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(54) Title: SEMI-PASSIVE CONTROL SYSTEM AND METHOD FOR ASSISTIVE ORTHOSES

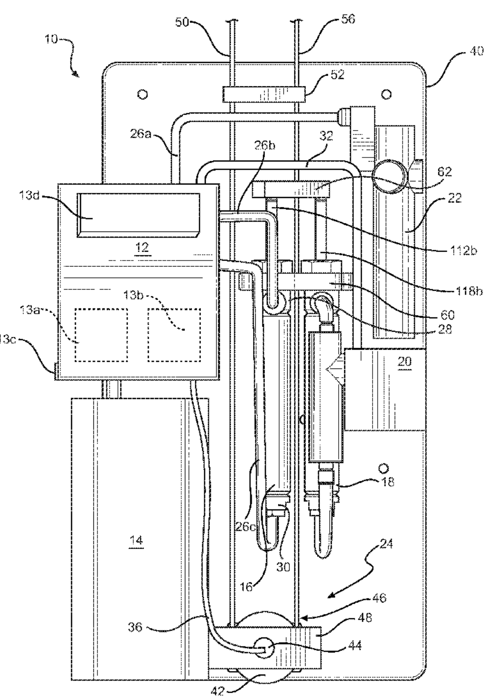

FIG. 1

(57) Abstract: Semi-passive control system (10) comprises a pneumatic spring actuator (16), a pressure regulator (22) in communication with the pneumatic spring actuator (16), a hydraulic locking actuator (18), a hydraulic valve (20) in communication with actuator (18), a power source (14), a pulley wheel (42), and a cable (46) having a first end in contact with pulley wheel (42), first and second side portions (50, 56) extending from opposing sides of pulley wheel (42), and a second end adapted to connect to an orthosis device (76). At least one cable clamp (62) attaches to second side portion (56) of cable (46) and interconnects cable (46) to shafts (112b, 118b) of actuators (16, 18). A central control unit (12) includes a processor (13a) and a computer readable storage medium (13b) having program instructions stored thereon for execution by the central control unit to adjust stiffness, damping or stiffness and damping parameters.

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SEMI-PASSIVE CONTROL SYSTEM AND METHOD FOR ASSISTIVE ORTHOSES

[0001] This invention was made with United States Government support under grant Nos. 1354321 and 1362172 awarded by the National Science Foundation (NSF). The U.S. Government has certain rights in the invention.

BACKGROUND

[0002] 1. Field of the Invention

[0003] The present invention pertains to the art of orthosis devices, and more particularly, to assistive orthosis devices for upper limbs.

[0004] 2. Discussion of the Prior Art

[0005] Existing assistive orthosis devices either use active or passive methods to assist an individual. Active devices use direct current (DC) motors to provide assistive torque to limbs of an individual. To change the perceived damping and stiffness felt by the wearer of an orthosis device, controllers need to be implemented. This requires the motors to be constantly run, which consumes a lot of power. The controllers are also complicated, making the modeling of a user very important and the motors expensive and specialized. Passive devices can provide assistance through fixed springs and dampers, which do not require electricity to operate. However the parameters (e.g. settings) of the fixed springs and dampers may not be suitable for every task. For instance, if a device holds the arm in front of the user, they will have difficulties holding their arm above their head, or down by their side.

[0006] U.S. Patent No. 6,821,259 depicts an orthosis device including two limb sections pivotally attached to each other. Each limb section includes a four-bar linkage and a spring member adapted to provide an equilibrium-inducing force, allowing a user with muscular abnormalities to move his or her limb and hold them in place. U.S. Patent No. 8,834,169 is directed to a method and apparatus for automating arm and grasping movement training for rehabilitation of patients with motor impairment. The apparatus includes a wheelchair mounted orthosis having a forearm link and an upper arm link. The '259 and '169 devices utilize fixed springs to compensate for gravity of an arm in order to stabilize the arm at a specific point.

[0007] U.S. Patent Nos. 8,409,117, 8,585,620 and 7,396,337 are directed to orthotic devices that utilize electric motors to directly drive a joint. Such devices are bulky, costly and inefficient.

[0008] Based on the above, there is seen to be a need in the art for a semi-passive fluidic orthosis system that consumes comparatively small amounts of energy while suiting a variety of applications. There is also a need for a device that stabilizes a user's arm at any point, allowing the device to assist a user in lifting and carrying objects. Further, there is a need for a device that can assist a user with dropping and catching. The present invention combines the advantages of active and passive methods to assist an individual.

[0009] The present invention includes variable stiffness devices that stabilize a user's arm at any point for both the arm and a load, and enable the introduction of damping into the system to assist a user with dropping and catching objects. Further, the present invention provides a lighter orthotic device that utilizes less energy compared to DC devices. The semi-passive device of the present invention can be adjusted to set the stiffness, equilibrium point and damping to whatever a user requires. After these parameters are set (actively), the actuators of the system become inert, requiring no power to function. This dramatically reduces the power consumption as compared to motorized assist devices. Also as the spring means (pneumatic spring actuator) and damper means (hydraulic actuator) are set directly and independently, the controllers can be simpler in that they do not require high fidelity models of a user or their intent.

SUMMARY

[0010] The present invention is directed to a semi-passive control system framework and method for assistive orthoses. The device of the present invention provides assistance in the form of gravity and weight compensation, as well as load carrying capacity through hydraulic locking. More specifically, gravity compensation through the use of a pneumatic spring provides a significant increase in the range of motion available to a user. The device can be used for a variety of tasks, thereby increasing the mobility and functionality of a user's arm.

[0011] The device of the present invention is semi-passive, and extremely efficient, which allows for significantly longer continuous usage. The device locks hydraulically, allowing for zero power consumption during long periods of usage. The exoskeleton device is lightweight, simplifying everyday wear, and reducing user fatigue common in other systems. The invention also is simple to don and doff, significantly increasing viability for patients with impaired mobility.

[0012] In an aspect of the invention, a semi-passive control system includes a pneumatic spring actuator having a shaft, a pressure regulator in communication with the pneumatic spring actuator, a hydraulic locking actuator having a shaft, a hydraulic valve in communication with the hydraulic locking actuator, a pulley wheel, and a cable having a first end in contact with the pulley wheel, first and second side portions extending from opposing sides of the pulley wheel, and a second end adapted to connect to an orthosis device. The system also includes at least one cable clamp attached to the second side portion of the cable and interconnecting the cable to the shaft of the pneumatic spring actuator and to the shaft of the hydraulic locking actuator, and a power source. A central control unit is also provided, including a processor and a computer readable storage medium having program instructions to adjust stiffness, damping or stiffness and damping parameters stored thereon for execution by the central control unit.

[0013] In another aspect of the invention, a computer-implemented method for controlling an orthosis joint comprises the steps of receiving, by a computing device, sensor information indicating that a user's limb is moving; determining, by the computing device, that the user's limb is moving in a manner that corresponds with a predefined movement based on the sensor information; determining, by the computing device, parameters associated with the predefined movement; determining, by the computing device, if the parameters require a change in stiffness of an orthosis joint; and determining, by the computing device, if the parameters require a change in damping of the orthosis joint. Upon determining, by the computing device, that the parameters require a change to the stiffness, damping or stiffness and damping of the orthosis joint, the method further comprises activating a power supply to power an adjustment of one or both of a pneumatic spring actuator and a hydraulic actuator, and adjusting, by the computing device, one or both of the pneumatic spring actuator and the hydraulic actuator to achieve the parameters.

[0014] Additional objects, features and advantages of the present invention will become more readily apparent from the following detailed description of a preferred embodiment when taken in conjunction with the drawings wherein like reference numerals refer to corresponding parts in the several views.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The present invention is described in the detailed description which follows, in reference to the noted plurality of drawings by way of non-limiting examples of exemplary embodiments of the present invention.

[0016] FIG. 1 is a front view of a semi-passive control system of the present invention;

[0017] FIG. 2 is a partial exploded view of a semi-passive control system of the present invention connected to an upper arm orthosis device;

[0018] FIG. 3 depicts details of the upper arm orthosis device of FIG. 2;

[0019] FIG. 4 is a perspective side view of a user wearing an upper arm orthosis device in accordance with embodiments of the invention;

[0020] FIG. 5 shows a cross-sectional view of a pneumatic spring actuator of the present invention;

[0021] FIG. 6 shows a cross-sectional view of a hydraulic actuator of the present invention;

[0022] FIG. 7 shows a control schematic of the present invention;

[0023] FIG. 8 is a back perspective view of an alternative upper arm orthosis device for use with the present invention; and

[0024] FIG. 9 is a diagram depicting methods of the present invention.

