the first force distribution segment **240**A includes a thumb tendon mount **260** which couples to the thumb tendon.

[0070] FIG. **5**D illustrates a cross-section of a wristband **550** including hinged segments, according to an embodiment. The wristband **550** may be part of a haptic glove (e.g., haptic glove **200**) and may include force distribution segments **240**A-**240**B. The force distribution segment **240**A includes an upper segment **560**A, and a hinge **570**A connecting the upper segment **560**A to a lower segment **560**A. The force distribution segment **240**B includes an upper segment **560**B, and a hinge **570**B connecting the upper segment **560**B to a lower segment **560**B. Each of the hinges **570**A, **570**B allows their respective upper and lower segments **560**A,**560**D to rotate with respect to each other. The axis of rotation of the hinges **570**A, **570**B may be approximately parallel to direction of the user's forearm. In some embodiments, each of the force distribution segments **240**A, **240**B include more than two segments (e.g., **560**A-D) and more than one hinge (e.g., hinges **570**A, **570**B) to connect them. In some embodiments, the upper segments **560**A, **560**B and lower segments **560**C, **560**D are rigid bodies. In alternate embodiments, the upper segments **560**A, **560**B and lower segments **560**C, **560**D are flexible in a direction perpendicular to the surface of the user's wrist **580**, but inflexible (i.e., not susceptible to bending) in directions parallel to the surface of the user's wrist **580**.

OTHER CONSIDERATIONS

[0071] The foregoing description of the embodiments of the disclosure have been presented for the purpose of illustration; it is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Persons skilled in the relevant art can appreciate that many modifications and variations are possible in light of the above disclosure.

[0072] Some portions of this description describe the embodiments of the disclosure in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are commonly used by those skilled in the data processing arts to convey the substance of their work effectively to others skilled in the art. These operations, while described functionally, computationally, or logically, are understood to be implemented by computer programs or equivalent electrical circuits, microcode, or the like. Furthermore, it has also proven convenient at times, to refer to these arrangements of operations as modules, without loss of generality. The described operations and their associated modules may be embodied in software, firmware, hardware, or any combinations thereof.

[0073] Any of the steps, operations, or processes described herein may be performed or implemented with one or more hardware or software modules, alone or in combination with other devices. In one embodiment, a software module is implemented with a computer program product comprising a computer-readable medium containing computer program code, which can be executed by a computer processor for performing any or all of the steps, operations, or processes described.

[0074] Embodiments of the disclosure may also relate to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, and/or it may comprise a general-purpose computing device selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a non-transitory, tangible computer readable storage medium, or any type of media suitable for storing electronic instructions, which may be coupled to a computer system bus. Furthermore, any computing systems referred to in the specification may include a single processor or may be architectures employing multiple processor designs for increased computing capability.

[0075] Embodiments of the disclosure may also relate to a product that is produced by a computing process described herein. Such a product may comprise information resulting from a computing process, where the information is stored on a non-transitory, tangible computer readable storage medium and may include any embodiment of a computer program product or other data combination described herein.

[0076] Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the disclosure be limited not by this detailed description, but rather by any claims that issue on an application based hereon. Accordingly, the disclosure of the embodiments is intended to be illustrative, but not limiting, of the scope of the disclosure, which is set forth in the following claims.

What is claimed is:

1. A force ground device comprising:

a finger sheath configured to enclose a finger of a user of the force grounding device;

a tendon having a first end and a second end, the first end coupled to the finger sheath;

an actuator coupled to the second end of the tendon, wherein the actuator is configured to produce tension in the tendon;

a wristband coupled to the actuator and configured to ground forces from the actuator to a wrist of the user, the wristband comprising:

a first force distribution segment inflexible in directions parallel to a surface of a wrist, the first force distribution band to distribute forces on the wristband from the actuator to a first side of the wrist;

a second force distribution segment inflexible in directions parallel to the surface of the wrist, the second force distribution band to distribute forces on the wristband from the actuator to a second side of the wrist.

2. The force ground device of claim **1**, wherein the wristband further comprises:

a first adjustable strip coupled at a first end to a first end of the first force distribution segment;

a second adjustable strip coupled at a first end to a first end of the second force distribution segment; and

a tension adjustment mechanism, the tension adjustment mechanism coupled at a first end to a second end of the first adjustable strip and coupled at a second end to a second end of the second adjustable strip, the tension adjustment mechanism configured to adjust tension in the first adjustable strip and tension in the second adjustable strip.

3. The force ground device of claim **2**, wherein:

the first adjustable strip comprises one or more first tendons, each of the one or more first tendons protruding from the tension adjustment mechanism and coupling to the first force distribution segment at a first end;

the second adjustable strip comprises one or more second tendons, each of the one or more second tendons protruding from the tension adjustment mechanism and coupling to the second force distribution segment at a first end;

the tension adjustment mechanism is configured to increase the tension in the first adjustable strip by partially withdrawing the one or more first tendons into itself; and

the tension adjustment mechanism is further configured to increase the tension in the second adjustable strip by partially withdrawing the one or more second tendons into itself.

4. The force ground device of claim **3**, wherein the tension adjustment mechanism withdraws the one or more first tendons and the one or more second tendons into itself with a ratcheting mechanism.

5. The force ground device of claim **2**, wherein the tension adjustment mechanism is adjacent to a posterior side of the wrist.

6. The force ground device of claim **1**, wherein the force ground device further comprises:

a thumb sheath;

a thumb tendon having a first end and a second end, the first end coupled to the thumb sheath;

a thumb actuator coupled to the second end of the thumb tendon, wherein the thumb actuator is configured to produce tension in the tendon; and

a thumb tension adjustment mechanism, the thumb tension adjustment mechanism configured to adjust tension in the thumb tendon.

7. The force ground device of claim **1**, wherein the first force distribution segment is adjacent to an ulna bone of the wrist and the second force distribution segment is adjacent to a radius bone of the wrist.

8. The force ground device of claim **1**, wherein each of the first and second force distribution segments comprises a plurality of interconnected rigid links.

9. The force ground device of claim **1**, wherein each of the first and second force distribution segments comprises a mesh and an elastic strip, the elastic strip between the wrist and the mesh.

10. The force ground device of claim **9**, wherein the elastic strip of each of the first and second force distribution segments is neoprene.

11. The force ground device of claim **9**, wherein the mesh of each of the first and second force distribution segments is a Milanese mesh.

12. The force ground device of claim **1**, wherein the first force distribution segment is flexible in a first direction perpendicular to the surface of the wrist and the second force distribution segment is flexible in a second direction perpendicular to the surface of the wrist.

13. The force ground device of claim **1**, wherein the wristband further comprises an anterior strip coupled at a first end to a second end of the first force distribution segment and coupled at a second end to a second end of the second force distribution segment.

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