United States Patent

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[45] Patented **Apr. 6, 1971**
[73] Assignee **The United States of America as represented by the Secretary of the Navy**

[54] **NATURAL RESPONSE MANIPULATOR APPARATUS**
8 Claims, 11 Drawing Figs.

[52] **U.S. Cl.** **200/157,** 200/6, 200/159, 200/172
[51] **Int. Cl.** **H01h 21/00**
[50] **Field of Search** ..... 200/159, 157, 61.58, 6 (A), 172 (A)

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ABSTRACT: A natural response manipulator apparatus which includes a controller and a responsive manipulator. The controller includes a support means; a generally tubular handle; and a plurality of switches which are mounted on the support means and which solely support the handle thereon so that the handle has floating action. The manipulator may include a simulated human arm which has its various components powered by a plurality of bidirectional power units. The power units may be controlled by the switches of the controller and may be connected to the various components of the simulated human arm so that the arm performs natural movements which correspond to hand-control of the controller.

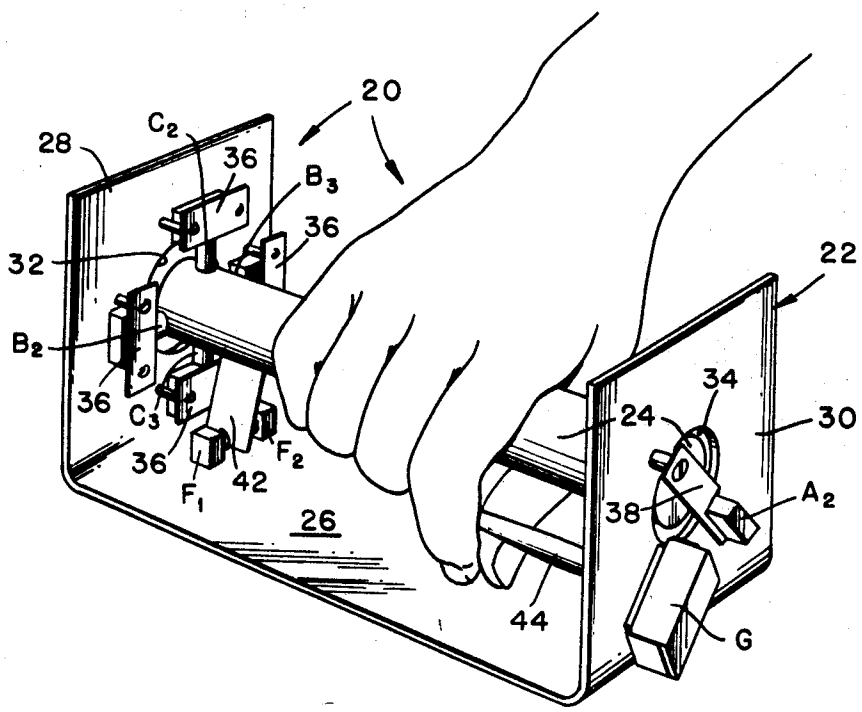


FIG. 1.

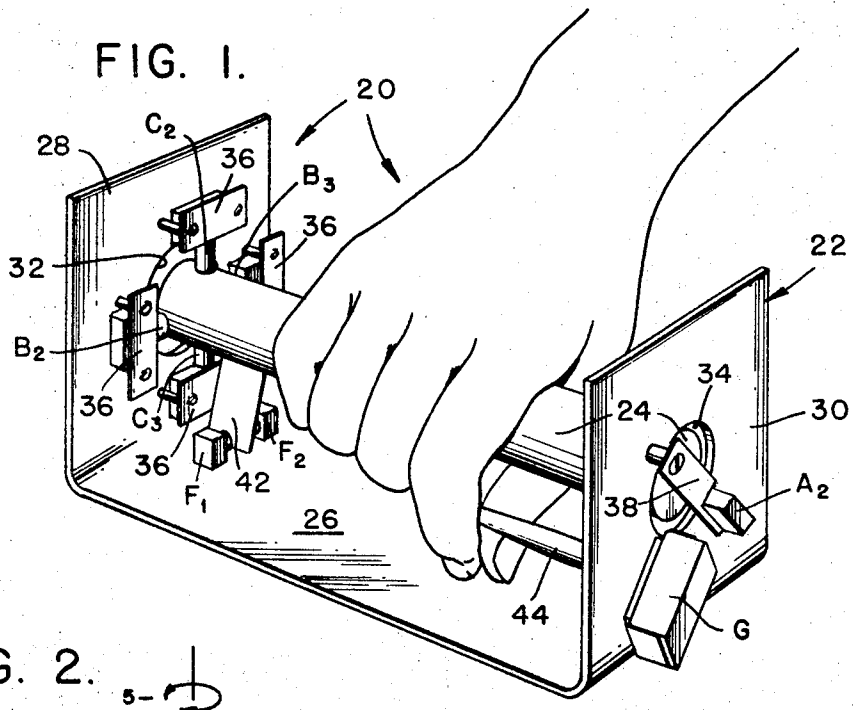
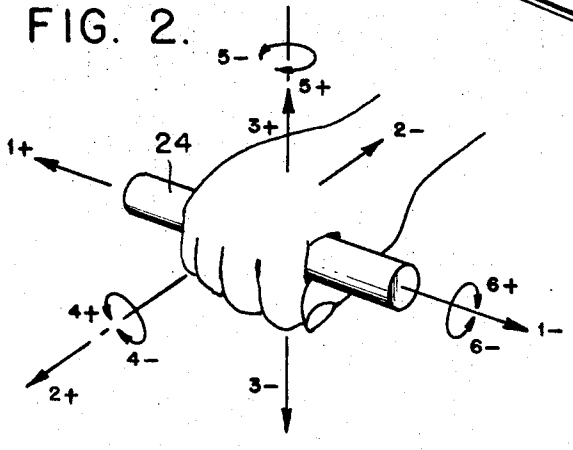