DETAILED DESCRIPTION

[0025] The present invention relates generally to semi-passive assistive devices for the upper limbs. The present invention may be a system, a method, and/or a computer program product. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention.

[0026] FIG. 1 depicts a semi-passive control system 10 of the present invention for use with assistive orthosis devices. Control system 10 includes a central control unit (computing device) 12, a power supply 14, a pneumatic spring actuator (pneumatic cylinder) 16, a hydraulic actuator (hydraulic cylinder) 18 including a hydraulic valve system 20, a pressure regulator and supply 22, and a pulley system generally indicated at 24. Central control unit 12 is in communication with a first pneumatic supply line 26a connected to pressure regulator and supply 22, a second pneumatic supply line 26b connected to a first end 28 of pneumatic spring actuator 16, and a third pneumatic supply line 26c connected to a second end 30 of pneumatic spring actuator 16. Central control unit 12 is also in communication with hydraulic valve 20 via a cable 32, and pulley system 24 via a cable 36. Central control unit 12 includes a computer processor 13a capable of implementing a control algorithm (computer readable program instructions). For example, central control unit 12 may be a commercial microcontroller adapted for use with the invention, such as an Intel® Edison Microcontroller. Central control unit 12 may also include other standard microprocessor components such as a computer readable storage medium or memory 13b, and an input/output (I/O) interface 13c. A display 13d may also be connected to central control unit 12.

[0027] The computer readable storage medium utilized with the present invention is a tangible device that can retain and store instructions for use by an instruction execution device. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. Computer readable program instructions described herein can be downloaded to central control unit 12 from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The computer readable program instructions may execute entirely on central control unit 12, partly on central control unit 12, as a stand-alone software package, partly on central control unit 12 and partly on a remote computer or entirely on the remote computer or server (not shown). In the latter scenario, the remote computer may be connected to central control unit 12 through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

[0028] In embodiments, semi-passive control system 10 is mounted on a support panel 40, which may be configured as a wearable support as will be discussed in more detail below. Pulley system 24 comprises an idle pulley wheel 42 with a rotary encoder 44 attached thereto, and a cable 46. Rotary encoder 44 is in communication with central control unit 12 via cable 36 and can be any standard rotary encoder for determining the position of pulley wheel 42. For example, rotary encoder can be a MA3 Miniature Absolute Magnetic Shaft Encoder from US Digital. A bearing holder 48 secures pulley wheel 42 and rotary encoder 44 to support panel 40. A first side portion 50 of cable 46 extends through a first aperture (not shown) in a cable guide 52 secured to an upper portion 54 of support panel 40. Likewise, a second side portion 56 of cable 46 extends through a second aperture (not shown) in cable guide 52. A piston mount 60 is utilized to connect pneumatic spring actuator 16 and hydraulic actuator 18 to support panel 40. Additionally, second side portion 56 of cable 46 is fixed to at least one cable clamp 62 mounted to shafts 112b and 118b of respective actuators 16 and 18.

[0029] Additional details of pulley system 24 will now be discussed with reference to FIG. 2. A bearing holder 70 is connected to support panel 40 for holding a lower bearing 72. Pulley wheel 42 engages lower bearing 72 and an upper bearing 74. Bearing holder 48 engages upper bearing 74 and secures pulley wheel 42, lower bearing 72 and upper bearing 74 to support panel 40. As depicted in FIG. 2, cable clamp 62 may be in the form of first and second cable blocks. It should be understood that semi-passive control system 10 may be utilized with a number of different orthosis devices.

[0030] By way of example, FIG. 2 depicts semi-passive control system 10 in use with an upper arm orthosis device 76. Upper arm orthosis device 76 includes an arm-mounted portion having an elbow pulley 80, a cable guide 82, a bicep mounting bar 84, a forearm mounting bar 86, a spacer 88, a pair of cable clamps 90a, 90b and a needle roller bearing 92. As depicted in FIG. 3, cable guide 82 is adapted to connect to bicep mounting bar 84 via fasteners (now shown). In use, a first end of cable 32 is connected to pulley wheel 42 and a second end is connected to elbow pulley 80. With this configuration, actuators 16 and 18 are connected through cable 32 to elbow pulley 80 and can be utilized to adjust stiffness and damping effects of elbow pulley 80.

[0031] FIG. 4 will now be referenced with respect to additional details of upper arm orthosis device 76. Support panel 40 may be utilized to support components of system 10 near a user, such as on a wheelchair or the like (not shown), or on a user. In embodiments, semi-passive control system 10 is mounted to a user via support panel 40. More specifically, support panel 40 may attached to a user via a means for connecting support panel 40 to a user, such as a chest strap 100 and a waist strap 102. A molded cushion 104 or other suitable structure may be added to a back of support panel 40 to provide comfort to a user. Bicep mounting bar 84 is secured to a user's bicep, such as through straps 106. Likewise, forearm mounting bar 86 is secured to a user's forearm, such as through straps 108. Sensor arrays 110, 111a, 111b, including a plurality of sensors are positioned on upper arm orthosis device 76 and are adapted to sense signals generated by a user of the device and provide information to central control unit 12. Sensor arrays 110, 111a, 111b may be comprised of pressure sensors, motion sensors, muscle sensors (e.g. surface electromyography sensors), or other sensors adapted to provide information regarding the user's movements to central control unit 12.

[0032] FIG. 5 will now be referenced with respect to details of pneumatic spring actuator 16. Pneumatic spring actuator 16 utilizes a compressible working fluid, such as air or carbon dioxide, to vary both its free length and its stiffness. This is achieved by modulating the pressure of the working fluid in first and second chambers 108, 109 of a piston/cylinder system. Modulation is achieved using high frequency valves. A piston head 112a is connected to a piston stem 112b. As pressure increases or decreases in either side of piston head 112a, the free length of piston stem 112b and its stiffness changes. The free length of piston stem 112b and stiffness of pneumatic spring actuator 16 may be controlled dynamically or held static, depending on the desired behavior of the overall assistive device. It should be understood that pneumatic cylinder 16 may be commercially available cylinder adapted for use with the present invention. For example, pneumatic cylinder 16 may be an SR-043-D air cylinder from BIMBA®.

[0033] FIG. 6 will now be referenced with respect to additional details of hydraulic actuator 18. Hydraulic actuator 18 utilizes an incompressible working fluid, such as water or oil, to vary the damping coefficient. First and second chambers 114, 115 of a piston/cylinder system are connected (as shown in FIG. 1), creating a closed loop of the working fluid. Linear actuation of a piston head 118a and piston shaft 118b forces fluid to move between the first and second chambers above or below piston head 118a. A variable aperture valve 20 (shown in FIG. 7) is connected between first and second chambers 114, 115. By varying the size of the valve aperture, different levels of flow restriction can be achieved. Changing the flow restriction changes the damping coefficient of hydraulic actuator 18. Complete flow restriction results in full locking. The fluidic damping actuator 18 only consumes power when changing the degree of damping. The damping coefficient may be controlled dynamically or held static depending on the desired behavior of the orthosis device used. It should be understood that hydraulic cylinder 18 may be a commercially available cylinder adapted for use with the present invention. For example, hydraulic cylinder 18 may be an SR-043-D from BIMBA®.

[0034] The manner in which semi-passive control system 10 may be operated will now be discussed with reference to FIG. 7. As previously discussed, sensors, such as motion, muscle and pressure sensors, are mounted on upper arm orthosis device 76 and are in communication with central control unit 12. Central control unit 12 utilizes data from sensor arrays 110, 111a and 111b to control pneumatic spring actuator 16 and hydraulic actuator 18. As depicted, a pressure reservoir or supply 22 in communication with pneumatic spring actuator 16 can be controlled through a valve array, including valves 130, 131. Similarly, hydraulic supply to hydraulic actuator 18 can be controlled through hydraulic valve 20. Central control unit 12 can be programmed to implement a pre-determined series of motions, depending on the data received from the sensor arrays 110, 111a, 111b. Power supply 14 is also connected to central control unit 12 and respective actuators 16 and 18.

