

[54] MANIPULATOR SYSTEM

[72] Inventor: **Kendall E. Gilbert**, 1174 Van Antwerp Road, Schenectady, N.Y. 12309

[22] Filed: **Aug. 19, 1970**

[21] Appl. No.: **65,138**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 779,795, Nov. 29, 1968, abandoned.

[52] U.S. Cl.**91/385**, 91/3, 91/217, 91/461, 180/8

[51] Int. Cl.**F15b 13/16**, F01b 15/02, F15b 13/042

[58] Field of Search.....91/388, 3, 385, 217, 461; 128/25; 180/8, 1.6

[56] **References Cited**

UNITED STATES PATENTS

3,171,330	3/1965	McCombs, Jr.	91/388
3,433,128	3/1969	Hayner et al.	91/388
3,449,769	6/1969	Mitzen.....	128/25
3,463,146	8/1969	Schwartz et al.	128/25

Primary Examiner—Paul E. Maslousky

Attorney—Paul A. Frank, John F. Ahern, Louis A. Moucha, Julius J. Zaskalicky, Neuhauser, Frank L., Oscar B. Waddell and Joseph B. Forman

[57] **ABSTRACT**

In a manipulator system including a master and a slave skeleton, each of which has a plurality of limbs, and each limb of which has a plurality of serially connected elements, each of the remote ends of corresponding elements of master and slave members are position sensed and brought into correspondence by a respective servo loop. Associated with each joint of a slave leg member are pairs of position sensing devices connected to points remote from the joint. Associated with each corresponding set of leg members is a device for producing a control signal representing grounding of a respective set of leg members. A pair of selector switches are provided. Each selector switch is responsive to a respective control signal for passing the signal from the appropriate position sensing device of a pair to maintain the leg members of a respective set in correspondence.