FIG. 2.



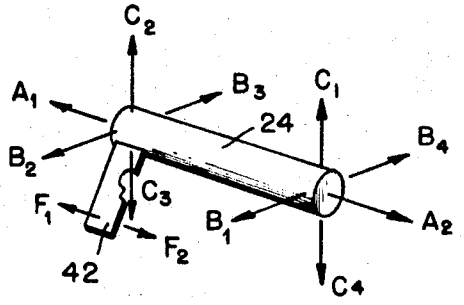


FIG. 3.

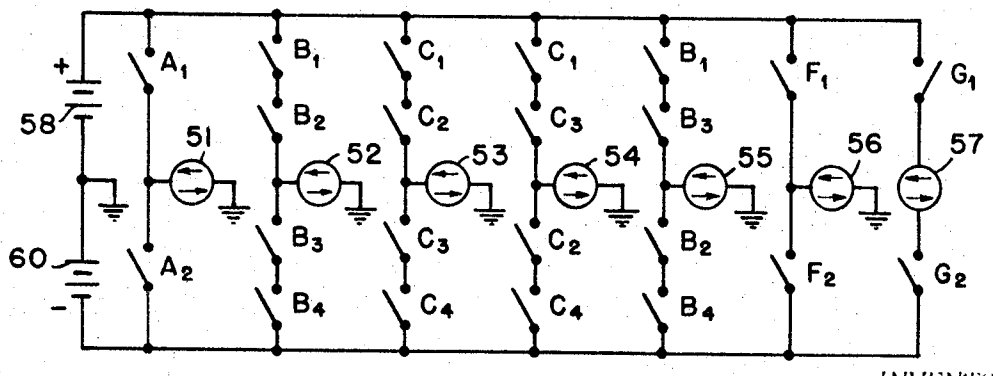


FIG. 4.

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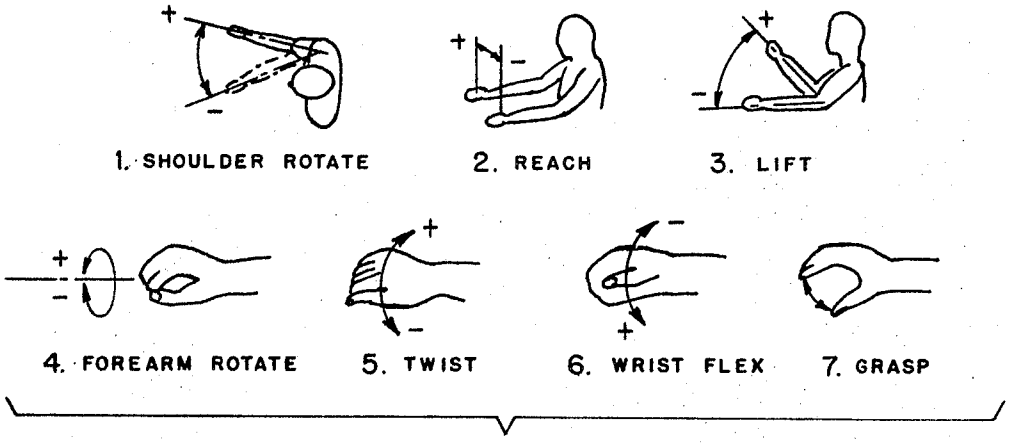


FIG. 5.

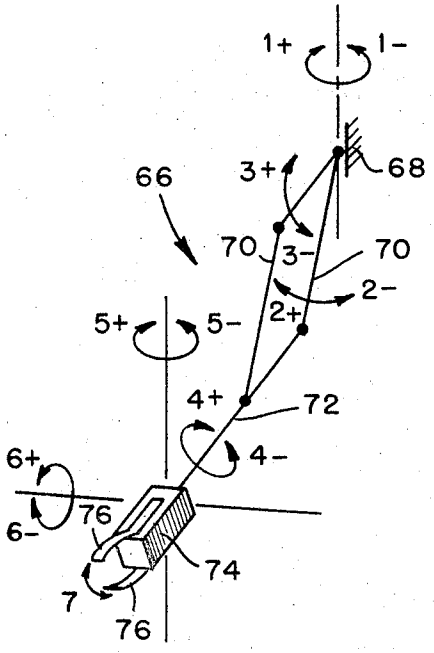


FIG. 6.