[0035] The main benefit of the present invention is that energy is only required to change the dynamic parameters of each joint of an orthotic device. By choosing the optimal parameter set (e.g., stiffness, damping or stiffness and damping setting) for a given set of tasks, and only changing the parameters when necessary, energy expenditure can be greatly reduced. As the dynamic parameters themselves can be changed, it is possible to inject, store and remove energy from the system directly. This allows the energy of a caught object to be absorbed into semi-passive control system 10 either by being dissipated through damping (utilizing the hydraulic actuator 18), or stored so that the energy can be returned in a throw (utilizing the pneumatic spring actuator 16). Similarly, a lifted load can be held by locking the joint (using the hydraulic actuator 18), allowing the weight to be supported by the assistive device, reducing the load experienced by a wearer of orthosis device 76.

[0036] The primary features of the semi-passive control system 10 in combination with orthosis device 76, are the pneumatic spring actuator 16 that assists in gravity/load compensation, and the hydraulic actuator 18 that allows users to hold loads without actively powering system 10. Actuators 16 and 18 are the primary source of weight of system 10, and are preferably located on a back of a user, allowing for the majority of the weight of the system

10 to be carried by a user's shoulders/torso, further reducing fatigue. System 10 transmits power from actuators 16 and 18 to a user's elbow joint through cable 46 of orthosis device 76, which drive the elbow to assist in movement of the user. More specifically, the drive system includes a single loop of steel cable 46 and pulleys 42 and 80. Cable brackets or guides 52 and 82 ensure the correct positioning of cable 46. Because of this loop and back plate system, actuators 16 and 18 can be easily added, further simplifying manufacturing and repair.

[0037] FIG. 8 depicts an alternative embodiment of the present invention, wherein means for connecting support panel 40 of a semi-passive control system 10′ to a user is in the form of a suit 150. More specifically, a support panel 40 with a semi-passive control system 10′ mounted thereto may be attached to an upper body suit 150. With this configuration, the weight of semi-passive control system 10′ can be distributed to a user's torso through suit 150. It should be understood that semi-passive control system 10′ includes the same components as semi-passive control system 10, although some components are not depicted in this figure (e.g. central control unit 12 and power supply 14). Further, some components are shown in a different configuration, such as pressure regulator and supply 22′ and hydraulic valve 20′. It should be understood that components of systems 10 and 10′ shown may be arranged in different configurations without compromising the function of the invention.

[0038] Method of using the present invention will now be discussed with reference to FIG. 9. At step 200 one or more sensors of sensor arrays 110, 111a, 111b detect a motion of a user's arm and send data to central control unit 12. Central control unit 12 then compares the data to information in its memory 13b to determine whether the motion detected is one of a plurality of preprogrammed or predetermined recognized motions or movements at step 201. Once central control unit 12 determines that the movement is a predetermined recognized movement, central control unit 12 utilizes information stored in memory 13b to determine whether the movement requires particular parameters to be set for actuators 16 and 18. More specifically, central control unit 12 looks up desired parameters for a particular motion stored in a look-up table in memory 13b and compares the parameters to the current parameters for actuators 16 and 18. If central control unit 12 determines that an adjustment to actuator 16 and/or 18 is required at steps 202 and/or 204, power supply 14 is actuated to power an adjustment of actuator 16 and/or 18 at steps 203 and/or 205. More specifically, if central control unit 12 determines that a change in joint stiffness is needed at step 202, power supply 14 is actuated to provide an adjustment to pneumatic spring actuator 16 to adjust the position of piston head 112a within actuator 16 at step 203. If central control unit determines that a change in damping is needed at step 204, then power supply 14 is actuated at step 205 to provide power to hydraulic valve 20 to adjust the flow of fluid in hydraulic actuator 18. If central control unit 12 determines that a joint lock is needed (e.g., elbow pulley 80 is locked so that it cannot move) at step 206, then power supply 14 is actuated to provide power to adjust hydraulic actuator 18 to lock hydraulic actuator 18 in a fixed position at step 207 so that cable 46 is held stationary. Once any necessary actuator adjustments are completed at step 208, power supply 14 is deactivated at step 209. It should be appreciated that, with this configuration, power consumption from power supply 14 is limited, and passive assistance is provided by actuators 16 and 18, in accordance with predetermined parameters.

[0039] Additionally, a user may utilize a manually control unit, such as a remote control unit 214 to initiate adjustments of actuators 16 and 18. Manual control unit 214 may include, for example, buttons which are preprogrammed to initiate the adjustment of actuators 16 and/or 18 based on predetermined parameters associated with a particular motion. For example, an oftrepeated motion, such a carrying a box, may be associated with a particular button on manual control unit 214, enabling a user to select the button when performing the repetitive motion. In accordance with the present invention, pneumatic actuator 16 can be utilized alone to provide a predetermined joint stiffness, hydraulic actuator 18 can be utilized alone to provide a predetermined damping, or actuators 16 and 18 can be utilized together to provide a combination of desired joint stiffness and damping. Examples of motions that could be aided by the semi-passive control system 10 of the present invention are set forth below.

[0040] Example 1: Catching

[0041] In a first example, a user is wearing upper orthosis device 76 connected to semi-passive control system 10. In this first example, a user is standing with their arm bent at the elbow in front of them. A mass is dropped onto their hand. This sudden load is detected using sensor arrays 110, 111a, 111b, and the sensor data is conveyed to central control unit 12. Central control unit 12 determines that the movement indicated by the data is a catching movement, which requires a particular preprogrammed damping parameter. Accordingly, central control unit 12 adjusts hydraulic actuator 18 such that damping at the elbow of the user is increased dramatically to the preprogrammed damping parameter, thereby reducing the braking force the individual's elbow needs to apply and minimizing the overextension of the user's elbow joint.

[0042] Example 2: Holding

[0043] In a second example, a user is wearing upper orthosis device 76 connected to semi-passive control system 10. The user needs to carry a heavy load. By increasing the damping at the elbow joint to full via adjustment of the hydraulic actuator 18, the elbow joint effectively locks in place. This makes orthosis device 76 load bearing, reducing the load experienced by the user. On prior art active devices this would require power for the entire length of time the object is held. However the semi-powered control system 10 of the present invention only requires power to increase the damping at the joint, after which the device can power off.

[0044] Example 3: Catch and throw

[0045] In a third example, a user is wearing upper orthosis device 76 connected to semi-passive control system 10. In this example, the user needs to catch an object, and then throw it. Instead of using the damper function of hydraulic actuator 18 to remove the energy from the caught object (as in case 1), pneumatic spring actuator 16 is utilized to absorb the energy. More specifically, when the object is caught, the compressible fluid within pneumatic spring actuator 16 becomes pressurized and cavitates on opposite sides of the actuator 16. Valve array 130, 131 closes, thereby locking pneumatic spring actuator 16 and storing this energy (energy from the pressurized fluid). When the user needs to return the object, valve 130 opens, allowing the stored elastic energy to be released through actuator 16.

[0046] Example 4: Reaching

[0047] In this example, semi-passive control system 10 is connected to a shoulder orthosis (not shown). The user, an individual with a weakened shoulder, is standing. The equilibrium point of the user's arm remains vertically down and the orthosis device has minimal stiffness or damping. The user wishes to pick up a bowl from head height, and place it in front of them. The user moves their arm upwards. This motion is detected by sensors arrays associated with the orthosis device (not shown), and motion data is relayed to central control unit 12. Central control unit 12 adjusts actuators 16 and/or 18 such that the equilibrium point of the arm is increased and the arm balances at shoulder height. By increasing the stiffness of the shoulder, it supports the mass of the arm, allowing the user to both reach the bowl and place it on the table.

Power is only required during the change in stiffness and equilibrium point. This cannot be achieved by a passive device, and would require a constant power drain from an active device.

[0048] Although described with reference to a preferred embodiment of the invention, it should be readily understood that various changes and/or modifications can be made to the invention without departing from the spirit thereof. For instance, the means for attaching the orthosis device to a user can take on any number of known forms, and the support plate could be mounted to a wheelchair, or in front of a user, depending on the particular use of the device and the needs of a user.