5 Claims, 5 Drawing Figures

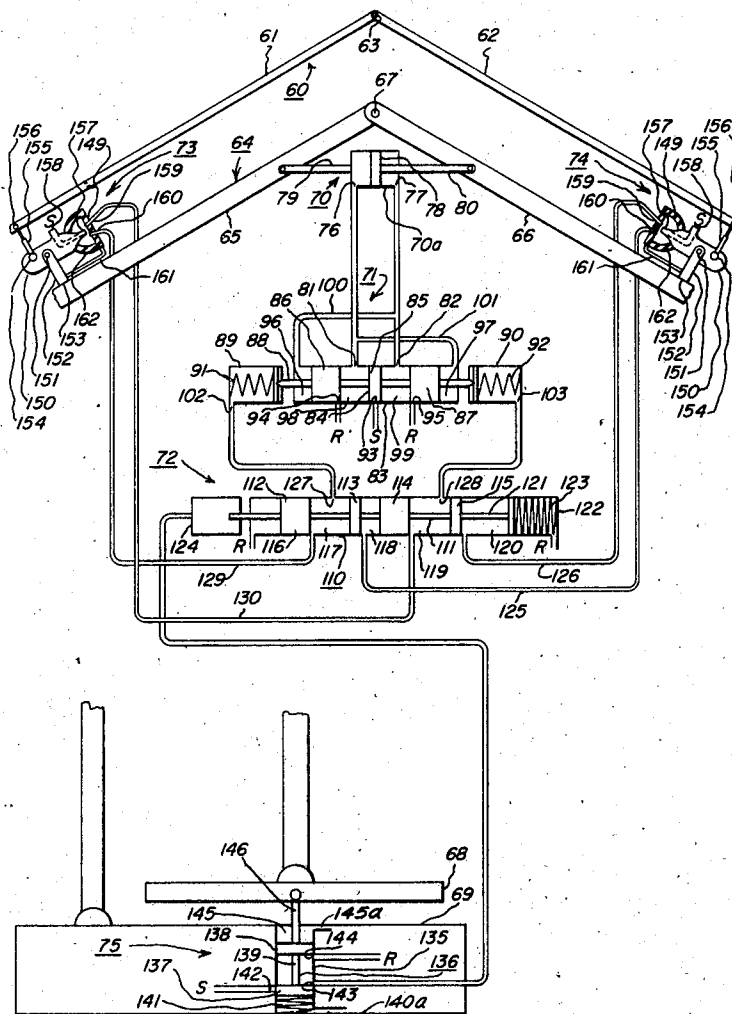


FIG. 1

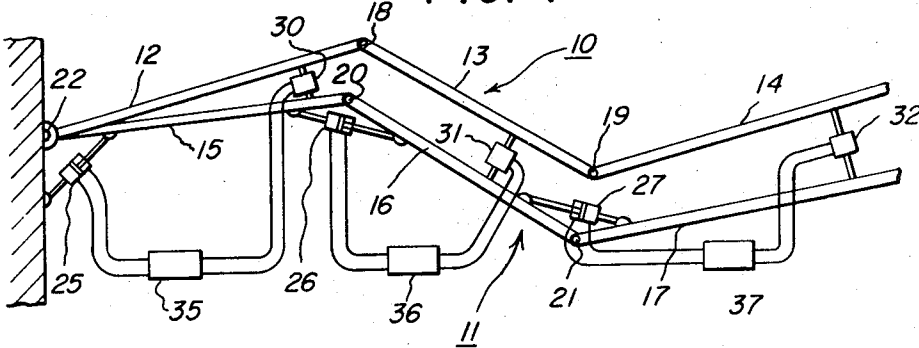


FIG. 2

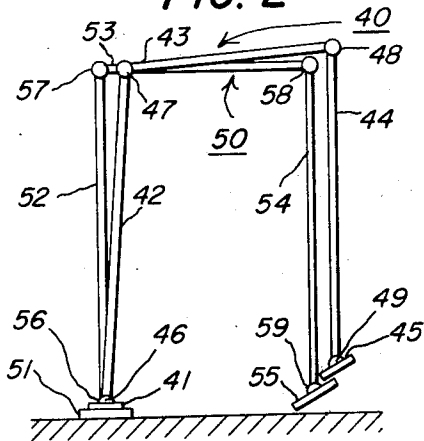


FIG. 3

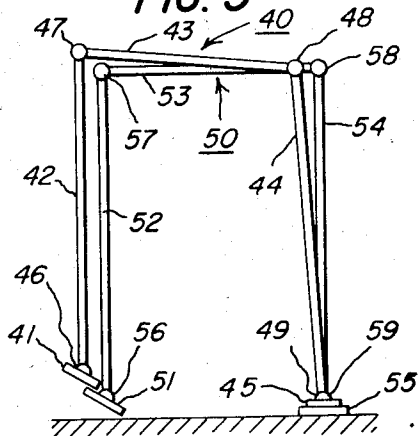
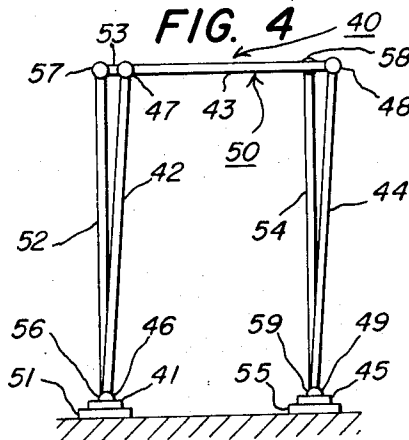


FIG. 4

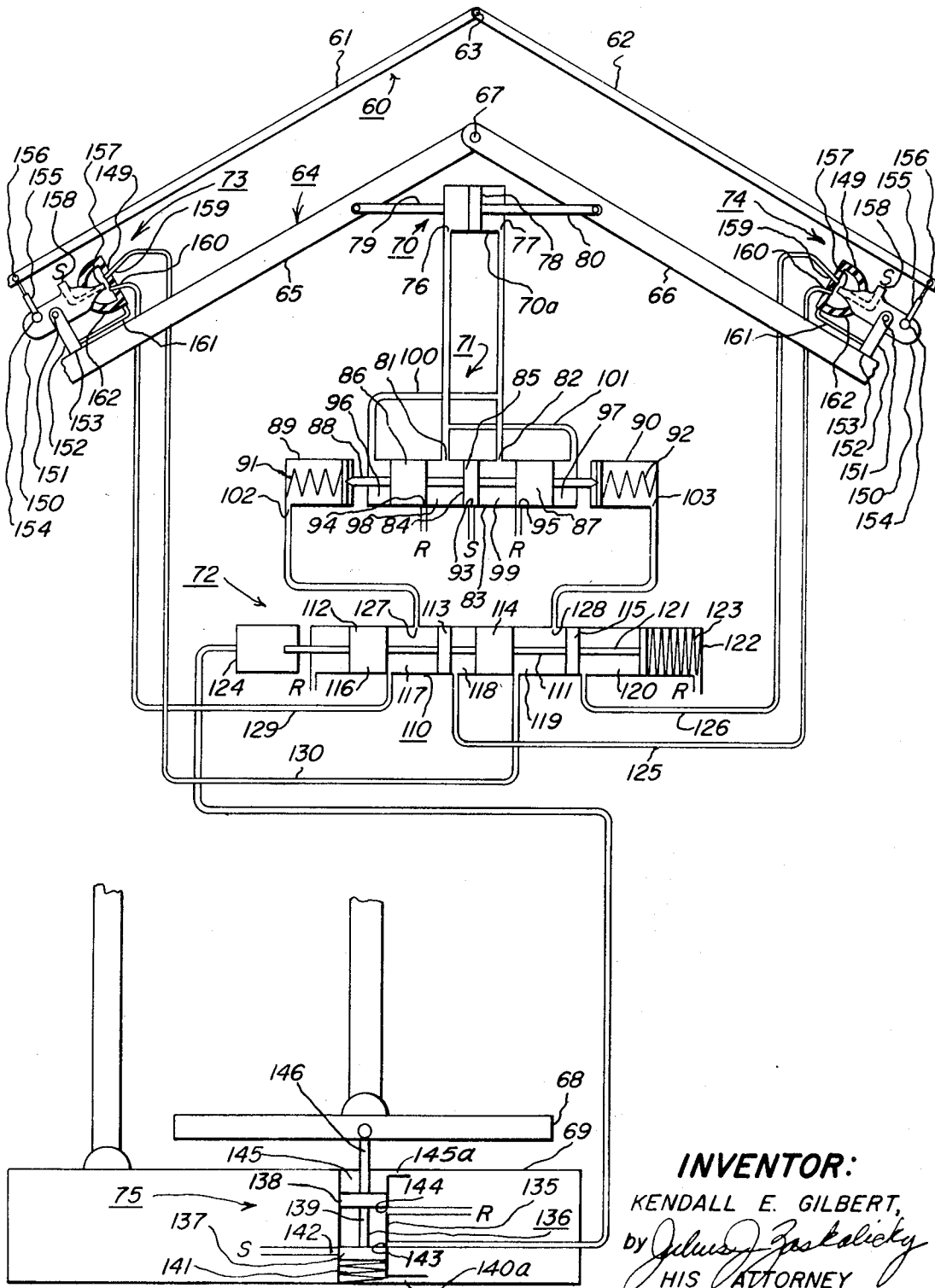


INVENTOR:

KENDALL E. GILBERT,

by *Julius J. Zaskalick*
HIS ATTORNEY

FIG. 5



INVENTOR:

KENDALL E. GILBERT,

by *Julius J. Zaskalick*
HIS ATTORNEY

MANIPULATOR SYSTEM

This application is a continuation-in-part of my copending application Ser. No. 779,795, filed Nov. 29, 1968, now abandoned, entitled "Manipulator System" and assigned to the same assignee.

The present invention relates in general to manipulators and in particular to manipulators of the kind referred to as bipedal walking machines including a master skeleton in which the limbs of an operator are situated and a slave skeleton having elements corresponding to the elements of the master and powered to move in spatial correspondence to the corresponding elements of the master skeleton. The invention herein described was made in the course of or under a contract with the United States Department of the Navy.

The slave skeleton of such manipulators may have an arm member including a plurality of elements, one end of which is grounded to a slave torso element and the other end of which is free. Also, the slave skeleton may include a pair of leg members having a plurality of elements, each having an end connected to a hip link and each having an end or foot element which may be individually or jointly grounded. In such manipulators it has been difficult to provide adequate control between the elements of the master and the elements of the slave skeletons. Heretofore the desired spatial correspondence between elements has been accomplished by sensing the error angle between the pivotally connected elements of the master and slave skeletons and servoing the slave into correspondence with the master. In such a system serious desynchronization occurs under load, particularly when a plurality of links are connected in series. Servomechanisms are inherently inaccurate when the slave skeleton is carrying load, that is, each slave angle is somewhat different from the corresponding master due to the compliance of the servomechanism. This effect accumulates along the series of links in a member until a serious desynchronization between the master and slave members occurs.

In accordance with one aspect of the present invention there is provided a system for obtaining closer correspondence between the elements of the master and slave skeletons. In the kind of system under consideration herein in which the elements of a master and slave members are situated close together, such objective is achieved by the provision of means to sense the displacement of selected corresponding points on elements of the master and slave and by servomechanisms responsive to such sensing to keep such corresponding points together. Such a system is particularly advantageous when a plurality of elements are provided in each of the master and slave members. When load forces are applied to the slave the corresponding points on slave and master elements will depart from each other because of the nature of servomechanisms, that is, error signals are required to drive the servomechanisms to bring the elements into correspondence. However, the effect of such errors does not accumulate to anywhere near the extent found in angle measuring methods heretofore used, as in a position measuring system any errors are recorrected at each pair of sensing and measuring points along the members, i.e., each subsequent pair of corresponding master and slave elements partially compensates for the preceding pair or pairs of elements.

Another problem arises in manipulators of the kind hereunder consideration in connection with the legs thereof. When the master slave skeletons are close together and equal in geometry, the situation arises in which a master foot lands on the slave foot and the master and the slave feet are temporarily clamped together by the weight of the operator. Three cases can occur during ambulation, namely, the left foot is grounded, the right foot is grounded and both feet are grounded. Assume that the left foot is grounded and the right foot is moving free. The operator positions the right master foot and the right slave foot which is not rigidly connected to the master follows by the action of the servomechanism. A similar situation exists when the right foot is grounded. However, when the grounding of the feet is alternated, the master and slave are connected together at the left or right foot alternately and servomechanism input signals from the master to slave come from alternate directions along the linkage. Any input mechanism to accept such alternating signals must be symmetrical about the joint being controlled so as to accept the signal from either direction. The angle measuring system has the symmetry required. The master angle in such a system may be changed by moving the link or element on either side of the joint. However, because the accumulation of desynchronization between master and slave previously mentioned is so great, it is impractical in application.

Accordingly, another object of the present invention is to provide a system for not only providing good control of compliance between corresponding elements of a master and slave skeleton but also to provide means for sensing direction of grounding about a joint to provide the proper directionality to the servomechanisms used. In accordance with this aspect of the invention, a pair of positioned sensing means are provided at selected points at the ends of a pair of master elements and a pair of corresponding slave elements, one on each side of the pair of joints so formed and a switching means is provided between them responsive to the grounding or ungrounding of a foot to render the servomechanism effective in the direction required.

In such a system, the situation where both feet are grounded is also provided for as will be apparent from the description below.

The features of my invention which I desire to protect are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings wherein:

FIG. 1 shows a schematic diagram of a slave member and a master member, each including a plurality of elements which may correspond to an arm of a manipulator and representing one manner of application of the invention of the present application.