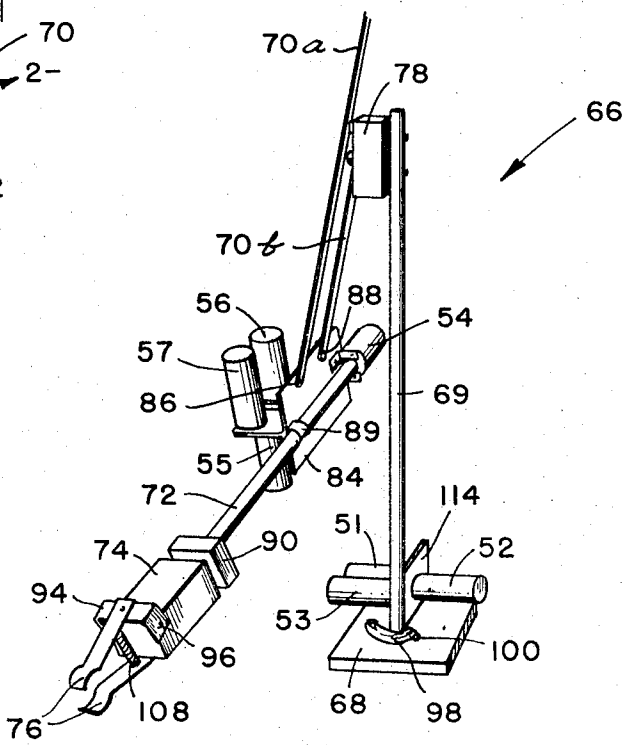


FIG. 7.