What is claimed is:

1. A semi-passive control system comprising:

a pneumatic spring actuator including a shaft;

a pressure regulator in communication with the pneumatic spring actuator;

a hydraulic locking actuator including a shaft;

a hydraulic valve in communication with the hydraulic locking actuator;

a pulley wheel;

a cable having a first end in contact with the pulley wheel, first and second side portions extending from opposing sides of the pulley wheel, and a second end adapted to connect to an orthosis device;

at least one cable clamp attached to the second side portion of the cable and interconnecting the cable to the shaft of the pneumatic spring actuator and to the shaft of the hydraulic locking actuator;

a power source; and

a central control unit including a processor and a computer readable storage medium having program instructions stored thereon for execution by the central control unit to adjust stiffness, damping or stiffness and damping parameters.

2. The system of claim 1, wherein the program instructions include:

program instructions to receive sensor information from an orthosis device worn by a user;

program instructions to determine that a user's limb is moving in a manner that corresponds with a predefined movement based on the sensor information;

program instructions to determine parameters associated with the predefined movement;

program instructions to determine if the parameters require a change in stiffness of an orthosis joint;

program instructions to determine if the parameters require a change in damping of the orthosis joint;

program instructions to activate a power supply to power an adjustment of one or both of a pneumatic spring actuator and a hydraulic actuator upon determining that the parameters require a change to the stiffness, damping or stiffness and damping of the orthosis joint;

program instructions to adjust one or both of the pneumatic spring actuator and the hydraulic actuator to achieve the parameters.

3. The system of claim 1, further comprising program instructions to deactivate the power supply upon completion of the adjusting the one or both of the pneumatic spring actuator and the hydraulic actuator to achieve the parameters.

4. The system of claim 1, further comprising a support panel, wherein the pneumatic spring actuator, pressure regulator, hydraulic locking actuator, hydraulic valve, pulley wheel, power source and central control unit are mounted to the support panel.

5. The system of claim 4, further comprising means for attaching the support panel to a user.

6. The system of claim 1, further including an orthosis device comprising:

an elbow pulley, wherein the second end of the cable extends about the elbow pulley;

a forearm mounting bar;

a bicep mounting bar pivotally connected to the forearm mounting bar;

at least one sensor array; and

a cable guide mounted to the bicep mounting bar and connecting the cable to the bicep mounting bar;

wherein a stiffness parameter of the pneumatic spring actuator, a damping parameter of the hydraulic actuator, or a combination of the stiffness and damping parameters is transmitted to the elbow pulley through the cable.

7. The system of claim 1, further comprising a manual control device for activating a predefined set of stiffness, damping or stiffness and damping parameters.

8. A computer-implemented method for controlling an orthosis joint, comprising:

receiving, by a computing device, sensor information indicating that a user's limb is moving;

determining, by the computing device, that the user's limb is moving in a manner that corresponds with a predefined movement based on the sensor information;

determining, by the computing device, parameters associated with the predefined movement;

determining, by the computing device, if the parameters require a change in stiffness of an orthosis joint;

determining, by the computing device, if the parameters require a change in damping of the orthosis joint;

upon determining, by the computing device, that the parameters require a change to the stiffness, damping or stiffness and damping of the orthosis joint, activating a power supply to power an adjustment of one or both of a pneumatic spring actuator and a hydraulic actuator;

adjusting, by the computing device, one or both of the pneumatic spring actuator and the hydraulic actuator to achieve the parameters.

9. The computer-implemented method of claim 8, wherein the parameters require locking of the joint, and the adjusting comprises adjusting the hydraulic actuator to a maximum damping to lock the joint.

10. The computer-implemented method of claim 8, wherein the adjusting comprises adjusting both the hydraulic actuator and the pneumatic actuator.

11. The computer-implemented method of claim 8, wherein the adjusting comprises adjusting only the pneumatic actuator.

12. The computer-implemented method of claim 8, wherein the adjusting comprises adjusting only the hydraulic actuator.

13. The computer-implemented method of claim 8, further comprising deactivating the power supply upon completion of the adjusting the one or both of the pneumatic spring actuator and the hydraulic actuator to achieve the parameters.

14. The computer-implemented method of claim 8, wherein the sensor information is received from an upper-arm orthosis device.

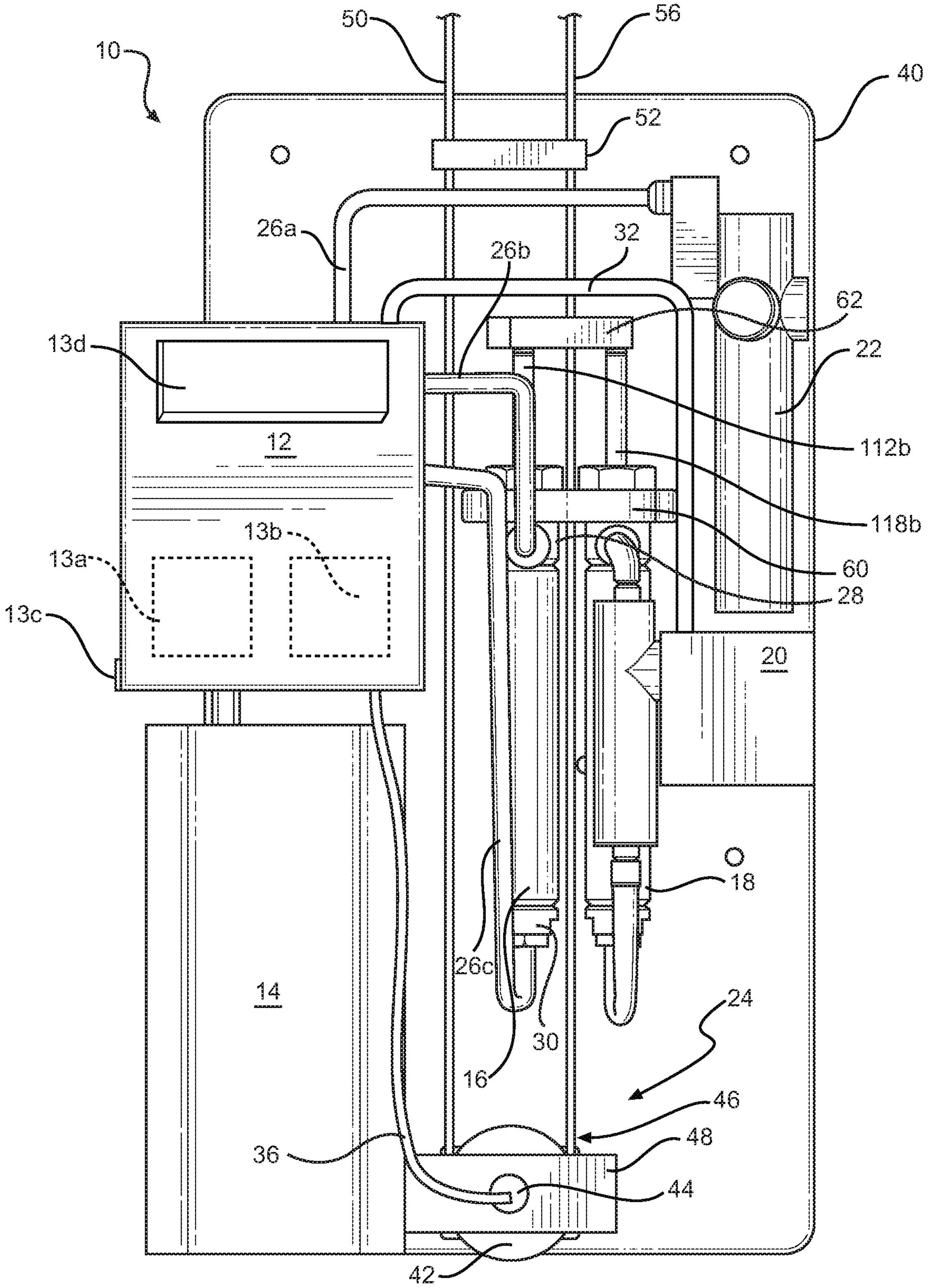
10
50
56
40
52
26a
26b
32
62
22
13d
12
112b
118b
60
28
13b
13a
13c
20
18
26c
14
30
16
24
46
48
36
44
42