FIG. 2 shows a schematic representation of a pair of members which may correspond to the master and slave feet members of a bipedal walking machine showing a condition in which one pair of corresponding elements or feet of the members is grounded.

FIG. 3 shows a schematic representation of members of FIG. 2 in which the other pair of corresponding elements or feet of the members is grounded.

FIG. 4 shows the schematic representation of the members of FIG. 2 in which both pairs of corresponding elements or feet of the members are grounded.

FIG. 5 shows a schematic diagram of a pair of members each having a pair of pivotally mounted elements showing the manner in which correspondence between the elements of the members is achieved and also showing the means for selection of the position error responsive device for control of the servomechanism to bring the elements of the members into correspondence.

Referring now to the drawings there is shown in FIG. 1 a master member 10 and a slave member 11 which could be the arm members of manipulator apparatus of the kind hereunder consideration. The master arm member 10 includes three elements 12, 13 and 14 and the slave arm member includes three elements 15, 16 and 17. The members 10 and 11 are placed close to one another so that corresponding elements of each of the members, namely elements 12 and 15, elements 13 and 16 and elements 14 and 17 are in corresponding spatial positions. Each element of the slave member 11 is the same length as the corresponding element of the master member 10. The elements of the master member are pivoted about adjacent ends at pivot points 18 and 19. The elements of the slave member are pivoted about adjacent ends at pivot points 20 and 21. The ends of the elements 12 and 15 are pivoted about a common axis 22 and the pivot points could be displaced in the direction perpendicular to the plane of the figure.

A plurality of actuators 25, 26 and 27 are provided for individually moving each of the elements of the slave member about the respective pivot point thereof. Each of the actuator shown schematically has a piston and cylinder to each of which is attached a rod and is responsive to fluid pressure applied therein at input ports for producing a displacement of the piston and cylinder rods with respect to one another. Actuator 25 has one rod connected to the element 15 near its pivot point on axis 20 and the other rod is connected to ground. Actuator 26 has one rod connected to element 15 and the other rod connected to element 16 near pivot point 20. Actuator 27 has one rod connected to element 16 and the other rod connected to element 17 near pivot point 21.

A plurality of position sensing devices 30, 31 and 32 are provided for sensing displacements in distance between corresponding points on the corresponding elements of the master and slave elements remote from the pivot points thereof. The position sensing device may be any of a variety of devices, one of which is shown in FIG. 5 and will be described in connection therewith. The position sensing device shown in FIG. 5 has a pair of levers for sensing displacement of a pair of elements and a pair of fluid terminals from which a fluid output is obtained representative of displacement. Each of the levers of device 30 are connected to a respective corresponding point on the elements 12 and 15 remote from the pivot points on the elements. Similarly, the levers of device 31 are connected to corresponding points on elements 13 and 16 remote from the pivot points of the elements. Similarly, the levers of device 32 are connected to corresponding points on the corresponding elements 14 and 17 of the slave and master members remote from the pivot point of the elements.

A plurality of amplifiers 35, 36 and 37 are provided, each of the amplifiers connected between a position sensing device and a corresponding actuator. Amplifier 35 has its input circuit connected to the output terminals of the position sensing device 30 and has its output circuit connected to the input ports of the actuator 25. Similarly, the amplifier 36 is connected between the position sensing device 31 and the actuator 26. Similarly, the amplifier 37 has its input connected to the position sensing device 32 and its output connected to the actuator 27.

Each of the sensing devices 30, 31 and 32 is set so that when corresponding elements of the members 10 and 11 are in a mean or neutral position, no differential signal is developed by the position sensing device. When a displacement occurs between the ends of corresponding elements, a differential signal is developed the magnitude of which depends upon the magnitude of the displacement and the polarity or direction of which depends upon the direction of displacement of the elements in reference to their mean position. Each of the amplifiers 35, 36 and 37 is responsive to the signal in magnitude and polarity to provide energization to the respective actuator to move the slave element into correspondence with the position of the corresponding master element. As the displacement of the elements is sensed at a point remote from the pivot points thereof, small angular displacements of the elements produce appreciable displacement in distance thereby providing a sensitive sensor of any lack of correspondence or desynchronization of the elements. While the servo loop associated with slave element 15 functions to servo such element along, the servo loops controlling actuators 26 and 27 function to servo their respective elements but also to compensate for desynchronization of elements 15, and elements 15 and 16, respectively, due to loading of the slave member 11, thereby providing good correspondence between the end of slave element 17 and the end of the master element 14. Thus, there is provided in the control system shown in FIG. 1, a good spatial and time correspondence of the extremity of the slave member 11 with a motion of the extremity of the master member 10.

In FIG. 1 a single degree of freedom exists for the members 10 and 11 and each is capable of rotation about its pivot point and in no other direction. To provide other degrees of freedom for the elements other pivot points with corresponding position sensing and servo loop elements could be provided. For reasons of simplicity of description such other degrees of freedom means have not been shown. Such could be provided by one skilled in the art if desired for the particular application.