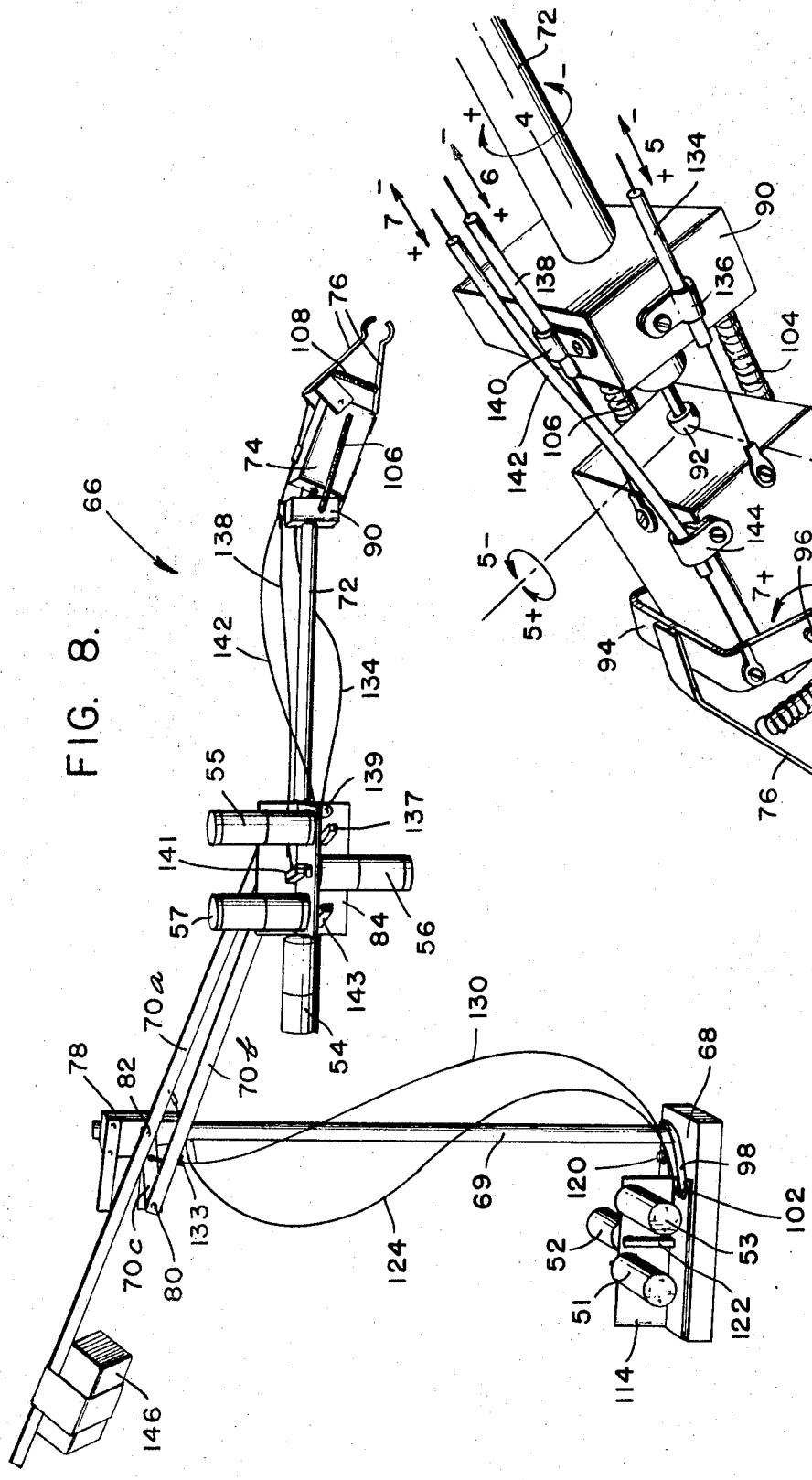

66
72
74
76
108
106
90
138
142
134
55
139
137
141
57
84
56
143
54
130
70a
70b
70c
78
82
80
133
124
69
68
98
120
102
52
53
51
122
114
146

FIG. 8.

72
4
5
6
7
134
90
136
138
104
140
106
142
74
92
144
96
94
76
108

FIG. 9.

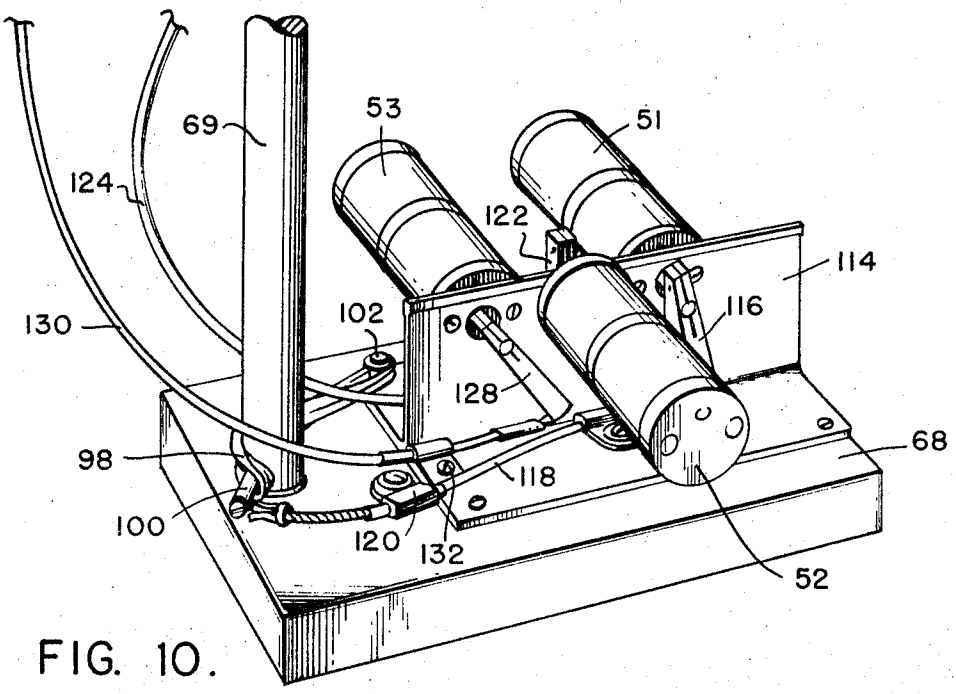

69
53
51
124
122
114
130
102
116
128
68
98
118
100
120
132
52

FIG. 10.

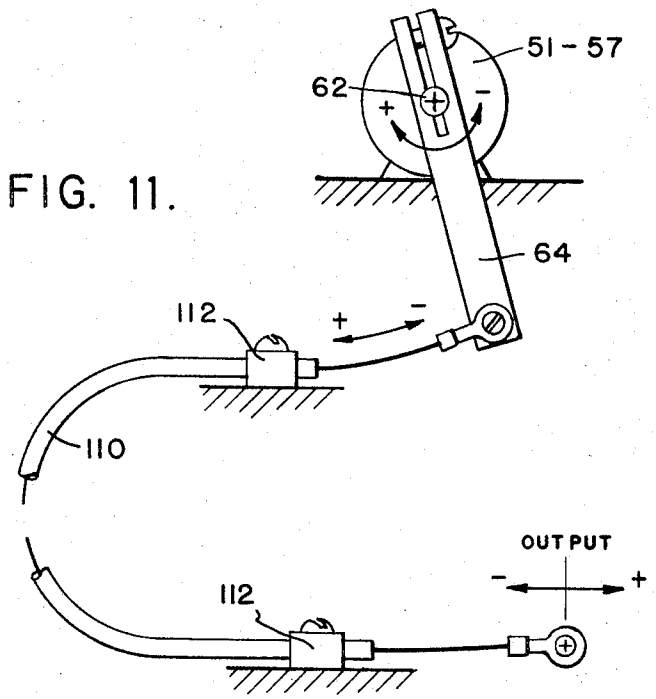

51 - 57
62
+
-
64
112
+
-
110
OUT PUT
-
+
112

FIG. 11.