FIG. 1

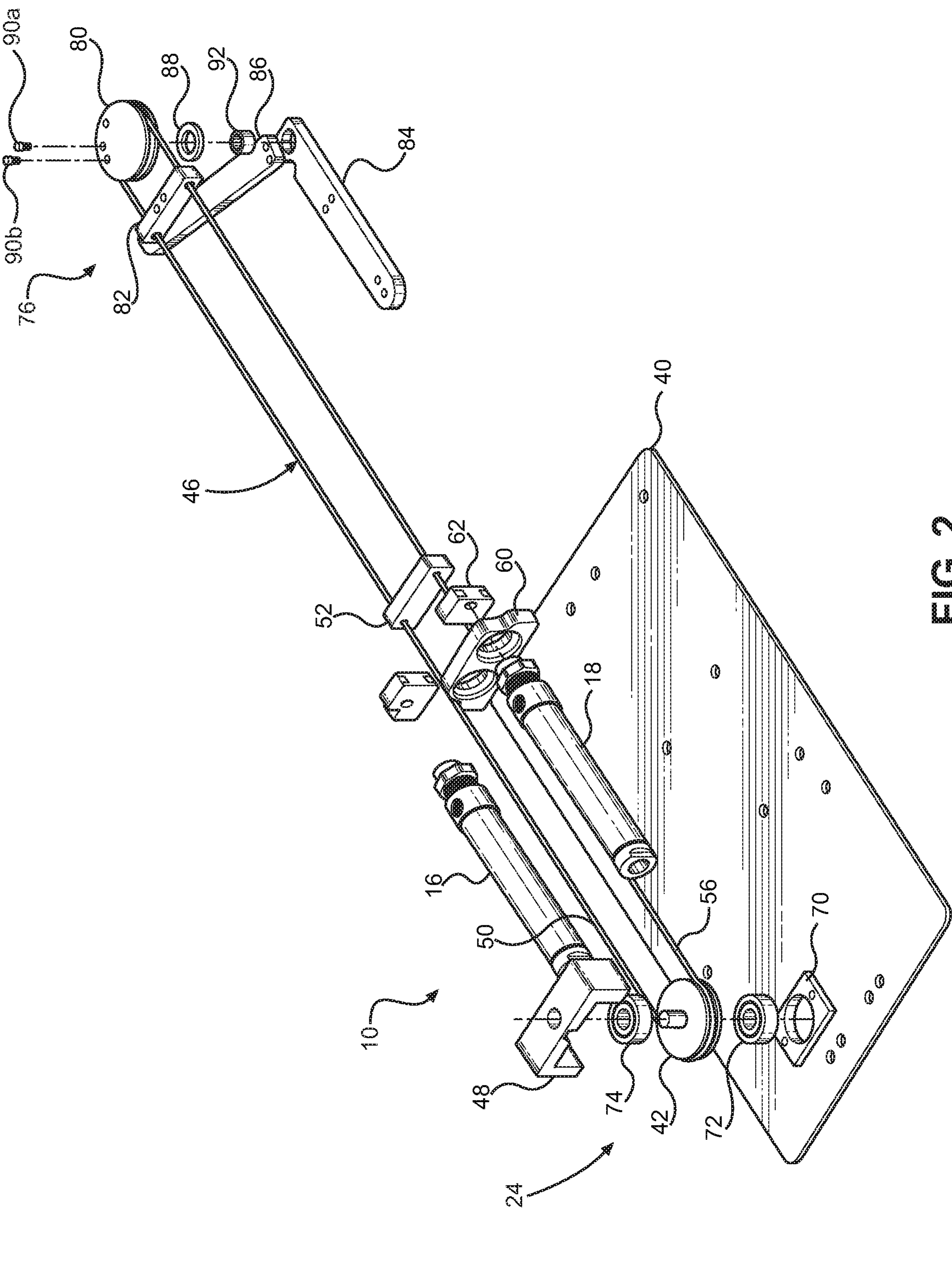
90a
80
88
92
86
84
90b
76
82
46
40
62
60
52
18
16
50
56
70
10
48
74
42
72
24