Referring now to FIGS. 2, 3 and 4, there is shown a diagrammatic representation in each of the figures of a master member and a slave member. Each member including three longitudinal elements pivoted about adjacent ends and each member including a pair of foot elements, each of which is pivotable about a respective end element to which it is attached. The diagrammatic representation of these figures may represent the two leg elements of the master and slave skeleton of a walking machine of the character described above. In each of the FIGS. 2, 3 and 4, the same numerical designation identifies the same element. The master leg assembly

40 includes elements 41, 42, 43, 44 and 45. Elements 41 and 42 are pivoted about adjacent ends at point 46 and each successive pair of elements from the sequence of elements 42, 43, 44 and 45 is pivoted, respectively, about points 47, 48 and 49. The slave leg assembly 50 includes elements 51, 52, 53, 54 and 55. Elements 51 and 52 are pivoted about adjacent ends at point 57 and each successive pair of elements from the sequence of elements 52, 53, 54 and 55 is pivoted, respectively, about points 57, 58 and 59. The elements of each of the pairs of elements 41 and 51, elements 42 and 52, etc., are referred to as corresponding elements. FIG. 2 shows the situation in which the foot elements 51 and 56 are fixed and the other foot elements 55 and 59 are free. This situation would correspond to the situation depicted in FIG. 1 where one end of each of members 10 and 11 are pivoted about adjacent grounded points. FIG. 3 depicts the situation where the other foot members 55 and 59 are fixed or grounded and the foot elements 51 and 56 are free. FIG. 4 depicts the situation where both pairs of foot elements are fixed and the intermediate elements of each of the members 40 and 50 are pivotal about the intermediate points thereof. FIGS. 2, 3 and 4 are included to show the manner in which the problem of maintaining synchronization between the leg elements of a walking machine arises. These figures illustrate the need for bidirectional selection system for actuation of the actuators to provide the space and time correspondence of the elements of the slave and master member for the three conditions. In these figures the amount of necessary desynchronization shown has been exaggerated for clarity.

FIG. 5 illustrates a schematic diagram of two pairs of elements associated with a slave and a master joint in a system for reducing the compliance between corresponding points on the master and slave elements and also shows a pair of foot elements tied into the system for selection of the pair of ends of a master and a corresponding slave element to be brought into correspondence. Master member 60 includes a pair of elements 61 and 62 pivotable about point 63 and a slave member 64 including a pair of elements 65 and 66 pivotable about point 67. The master elements 61 and 62 of this figure may, for example, correspond to the master elements 42 and 43 of FIGS. 2, 3 and 4 and slave elements 65 and 66 may correspond to slave elements 52 and 53 of FIGS. 2, 3 and 4. Master foot element 68 and a slave foot element 69 may correspond to master and slave foot elements 41 and 51, respectively, of FIGS. 2, 3 and 4. Also shown in this figure are a hydro-mechanical actuator 70 for moving the slave elements 65 and 66, a hydraulic amplifier 71 for providing hydraulic energization to the actuator 70 in response to fluid control signals applied thereto, a selector switch 72 for selecting the signals to control the actuator 70, a pair of positioned sensing devices 73 and 74 connected at corresponding points of the elements of the master and slave element remote from the pivot points thereof for providing a signal to hydraulic selector switch 72, and a directional control switch 75 which is located between the master and foot elements for providing a signal representative of a ground or ungrounded condition of the foot elements 68 and 69 to control the selector switch 72 to direct control signals from either one or the other of the position sensing devices 73 and 74 for actuating the power amplifier 71 and actuator 70.

The hydro-mechanical actuator 70 includes cylinder 70a having a pair of ports 76 and 77 located adjacent the ends thereof and a piston 78 movable therein. A rod 79 secured to cylinder 70a is pivotally connected to the slave element 65 and a rod 80 attached to the piston 78 is pivotally connected to the slave element 66. Each of the ports 76 and 77 is connected to a respective output port 81 and 82 of the fluid power amplifier 71.

The fluid power amplifier 71 includes a main sleeve 83 in which is movable a spool 84 having three lands, an intermediate land 85 and a pair of end lands 86 and 87. The shaft 88 of the spool 84 extends into a pair of end cylinders 89 and 90 in each of which is located respective spring members 91 and 92 for centering the spool 84 in the sleeve. The main sleeve also includes an inlet port 93 connected to a source S of hydraulic pressure and a pair of return or drain ports 94 and 95 connected to return duct R for return of fluid to the pressure source. The main sleeve and the lands form within the main sleeve a pair of end chambers 96 and 97 and a pair of intermediate chambers 98 and 99. In the central or neutral position of the spool the intermediate land 85 blocks the source port 93 and the end lands 86 and 87 block the drain ports 94 and 95. Output ports 81 and 82 are connected to respective intermediate chambers 98 and 99. Feedback is provided from an end chamber to a remotely located intermediate chamber through ducts 100 and 101. An input port 102 is provided in the end cylinder 89, and an input port 103 is provided in end cylinder 90. Accordingly, depending upon whether the pressure at one of the input ports 102 and 103 is greater than the other of the input ports, the spool 84 is caused to move in one direction or the other to provide a difference in pressure across the output ports 81 and 82 in one direction or the other to power the actuator 70 and move the elements of the slave member 64 in one direction or the other about the pivot point 67.