NATURAL RESPONSE MANIPULATOR APPARATUS

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The tremendous increase in underwater research in the past few years has brought about an urgent need for underwater manipulator devices which can be remotely controlled by a person on a surface ship or in a deep submersible. In any type of manipulator work it is desirable to have a manipulator device which will simulate the natural motions of the operator. Since the human arm is the primary working tool of the human body, it is this portion which is most often simulated. The human arm with its upper arm, forearm, wrist, and fingers have seven basic movements. These basic movements are shoulder rotate, reach, lift, forearm rotate, wrist twist, wrist flex, and finger grasp.

The present invention provides a controller which enables an operator to control motions of a responsive device such as a simulated human arm wherein the motions correspond to the forces applied by his own arm. The present invention also provides a simulated human arm which is operable with the controller. The controller includes a support means, a generally tubular handle, and a plurality of switches which are mounted on the support means and which solely support the handle thereon so that the handle has floating action with respect to the support means. The manipulator device, which is operable with the controller, is a simulated human arm. The switches are arranged in such a manner on the controller so that when the operator grasps the controller handle with his hand and applies forces with his arm, selected power units are actuated to move the simulated human arm in a like manner. The teachings of this invention overcome many of the complexities associated with prior art manipulator systems.

An object of the present invention is to provide a natural response manipulator apparatus.

Another object is to provide a controller which will enable an operator to control a responsive device, such as simulated human arm with movements which correspond to directional forces of his own arm.

A further object is to provide a manipulator controller which is simple in construction and easy to operate.

Other objects and many of the attendant advantages of this invention will be readily appreciated as it becomes better understood by reference to the description and accompanying drawings which follow.

FIG. 1 is an axonometric illustration of the present controller which may be used for controlling a responsive device, such as a simulated human arm;

FIG. 2 is a schematic illustration of the handle of the controller with the various operator arm movements numbered thereon;

FIG. 3 is a schematic illustration of the controller handle with switch locations indicated in capital letters thereon;

FIG. 4 is a schematic illustration of an exemplary circuit showing controller switch locations for actuating respective bidirectional power units;

FIG. 5 is a series of schematic illustrations showing the seven basic movements of a human arm;

FIG. 6 is a schematic illustration of a simulated human arm;

FIG. 7 is a generally schematic illustration of an exemplary manipulator control apparatus;

FIG. 8 is a side view of the manipulator control apparatus;

FIG. 9 is an enlarged illustration of the hand portion of the manipulator control apparatus;

FIG. 10 is an enlarged illustration of the bottom portion of the manipulator control apparatus; and

FIG. 11 is a schematic illustration of a bidirectional power unit and mechanical push-pull cable.

Referring now to the drawings wherein like reference numerals designate like or similar parts throughout the several views, there is shown in FIG. 1 an exemplary natural response controller **20** which includes a support means **22**, an elongated handle **24**, and a plurality of switches mounted on the support means **22**. The switches, which will be described in detail hereinbelow, suspend and solely support the handle on the support means **22** so that the handle **24** has floating action thereon. The support means **22** may be a generally U-shaped frame having a base **26** and right and left upstanding flanges **28** and **30** respectively. The flanges **28** and **30** may be provided with circular openings **32** and **34** for receiving respective right and left ends of the handle **24** with annular spaces located therebetween. Accordingly, the ends of the handle **24** will have freedom of movement in all directions within the circular openings **32** and **34** because of the annular spaced relationship. The handle **24** is also free to move along its longitudinal axis within these openings.

Because of the aforementioned switches the handle **24** has floating action within the openings **32** and **34**. These switches may be of the single pole pushbutton type with single throw action so that when the handle is moved against the button of a particular switch, the switch is placed in an on position for control purposes and when the handle is moved back the switch goes to an off position. In the preferred embodiment, the aforementioned switches include two pair of switches which are mounted on the flanges **28** and **30** at each end of the handle **24**. Referring to FIGS. **1** and **3** one pair of switches B_1 and B_2 horizontally support forward movements of the left and right ends of the handle **24**, and another pair of switches B_3 and B_4 horizontally support after movements of the right and left ends of the handle **24**. Another pair of switches C_1 and C_2 vertically support movements of the left and right ends of the handle **24**, and still another pair of switches C_3 and C_4 vertically support downward movements of the right and left ends of the handle **24**. Each of these switches may be mounted on the respective support flanges **28** and **30** by brackets **36** so that the pushbutton of each switch slidably engages the handle **24**. Accordingly, the handle **24** can slidably rotate in either direction about its longitudinal axis and can slidably extend in either direction along its longitudinal axis.