FIG. 2

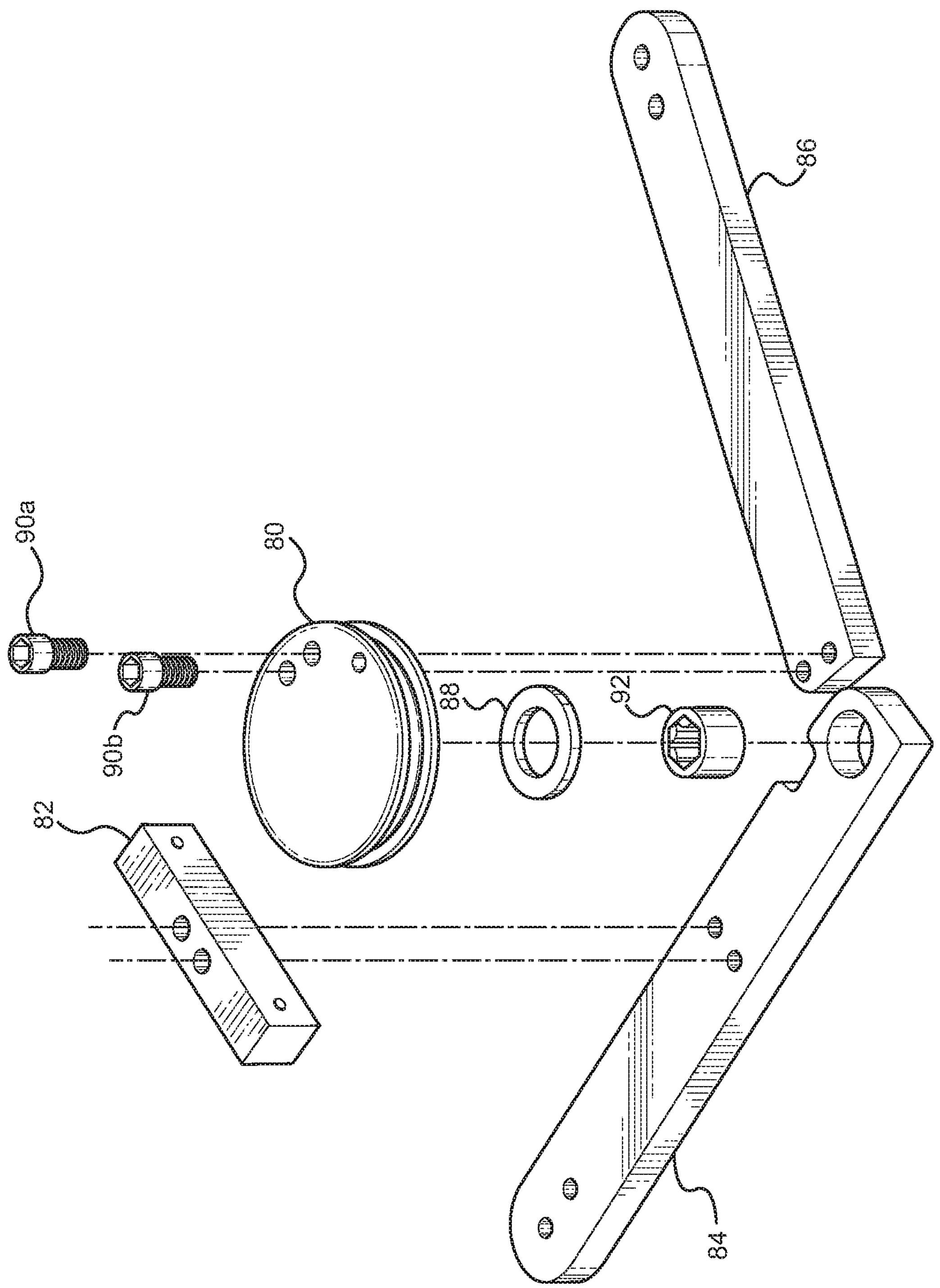

FIG. 3

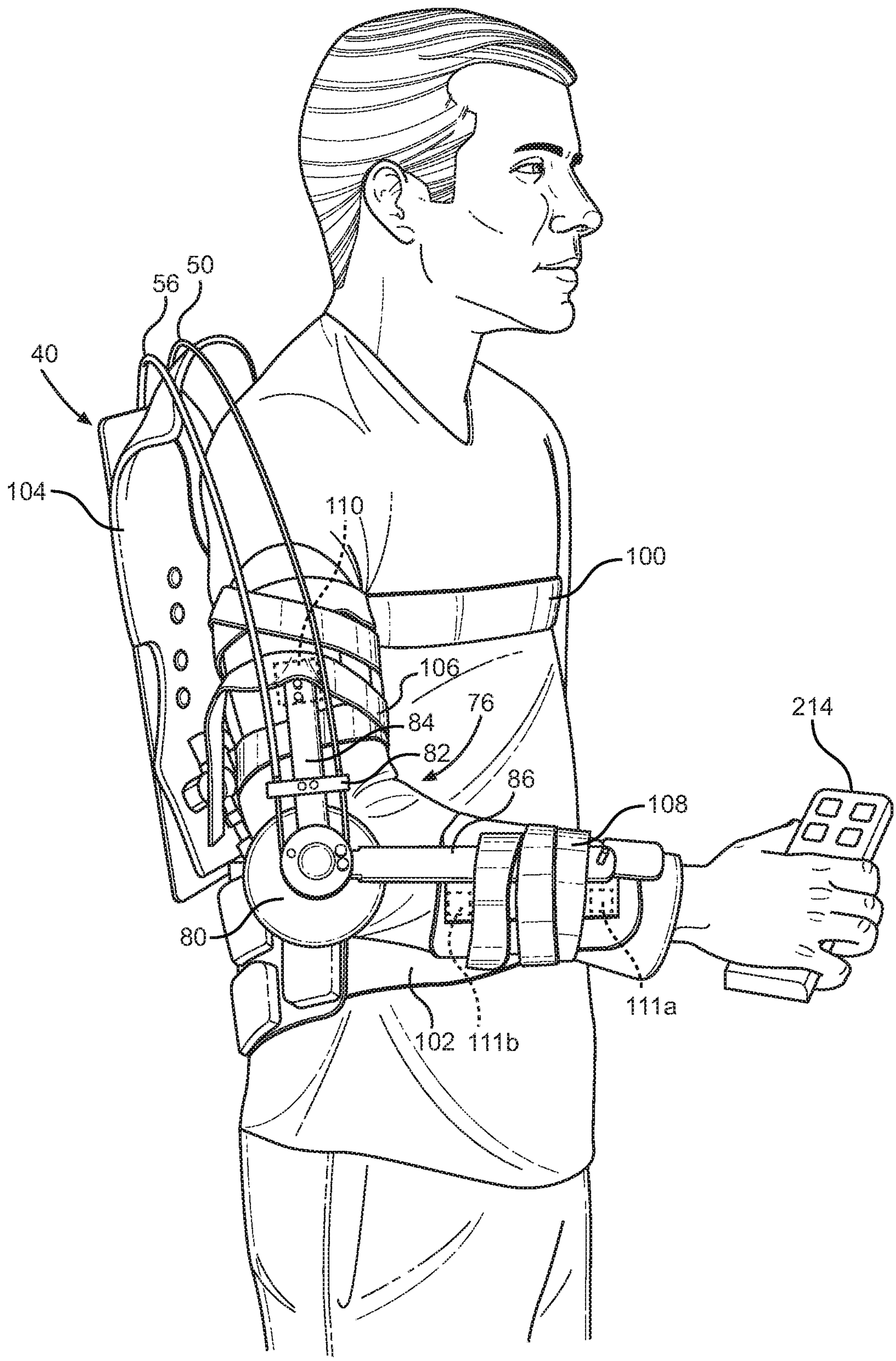

FIG. 4

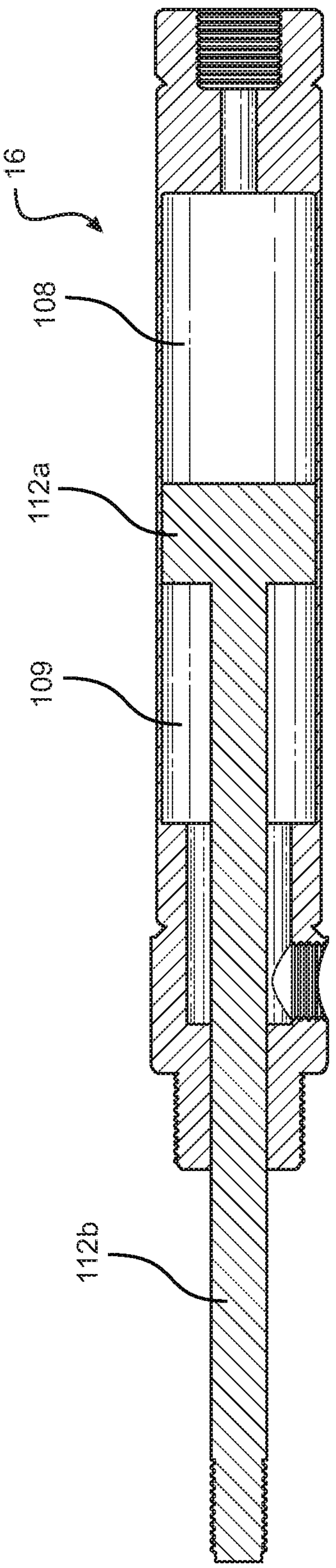

FIG. 5

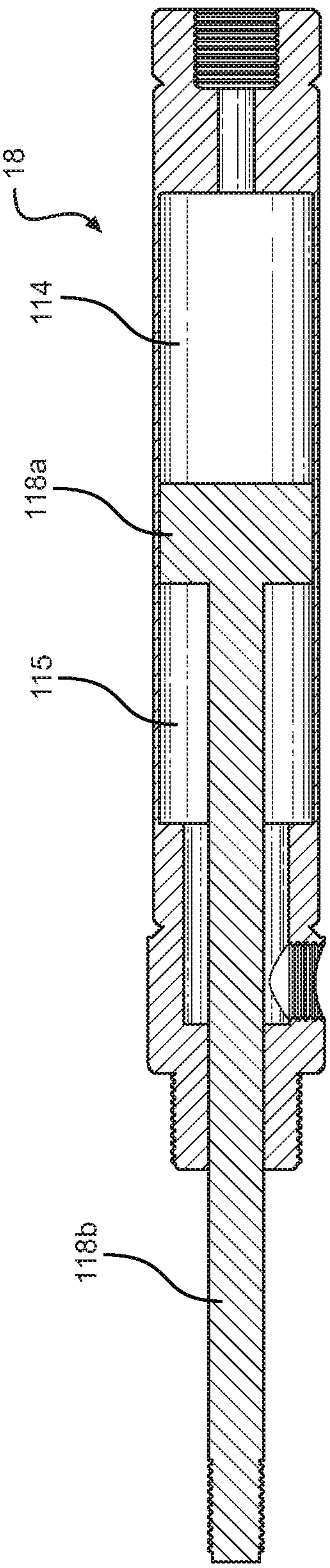

FIG. 6

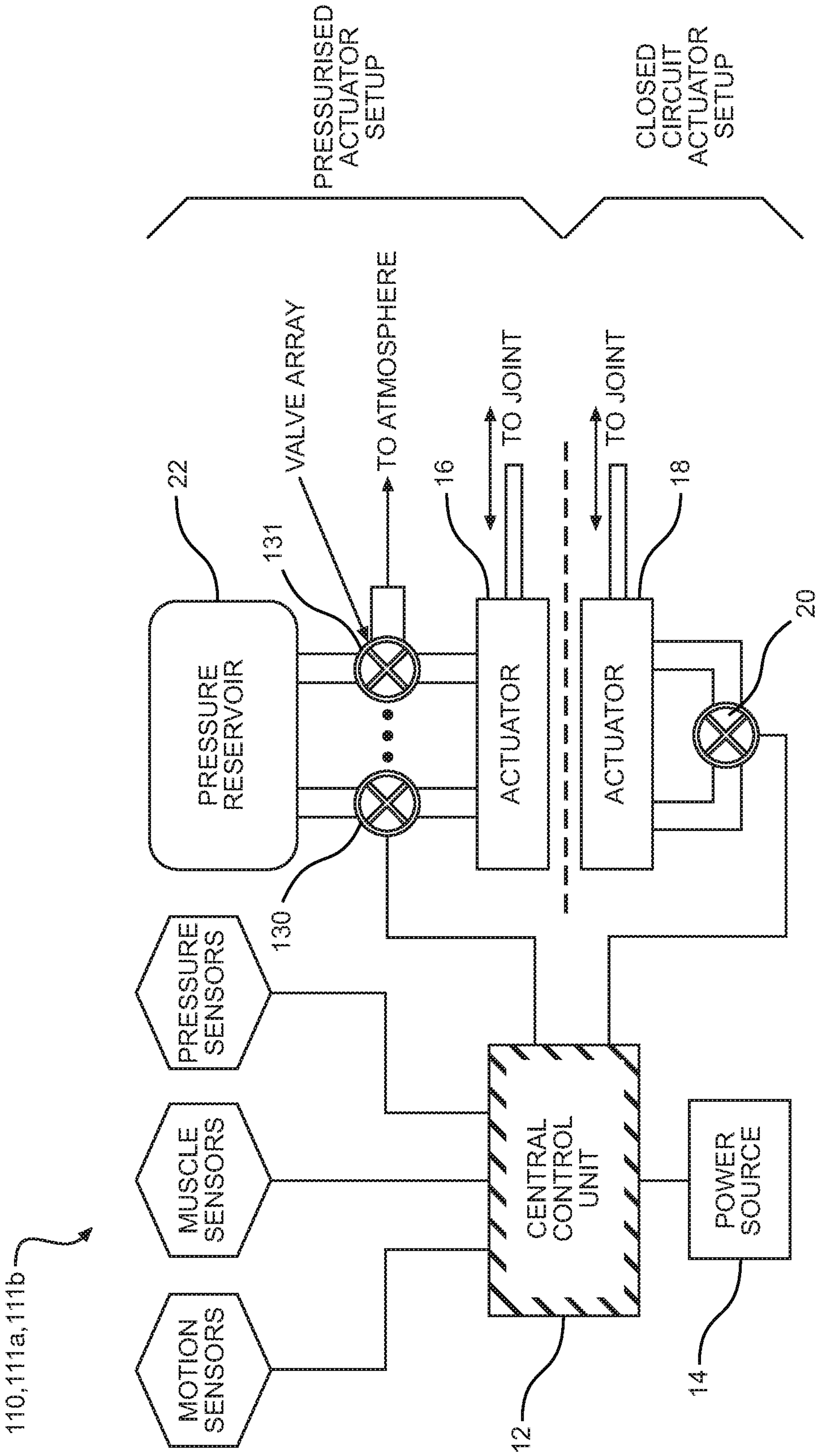
PRESSURISED ACTUATOR SETUP
CLOSED CIRCUIT ACTUATOR SETUP
VALVE ARRAY
TO ATMOSPHERE
TO JOINT
TO JOINT
22
131
16
18
20
130
PRESSURE RESERVOIR
ACTUATOR
ACTUATOR
PRESSURE SENSORS
MUSCLE SENSORS
MOTION SENSORS
CENTRAL CONTROL UNIT
POWER SOURCE
110,111a,111b
12
14