The selector switch 72 comprises a main cylinder 110 in which is located a spool 111 having a plurality of lands 112, 113, 114 and 115. The arrangement of lands on this valve is such that switching takes place at constant volume within the valve. Such an arrangement eliminates false input to the servo loop during switching from one position sensing device to another. Lands 112, 113, 114 and 115 in conjunction with the sleeve 110 form a plurality of chambers 116, 117, 118, 119, 120 and 122. Chambers 117, 118, 119 and 120 are constant in volume as the spool is moved in the sleeve. Chambers 116 and 122 include drain ports. In end cylinder 122 is located a spring 123 for biasing the spool 111 in one position. The shaft 121 at the end remote from cylinder 122 extends into another end cylinder 124 to which pressure is applied for counteracting the force of spring 122 to shift the spool into the other position thereof. End chamber 116 and end chamber 122 are each provided with a return duct R. The main cylinder 110 is provided with a pair of input ports connected to device 73, a pair of input ports connected to device 74 and a pair of output ports connected to the fluid amplifier 71. In the one position of the spool 111 shown in the drawings, ducts 125 and 126 from device 74 enter chambers 118 and 120 and are blocked from feeding pressure to the output ports 127 and 128 of the selector switch 72. In this position

ducts 129 and 130 from device 73 enter chambers 117 and 119, and the pressure signals are fed to the output ports 127 and 128. In the other position ducts 125 and 126 from device 74 enter chambers 117 and 119, respectively, and feed respectively to output ports 127 and 128. In the other position the ducts from device 73 are blocked. Input pressure is applied to the end cylinder 124 through the directional control switch 75 to switch from the one to the other switch position.

The directional control switch 75 includes a cylinder 135 in which is located a spool 136 having two lands 137 and 138 on shaft 139. In end chamber 140 of the cylinder is located a spring 141 for biasing the lands 137 and 138 as shown, that is, when the master foot 68 is spaced from the slave foot 69, the spool is in the position shown. A drain port 140a is provided in the end chamber 140 and another drain port 145a is provided in the other end chamber 145 to drain off leakage around lands 137 and 138. Application of force at the upper end of the shaft 146, i.e., when master foot 68 is placed on slave foot 69, causes the spool to move into the other switch position thereof. Three ports are provided on the sleeve, a pressure supply port 142, a signal port 143 and a drain port 144. When the master foot is separated from the slave foot, land 137 covers the port 142, and the drain or return port 144 and signal port 143 are in communication with one another through the chamber formed between the two lands 137 and 138. When the master foot is placed on the slave foot, the shaft 146 of the spool is depressed and the land 138 covers the drain port 144 and the land 137 is removed from the support port 142 thereby allowing fluid under pressure to be applied to the signal port 143 and hence switch the spool of selector switch 72 to the other switch position.

In the position of selector switch 72 shown in FIG. 5, the actuator 70 is under the control of position sensing device 73. Such a switch position would correspond to the situation depicted in FIG. 3 in which foot elements 45 and 55 are grounded and foot elements 41 and 51 are ungrounded, assuming that elements 61 and 62 in FIG. 5 represent elements 42 and 43 in FIG. 3 and similarly elements 65 and 66 represent elements 52 and 53. With elements 68 and 69 grounded, the selector switch 72 is switched to the other switch position and the actuator 70 is under the control of position sensing device 74. This switch position would correspond to the situation depicted in FIG. 2 in which foot elements 41 and 51 are grounded and foot elements 45 and 55 are ungrounded. When both feet of master and slave are grounded as depicted in FIG. 4 each of the selector switches and each of the foot switches associated with a respective leg member would allow the appropriate position sensing device of the pair associated with each joint to be connected in circuit.

Each of the position sensing devices 73 and 74 includes a rotary member 150 pivotally mounted on one end 151 of a support 152 the other end of which is fastened securely to a point 153 on the slave element. The rotary member has a pivot point 154 near one end thereof which is connected by a fixed linkage 155 to a pivot point 156 on a point of the master member corresponding to the point 153 of the slave member. At the other end of the rotary member 150 is located a fluid projecting jet 157 which is connected by a pipe

158 to oil pressure supply. Mounted adjacent the jet 157 is a base member 149 having a pair of exit pipes 159 and 160 connected thereto and displaced from the central axis of the armature and the jet, and adapted to receive the fluid ejected from the jet. The base member 158 is supported by a mounting frame 161 on support member 152. A resilient housing member 162 encloses the base member 149 including the exit pipes 159 and 160 and the jet 157 of the rotary member 150 with the jet in the central or neutral position corresponding to alignment in spatial correspondence of a slave element with a corresponding master element. Oil pressure applied at the support port 158 is equally received by the exit pipes when the rotary member is in the neutral position and accordingly no net pressure differential appears in the pipes 159 and 160 with the result that when such pressures are communicated through the selector switch 72 to the amplifier 71 no motion of the spool 83 thereof occurs.

When a displacement of a master element with respect to the corresponding slave element occurs in one direction or the other, the jet 157 is tilted to provide increased flow and pressure into one of pipes 159 and 160 over the other. Such net pressure differential is communicated through the selector switch 72 to the amplifier 71 which causes a shift in the spool 83 thereof and a pressure differential to appear across the output of the amplifier which in turn causes actuator 70 to respond and move the slave elements in a direction to compensate for the change, that is, to move the slave elements so that they are in correspondence with the master elements and cause the rotary member 150 to be realigned on the central axis thereof.