The switches, which support the handle **24** within the apertures **32** and **34**, may further include a pair of pushbutton switches A_1 and A_2 which are mounted on the support flanges **28** and **30** respectively at each end of the handle **24** along the handles' longitudinal axis. The pushbuttons on the switches A_1 and A_2 engage the right and left ends respectively of the handle **24** so as to support the handle **24** in right and left directional movement along the handles' longitudinal axis. Accordingly, as the handle is pushed to the right switch A_1 is activated and when the handle is pushed to the left switch A_2 is activated. In the case of all switches described hereinabove, the switches will be in a condition of inactivation when the handle **24** is in a neutral position, that is no force being applied to the handle **24** by an operator's hand, and when the handle is pushed in one direction the switch in that direction will be activated and the switch in the opposite direction will remain inactivated. All switches described herein may be microswitches so that a slight pressure will cause their activation. The end switches A_1 and A_2 may be mounted on the support flanges **28** and **30** by brackets **38**.

In order to utilize to an advantage the aforementioned rotative movement of the handle **24** about its longitudinal axis a pair of lever actuated pushbutton switches F_1 and F_2 are mounted in a spaced-apart opposing relationship on the support base **26**. These switches may be mounted on the support **26** directly below one end portion of the handle **24** in an opposing facing relationship. The handle **24** is provided with a radially extending lever **42** which is located between the pushbutton switches F_1 and F_2 for selectively actuating these switches as the handle **24** is rotated about its longitudinal axis. The switches F_1 and F_2 may be microswitches and may be of the single pole single throw type.

It is preferable that all of the pushbutton switches described hereinabove be mounted with their pushbuttons simultaneously directly engaging the handle **24**. Within this description pushbutton switches are intended to include any switch means

which is operated by a force. Accordingly, a pushbutton switch would include any switch which is operated by a force on a button, lever, or other mechanical appendage which is engageable with the handle **24**. Further the term "switch" is intended to include any on-off device whether it snaps from one condition to another condition or is a rheostat which is gradually increased from an off condition.

As presently described the controller **20** is now capable of controlling six primary functions of an arm manipulator. Since there are seven primary movements of a human arm this last control function may be provided for by a toggle actuated double pole double throw switch G which is mounted on the support flange **30** adjacent the left end of the handle **24**. The toggle switch G has a toggle lever **44** which extends inwardly from the flange **30** and is located for finger action by a hand grasping the handle **24**. Accordingly, when no pressure is applied to the toggle **44** the switch G is inactivated, when the toggle **44** is pushed in one direction one throw G_1 of the switch G is activated, and when the toggle **44** is pushed in an opposite direction the other throw G_2 of the switch G is activated.

FIG. **2** is a schematic illustration of the controller handle **24** and operator's hand with numerals showing the various primary movements of a human arm. A seventh primary movement which is opening and closing of the hand is not illustrated, but this function would be performed with the operator's forefinger on the toggle **44** of the G_1 switch. All of these primary movements are related in both directions to human arm movements in the table immediately below.

TABLE OF ARM MOVEMENTS OF OPERATOR AND MANIPULATOR

1 + shoulder external rotation
1 − shoulder internal rotation
2 + elbow extension and shoulder flexion
2 − elbow flexion and shoulder extension
3 + elbow flexion
3 − elbow extension
4 + supination
4 − pronation
5 + ulnar deviation
5 − radial deviation
6 + **wrist flexion**
6 − wrist extension
7 + hand open
7 − hand close

FIG. **3** is a schematic illustration showing the various switch locations with respect to the controller handle **24** for accomplishing the first six primary movements of a manipulator arm. The seventh primary movement is accomplished by switch G which is shown in FIG. **1**. These switches are wired in a circuit so that they will activate power units which in turn operate a manipulator arm to follow the natural movements of an operator's hand on the handle **24**. An exemplary circuit diagram to accomplish this purpose is shown in FIG. **4**. In this circuit the seven primary arm movements are enabled by seven bidirectional power units **51** through **57**, each power unit being connected in series across first and second electrical power sources **58** and **60** which are of opposite polarity. Accordingly, when one of the power units is energized by one of the power sources it will provide power in one direction and when energized by the other power source will provide power in an opposite direction. The power units **51** through **57** may be D.C. operated, and, as shown in FIG. **11**, may be provided with an output shaft **62** upon which there is mounted a lever arm **64**.