FIG. 7

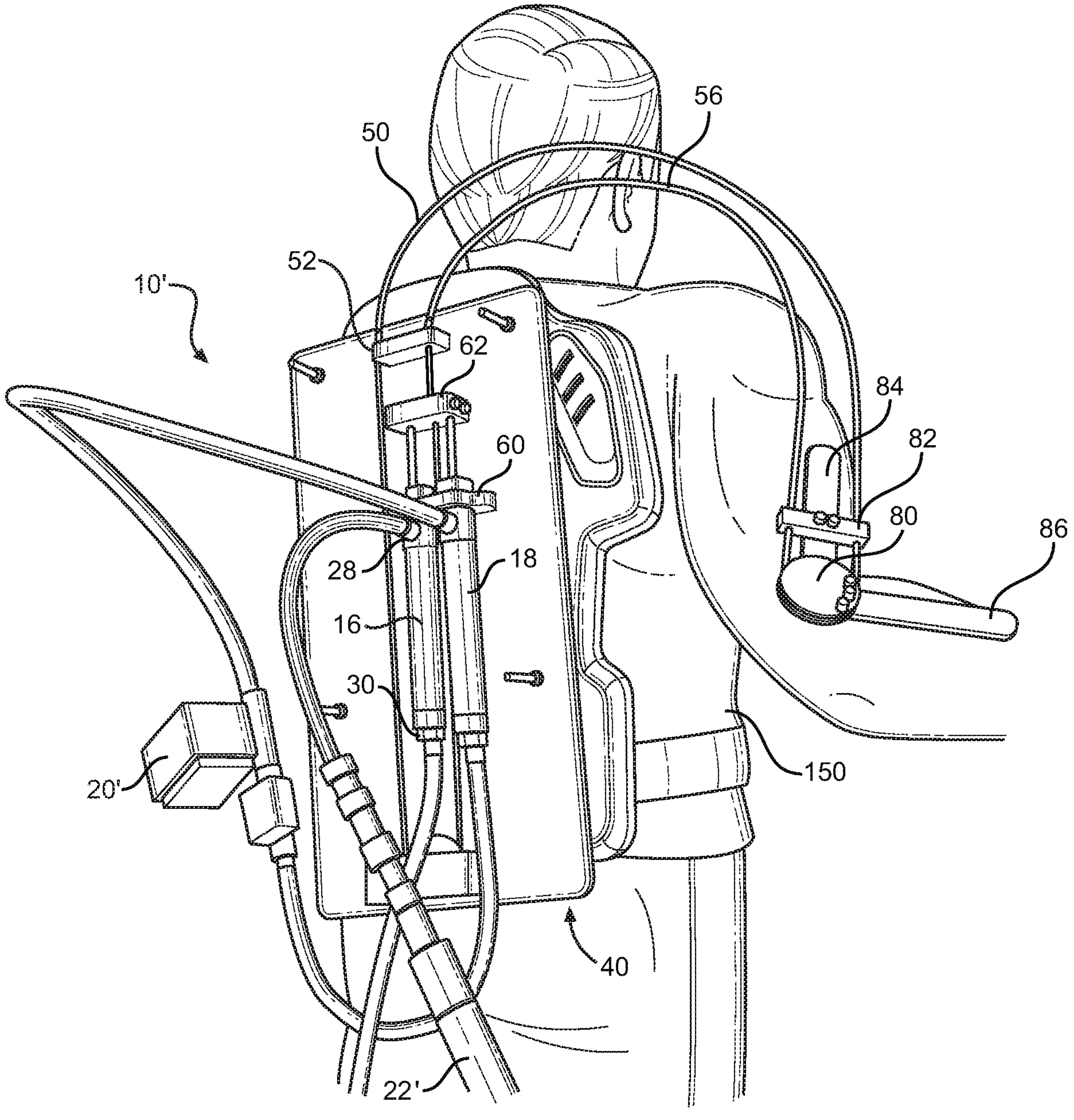

FIG. 8

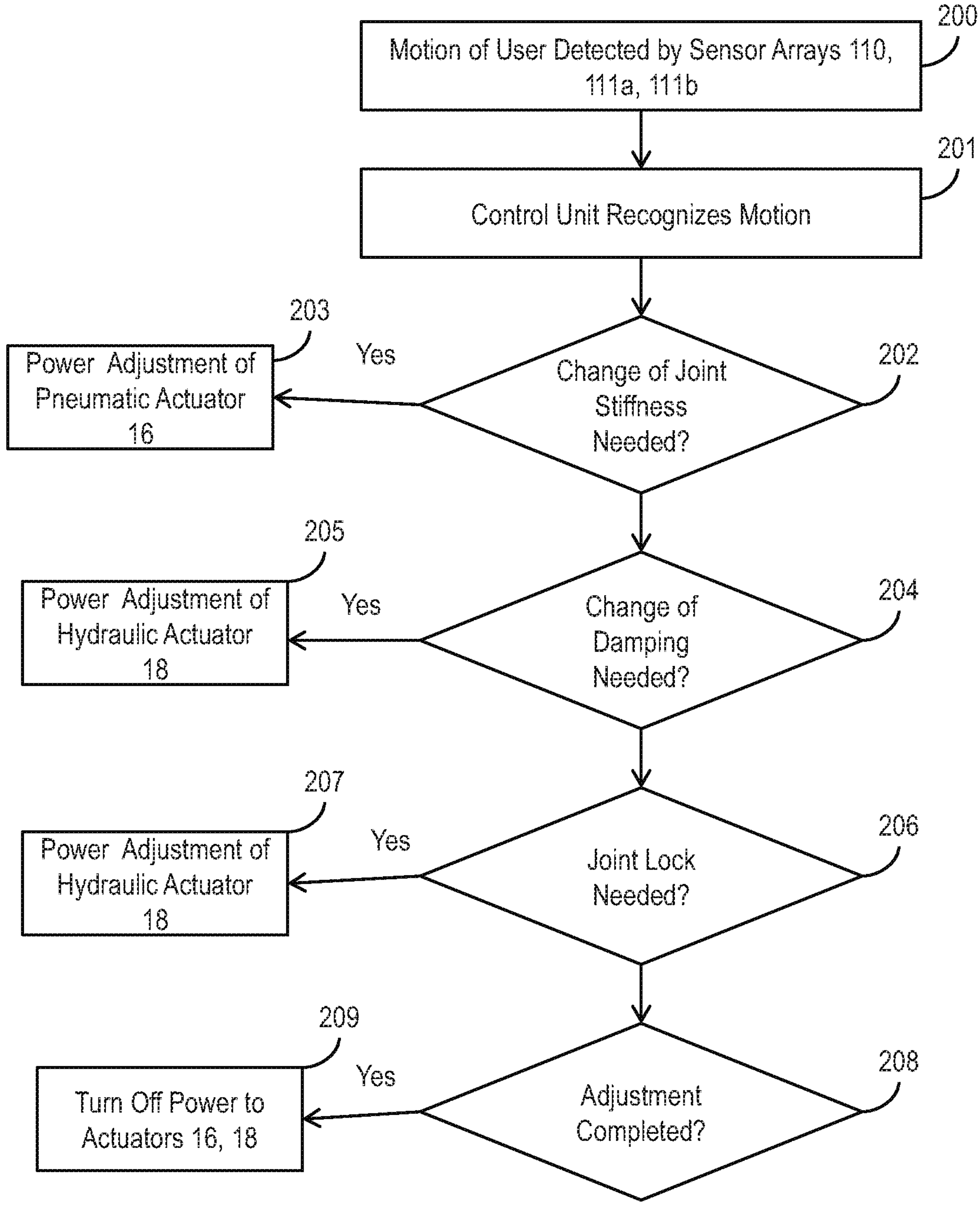
200
Motion of User Detected by Sensor Arrays 110, 111a, 111b
201
Control Unit Recognizes Motion
202
Change of Joint Stiffness Needed?
Yes
203
Power Adjustment of Pneumatic Actuator 16
204
Change of Damping Needed?
Yes
205
Power Adjustment of Hydraulic Actuator 18
206
Joint Lock Needed?
Yes
207
Power Adjustment of Hydraulic Actuator 18
208
Adjustment Completed?
Yes
209
Turn Off Power to Actuators 16, 18

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/018394

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A61F 2/68; A61F 2/70; A61F 2/72; A61F 2/74; A61F 5/052; A61H 1/00; A61H 3/00 (2016.01)
CPC - A61F 2/68; A61F 2002/6854; A61F 2002/741; A61F 2002/745; A61F 5/0102 (2016.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - A61F 2/48; A61F 2/50; A61F 2/60; A61F 2/62; A61F 2/64; A61F 2/66; A61F 2/68; A61F 2/70; A61F 2/72; A61F 2/74; (see below)
CPC - A61F 2/64; A61F 2/68; A61F 2002/6854; A61F 2002/701; A61F 2002/704; A61F 2002/741; A61F 2002/745; A61F 2002/748; A61F 2002/7625; A61F 2002/7635; A61F 5/0102; A61H 3/00; A61H 2201/165; B25J 9/0006 (2016.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC (continued) - A61F 2/76; A61F 5/00; A61F 5/01; A61F 5/052; A61H 1/00; A61H 3/00 (2016.01)
USPC - 600/595; 601/5, 34, 35; 602/16, 26; 623/24, 25, 26, 27, 32, 39, 44, 47, 50, 52, 53 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patents, Google Scholar.
Search terms used: orthosis, prosthesis, pneumatic, hydraulic, pulley, joint, pivot, actuator, spring, elastic, valve, stiffness, rigidity, dampen, pressure, regulator, monitor, locking

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009/0264799 A1 (BONUTTI et al) 22 October 2009 (22.10.2009) entire document	1-7
A	US 2014/0358053 A1 (CASE WESTERN RESERVE UNIVERSITY) 04 December 2014 (04.12.2014) entire document	1-7
A	US 5,662,693 A (JOHNSON et al) 02 September 1997 (02.09.1997) entire document	1-7
A	US 2013/0261766 A1 (OSSUR HF) 03 October 2013 (03.10.2013) entire document	1-7
A	WO 2014/109799 A1 (PRESIDENT AND FELLOWS OF HARVARD COLLEGE) 17 July 2014 (17.07.2014) entire document	1-7

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 May 2016	30 JUN 2016
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/018394

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See supplemental page

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-7

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-7, are drawn to a semi-passive control system.

Group II, claims 8-14, are drawn to a computer-implemented method for controlling an orthosis joint.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I, a semi-passive control system comprising: a pneumatic spring actuator including a shaft; a pressure regulator in communication with the pneumatic spring actuator; a hydraulic locking actuator including a shaft; a hydraulic valve in communication with the hydraulic locking actuator; a pulley wheel; a cable having a first end in contact with the pulley wheel, first and second side portions extending from opposing sides of the pulley wheel, and a second end adapted to connect to an orthosis device; at least one cable clamp attached to the second side portion of the cable and interconnecting the cable to the shaft of the pneumatic spring actuator and to the shaft of the hydraulic locking actuator; a power source; and a central control unit including a processor and a computer readable storage medium having program instructions stored thereon for execution by the central control unit to adjust stiffness, damping or stiffness and damping parameters, are not present in Group II; and the special technical features of Group II, a computer-implemented method for controlling an orthosis joint, comprising: receiving, by a computing device, sensor information indicating that a user's limb is moving; determining, by the computing device, that the user's limb is moving in a manner that corresponds with a predefined movement based on the sensor information; determining, by the computing device, parameters associated with the predefined movement; determining, by the computing device, if the parameters require a change in stiffness of an orthosis joint; determining, by the computing device, if the parameters require a change in damping of the orthosis joint; upon determining, by the computing device, that the parameters require a change to the stiffness, damping or stiffness and damping of the orthosis joint, activating a power supply to power an adjustment of one or both of a pneumatic spring actuator and a hydraulic actuator; adjusting, by the computing device, one or both of the pneumatic spring actuator and the hydraulic actuator to achieve the parameters, are not present in Group I.

Groups I and II share the technical feature of an orthosis device, a pneumatic spring actuator, a hydraulic actuator, a power supply, and a computing device; and adjusting, by the computing device, stiffness, damping or stiffness and damping parameters. However this shared technical feature does not represent a contribution over the prior art. Specifically US 2005/0101448 A1 to He et al. disclose an orthosis device (orthotic 26 and 28; FIG. 2), a pneumatic spring actuator (pneumatic muscles 50, 52, 54, 56; FIG. 2; para. [0029] "pneumatic muscles are used as adjustable linkages 50, 52, 54, and 56" and para. [0032] "Pneumatic muscles allow a great deal of flexibility in adjusting the range of motion imparted to a part of the body undergoing therapy. A combination of air pressure adjustment, in conjunction with the amount of resistance supplied by the patient and equipment determine the proper range of motion. Such parameters as air pressure can be easily controlled and tailored to the individual patient"; it is noted that the pneumatic muscles described operate in the same manner as a pneumatic spring), a hydraulic actuator (para. [0046] "Another embodiment uses hydraulic mechanisms to actuate the adjustable linkages. Hydraulic actuators work to move the adjustable linkages forwards and to return them to the previous state"), a power supply (control mechanism 78; FIG. 2; it is noted that the control mechanism would require a source of power to operate with a computer or microprocessor, as described by para. [0042]), and a computing device (control mechanism 78; FIG. 2; para. [0042] "control mechanism 78... could be comprised of a computer or microprocessor driven system"); and adjusting, by the computing device, stiffness, damping or stiffness and damping parameters (FIG. 2; para. [0042] "a control mechanism 78 to control the movement and actuation of the pneumatic muscles and winding spool. Control mechanism 78 may control such parameters as time of activation and length of activation of the pneumatic muscles. Additionally, control mechanism 78 may control the delay between upper and lower pneumatic muscles"; para. [0046] "A connected control mechanism controls such parameters as hydraulic motion and duration of motion"; and para. [0050] "Control mechanisms 78 is again shown connected to air source 94. Control mechanism 78 may control such parameters as air pressure, duration of contraction and delays as they relate specifically to air source 94").

Since none of the special technical features of the Group I-II inventions are found in more than one of the inventions, unity of invention is lacking.