The operation of the system of FIG. 5 is as follows. With the master foot 68 displaced from the slave foot 69 as shown the directional control switch 75 is not applying a pressure signal to the selector switch 72 consequently it is in the position shown in the drawing. In such a position, the position sensing device 74 is disabled by the selector switch from providing a signal to the amplifier 71. Signal to the amplifier 71 is provided by the position sensing device 73. Accordingly, the displacement of element 65 from correspondence in orientation from element 61 produces a signal in the position sensing device 73 which is passed by the selector switch and energizes the hydraulic amplifier 71. The output terminals or outlets of the fluid amplifier 71 are so connected to the actuator 70 that the amplifier drives the actuator 70 to pivot the element 65 about the point 67 to bring element 65 into orientation with element 61. It will be appreciated that elements 62 and 66 are pivoted at their remote ends, that is remote from points 63 and 67 about other pivotal axes. Associated with those other pivotal axes will be another pair of position sensing devices such as position sensing device 74. The location of those position sensing devices would be at points remote from those pivot points. One of such positioning devices would be located adjacent the pivot points 63 and 67 between elements 62 and 66. The alignment of elements 62 and 66 with respect to those pivot points would be accomplished by means of a sensing signal picked up by such sensing device located near points 63 and 67 and applied through servo loop such as shown in FIG. 5 to bring element 66 into alignment with element 62. Such servo loop would

hold elements 62 and 66 into alignment and allow the servo loop driven by position sensing device 73 to bring elements 61 and 65 into alignment.

Similarly, when the master foot 68 is brought into contact with the slave foot 69, a pressure signal is produced by the directional control switch 75 which actuates the hydraulic selector switch 72 to put the actuator 70 and the amplifier 71 under the control of the position sensing device 74. Signals from the position sensing device 73 are blocked by the hydraulic selector switch 72. Accordingly, any misalignment of the slave element 66 with respect to the slave element 62 about their respective pivot points produces an error signal in the position sensing device 74. The error signal is passed through the selector switch 72 and to the amplifier 71 which provides an output which drives the actuator 70 to bring the slave element 66 into alignment or orientation with the master element 62. It will be appreciated that elements 61 and 65 are pivoted at their remote ends, that is remote from points 63 and 67 about other pivotal axes. Associated with those other pivotal axes will be another pair of position sensing devices such as position sensing devices 73. The location of those position sensing devices would be at points remote from those pivot points. One of such positioning devices would be located adjacent the pivot points 63 and 67 between elements 61 and 65. The alignment of elements 61 and 65 with respect to that pivot point would be accomplished by means of a sensing signal picked up by such sensing device located near points 63 and 67 and applied through servo loop such as shown in FIG. 5 to bring element 65 into alignment with element 61. Such servo loop would hold elements 61 and 65 into alignment and allow the servo loop driven by position sensing device 74 to bring elements 62 and 66 into alignment.

The manner in which the subsystem of FIG. 5 would be incorporated in a bipedal walking machine, the leg assemblies of which are schematically illustrated in three possible positions in FIGS. 2, 3 and 4, will now be explained. A pair of position sensing devices such as position sensing devices 73 and 74 would be located at the ends of corresponding slave and master elements about each of the pairs of points 46 and 56, 47 and 57, 48 and 58, and 49 and 59. Linear actuators such as actuator 70 and a hydraulic amplifier 71 would be operatively connected as shown in FIG. 5 with the slave elements pivoted about each of the points 56, 57, 58 and 59. The position sensing devices would be located at the extremities of the elements of the corresponding master and slave members. A selector switch such as selector switch 72 would be associated with each of the pairs of slave elements positioned about points 56, 57, 58 and 59. The selector switch associated with elements pivoted about points 56 and 57 would be operated by a directional control switch such as switch 75 associated with master foot 41. Also, the selector switches associated with the elements pivoted about points 58 and 59 would be operated by the directional control switch such as switch 75 associated with the master foot 45. When the leg assembly of the bipedal machine is in the position shown in FIG. 2, that is with the left master foot grounded, the directional control switch directs control of the servo positioning apparatus to the position sensing device located remotely

from the point 46 and from the point 47 to bring element 52 into correspondence with element 42 and to bring element 53 into correspondence with element 43. The directional control switch associated with master foot 45 is not putting out any pressure signal. Accordingly, the servo loops associated with the pivot points 45 and 48 are under the control of position sensing devices at the ends of elements 45 and 55 remote from the points 49 and 59 and also under the control of position sensing device associated with the pivot points 48 and 58 located on the members 44 and 54 remote from their pivot points. Accordingly, the grounding of master foot 41 on slave foot 51 actuates a selector switch in one position and the selector switch associated with foot element 45 is set in the other position to render operative appropriate position sensing devices for bringing the slave elements of the assembly of FIG. 2 into correspondence with the master elements thereof. When the right foot is grounded and the left foot is free, such as shown in the assembly of FIG. 3, a similar sequence of operation occurs to enable pivoting of element 54 about pivot point 59 and element 53 about pivot point 58 and also to enable pivoting of slave element 52 about pivot point 57 and slave foot member 51 about pivot point 56 to bring all of the slave elements into correspondence with corresponding master elements.