The power units of FIG. **4** are capable of functioning with a manipulator arm to control all of the movements set forth in the above chart. Referring to the chart and FIGS. **2** and **4**, power units **51** through **57** control both directions of movements **1** through **7** respectively, movement **7** being operation of toggle switch G with the forefinger. The switches are arranged in the circuit of FIG. **4** so that the power units **51** through **57** power a manipulator arm in natural response to arm forces of an operator on the control handle **24**. Accordingly, the right and left direction pushbutton switches A_1 and A_2 are connected between the first power unit **51** and respective electrical power sources, such as power sources **58** and **60** respectively. The horizontally supporting pair of forward switches B_1 and B_2, and the pair of after switches B_3 and B_4 are connected between the power unit **52** and electrical power sources **58** and **60** respectively. The horizontally supporting pair of forward switches B_1 and B_2, and the pair of after switches B_3 and B_4 are connected between the power unit **52** and electrical power sources **58** and **60** respectively. The vertically supporting pair of upward switches C_1 and C_2 and the pair of downward switches C_3 and C_4 are connected between the power unit **3** and electrical power sources **58** and **60** respectively. A pair of switches C_1 and C_3, at opposite ends of the handle **24** and selected one from each of the vertically supporting pairs of upward and downward switches, and the remaining pair of switches C_2 and C_4 of the vertically supporting pairs of upward and downward switches, are connected between the power unit **54** and the electrical power sources **58** and **60** respectively. Another pair of switches B_1 and B_3, at opposite ends of the handle **24** and selected one from each of the horizontally selected pairs of forward and after switches, and the remaining pair of switches B_2 and B_4 of the horizontally supporting pairs of upward and downward switches, are connected between the power unit **55** and the electrical power sources **58** and **60** respectively. Each of the lever actuated switches F_1 and F_2 are connected between the power unit **56** and the electrical power sources **58** and **60** respectively. Each of the throws G_1 and G_2 of the toggle actuated switch G is connected between the power unit **57** and the electrical power sources **58** and **60** respectively.

It should be noted that the placement of the switches in the circuit of FIG. **4** is merely exemplary and that they could be placed in a different relationship in respect to the electrical power sources **58** and **60** since the power units can be selectively positioned with respect to a manipulator arm to obtain the desired directional movements. Further, a pair of single-pole single-throw switches could be substituted for the double-throw switch G in which event the pair of switches would be separately controlled by forefinger control rather than using a single toggle switch arrangement. If desired, proportional devices, such as a bridge with a rheostat or strain gauges, may be connected in each circuit between each power unit and each electrical power source in order to obtain output movements from the power units which are proportional to forces of the operator's arm upon the control handle **24**. These proportional devices could be used in lieu of or in combination with the aforementioned switches.

FIG. **5** illustrates the seven primary movements of the human arm. The nomenclature in FIG. **5** corresponds to the chart hereinabove except that the primary arm movements are described in more generic common terminology. It is these seven primary movements that the controller **20** is able to accomplish when combined with a manipulator arm which is described hereinbelow. In FIG. **6** there is shown a schematic manipulator arm with the various primary movements shown thereon. The manipulator arm **66** may include a support means **68**, an upper arm **70** which is rotatably connected to the support means **68**, a forearm **72** which is pivotally connected to the upper arm **70**, a wrist **74** which is pivotally connected to the forearm **72**, and a plurality of fingers **76**, at least one of which is pivotally connected to the wrist **74**.

An exemplary embodiment of the manipulator **66** is illustrated in FIGS. **7**—**10**. The support means may be a support base **68** and an upstanding rod **69** which is journaled for rotation about its longitudinal axis within the base **68**. A block **78** may be fixedly connected to a top portion of the rod **69**. The upper arm **70** may include lever arms **70***a* and **70***b* which are pivotally interconnected at their tops by a crossbar **70***c* at pivot locations **80** and **82**. The lever arm **70***a* is further pivoted at the pivot location **82** to the block **78** so that the upper arm

components can pivot and rotate in a vertical plane. The bottom ends of the upper arm levers **70***a* and **70***b* may be pivoted to a 90° bracket **84** at pivots **86** and **88** respectively. A tubular member **72**, comprising the forearm, may be rotatably connected to the bracket **84** generally parallel to the line of direction of the pivot points **86** and **88** by a bearing **89**. The forward portion of the forearm **72** may fixedly extend through a block **90** and may have a forwardly extending reduced portion which is pivotally connected to a wrist block **74** by a ball and socket connection **92**. Connected at the forward end of the wrist **74** is a pair of fingers **76**. The bottom finger **76** may be rigidly attached to the block **74** and the top finger **76** may be pivotally connected thereto by a yoke **94** which is pivoted at locations **96** (one of which is shown in FIG. **9**). If desired, some of the primary movements of the manipulator arm may be provided with spring returns. A spring return may be provided for shoulder rotation by a spring **98** which is connected between a radially extending pin **100** on the upstanding rod **69** and another pin **102** which projects upwardly from the base **68**. Spring return for wrist movements may be accomplished by springs **104** and **106** which are located 90° apart and are each connected between the forearm block **90** and the wrist block **74**. Spring return for the top finger **76** may be accomplished by a spring **108** which is connected between the fingers **76**.