When both of the master feet 41 and 45 are grounded on slave feet 51 and 55, respectively, as shown in FIG. 4, the position sensing device associated with pivot point 46 but located adjacent pivot point 47 is operative and similarly the position sensing device associated with pivot point 47 but located adjacent pivot point 48 is operative. The other position sensing devices associated with these points and responsive to the selector switch associated with the master foot member 41 are inoperative. Similarly, the position sensing devices associated with point 49 but located near point 48 is operative and the other position sensing device associated with point 49 is inoperative. Also the position sensing device associated with pivot point 48 but located adjacent pivot point 47 is operative and the position sensing device located adjacent point 49 is inoperative. Accordingly, displacement of the ends of members 42 and 52 remote from the pivot points 46 and 56 produces an error signal in the positioning device and causes the servo loop associated therewith to bring slave element 52 into correspondence with master element 42. Similarly, the position sensing device associated with point 49 and located near point 48 produces an error signal and also has the same effect in bringing element 52 into correspondence with 42 by virtue of the fact that it brings element 54 into correspondence with element 44. The fact that the position sensing element adjacent point 47 but associated with the servo system which pivots element 53 about pivot point 58 to bring it into correspondence with master element 43 and responsive to the directional control switch associated with master foot 45 is operative is of little consequence since no vertical displacement as viewed in the plane of the figure occurs in respect to element 53 with respect to element 43, that is these elements can only move sideways. Similarly, the position sensing device located adjacent pivot point 58 but associated with the servo system

operative with respect to point 57 and further responsive to the directional control switch associated with foot element 41 is of no consequence for the same reason, i.e., there is no vertical displacement of element 53 with respect to element 43. If desired, a logic system could be provided responsive to pressure signals from the directional control switch associated with master foot 41 and master foot 45 to actuate a switch which disables the position sensing devices aforementioned in the preceding two sentences when both master feet are grounded on the slave feet.

The servo loop components described in FIG. 5 could be used in the embodiment of FIG. 1. Each of the position sensing devices 30, 31 and 32 of FIG. 1 could be position sensing devices of the kind designated 73 and 74 in FIG. 5. Also, actuator devices 25, 26 and 27 of FIG. 1 could be devices of the kind designated 70 in FIG. 5. Further, the power amplifiers 35, 36 and 37 of FIG. 1 could be power amplifiers of the kind shown at 71 of FIG. 5.

While mechanical hydraulic components have been described in the illustrative embodiments for carrying out the invention, it will be appreciated that electromechanical and other components may be used to perform the functions indicated, namely, position sensing, power amplification and mechanical movement.

While I have shown particular embodiments, it will of course be understood that I do not wish to be limited thereto since many modifications may be made in the arrangement shown and in the instrumentalities employed. I contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination,

a pair of members, each including a plurality of longitudinal elements, each element of one member situated closely to and in similar orientation to a respective corresponding element of the other member,

the elements of each of said members pivotally mounted at adjacent ends thereof,

a plurality of actuators, each connected to a respective adjacent pair of elements of said one member to move said elements with respect to one another about the respective pivot point thereof in response to energization applied thereto,

one of the end elements of one of said members pivotally mounted about a fixed point,

one of the end elements of the other of said members pivotally mounted about another point adjacent to said one point,

a plurality of position sensing devices, each connected to corresponding points on corresponding elements of said members which are remote from the pivot points thereof to sense the displacement thereof from a neutral position and develop a signal corresponding to such displacement,

means for applying each of said signals to a respective actuator for maintaining correspondence of corresponding elements of said members.

2. In combination,
a pair of members, each including a pair of longitudinal elements, each element of one member situated closely to and in similar orientation to a respective corresponding element of the other member,

the elements of each of said members pivotally mounted at adjacent ends thereof,

an actuator connected to the elements of said one member near the pivot point thereof to move the elements thereof with respect to said pivot point in response to energization applied thereto,

a pair of position sensing devices, each connected near a respective end of corresponding elements to sense the displacement of position thereof from a neutral position and develop a signal corresponding to such displacement,

selective means for alternately selecting signals from said pair of position sensing devices,

means for applying said selected signal to energize said actuator in a direction to maintain correspondence of the ends of corresponding elements which produced such selected signal.

3. The combination of claim 2 in which are provided means for deriving a control signal representing a condition of close proximity of adjacent ends of corresponding elements remote from the pivot points thereof, and

means responsive to said control signal to actuate said signal selective means.

4. In combination,

a pair of members, each including a plurality of longitudinal elements, each element of one member situated closely to and in similar orientation to a respective corresponding element of the other member, the elements of each of said members pivotally mounted at adjacent ends thereof,

a plurality of actuators, each connected to a respective adjacent pair of elements of said one member to move said elements with respect to one another about the respective pivot point thereof in response to energization applied thereto,

a plurality of pairs of position sensing devices, each device of said pair connected near a respective end of corresponding elements to sense the displacement of position thereof from a neutral position and develop a signal corresponding to such displacement,

a plurality of selective means, each selective means alternately selecting signals from a respective pair of position sensing devices, and

means for applying each said selected signal to energize a respective actuator to maintain correspondence of each pair of corresponding elements which produced such respective selected signal.

5. The combination of claim 4 in which are provided means for deriving a control signal representing a condition of close proximity of a pair of adjacent ends of corresponding end elements of said members remote from the pivot points thereof, and means responsive to said control signal to actuate a signal selective means.

* * * * *