In order to accomplish the various movements of the manipulator arm **66** a plurality of sheathed cables may be appropriately connected between the power units **51** through **57** and various control points on the manipulator arm. One of such sheathed cables is illustrated at **110** in FIG. **11**. This cable is similar to a choke cable in an automobile and has clamps **112** at various locations to achieve the desired movements. As shown in FIG. **10** the power units for the first three primary movements may be mounted on the support base **68** by a T-shaped bracket **114**. The output shafts of the power units may be journaled through the upstanding portion of the bracket **114** and may each be provided with a lever arm **64** which in turn is connected to an appropriate cable **110** (see FIG. **11**). As shown in FIG. **10** the power unit **51** may have a lever arm **116** which is connected to one end of a cable **118**. The other end of the cable **118** may be connected to the pin **100** on the upstanding rotatable rod **69**. The sheath of the cable **118** is connected to the support base **68** by a clamp **120**. The power unit **52** may have a lever arm **122** which is connected to one end of a cable **124**. The opposite end of the cable **124** may be connected to a top portion of the upper arm lever **70***a* between pivot points **82** and **86**. The bottom sheath portion of this cable **124** may be clamped to the bracket **114** by a clamp (not shown) and the top sheath portion may be clamped to the bottom of the block **78** by a clamp (not shown). The power unit **53** may have a lever arm **128** which is connected to one end of a cable **130**. The opposite end of the cable **130** may be connected to the middle portion of the crossbar **70***c*. The sheath of the cable **130** may be fixed to the bracket **114** at one end by a clamp **132** and the other end of the sheath may be clamped to the block **78** by a clamp **133**. Power unit **54**, which controls primary movement **4**, is mounted on bracket **84** by a clamp **135** and has its output shaft directly connected to the end of the forearm rod **72**.

The power units **55**, **56** and **57**, controlling primary movements **5**, **6** and **7** of the manipulator arm, may be mounted on the bracket **84** in a similar manner to the mounting of the power units **51**, **52** and **53** on the bracket **114**. Power unit **55** may have a lever arm **137** which is connected to one end of a cable **134**. The other end of the cable **134** is connected to one side of the wrist block **74** and the sheath of the cable **134** is clamped to the bracket **84** by a clamp **139** and to the block **90** by a clamp **136**. The power unit **56** has a lever arm **141** which is connected to one end of a cable **138**. The other end of the cable **138** is connected to an opposite side of the wrist block **74** and its sheath is connected to the bracket **84** at one end by a clamp (not shown) and is connected at its opposite end to the block **90** by a clamp **140**. The power unit **57** has a lever arm **143** which is connected to one end of a cable **142**. The other end of the cable **142** is connected to the yoke **94** for movement of the top finger **76**. One end of the sheath of cable **142** is fixed to the bracket **84** by a clamp (not shown) and the other end of the sheath is fixed to the wrist block **74** by a clamp **144**.

In order to counterbalance the upper arm **70**, forearm **72** and wrist **74** the lever arm **70***a* may be extended beyond pivot **82** and may be provided at its end with a weight **146**.

In the operation of the present invention the operator places his hand on the control handle **24** of the controller **20**. The upper arm, forearm, and wrist movements or forces of the operator will be reflected in control functions **1** through **6**. These movements will in turn be sensed by pushbuttons of the switches associated with the handle **24** to selectively operate the power units **51** through **56**. These power units in turn operate the cables to move the manipulator arm **66** in natural corresponding movements to the forces of the operator's arm. The finger grasping action of the manipulator arm by fingers **76** is accomplished by the operator's forefinger working the toggle **44** of switch G. This in turn actuates the power unit **57** to move the finger **76** by action of the cable **142**.

It is now readily apparent that the present invention provides a simple natural response manipulator. The manipulator includes a controller which enables an operator to move a simulated human arm with movements which correspond to his own arm. It should be understood that hydraulic valves may be substituted for the switches and hydraulic actuators could be substituted for the power units described herein. It should also be understood that the controller **20** can be used for controlling any responsive device such as an underwater vehicle, aircraft, missile, or the manipulator arm disclosed herein.

Other objects and many of the attendant advantages of this invention will be readily appreciated as it becomes better understood by reference to the description and accompanying drawings which follow.

I claim:

1. A natural response controller comprising:
support means;
an elongated handle; and
a plurality of pushbutton switches mounted on the support means and solely supporting the handle thereon,
whereby forces on the handle in various directions will selectively operate the switches to enable the performance of controlling functions in directions corresponding to the applied forces.

2. A natural response controller as claimed in claim **1** comprising the pushbuttons of said switches simultaneously directly engaging said handle.

3. A controller as claimed in claim **2** comprising:
the handle being supported on the support means in a generally horizontal position and having right and left ends;
said switches including two pair of switches mounted on the support means at each end of the handle, one pair of switches horizontally supporting forward movement of each end of the handle and another pair of switches horizontally supporting after movement of each end of the handle, another pair of switches vertically supporting upward movement of each end of the handle and still another pair of switches vertically supporting downward movement of each end of the handle.

4. A controller as claimed in claim **3** comprising:
said switches supporting the handle for slidable movement along its longitudinal axis; and
said switches including a pushbutton switch mounted on the support means at each end of the handle along the longitudinal axis thereof, the latter switches supporting the handle in left and right directions along said longitudinal axis.

5. A controller as claimed in claim **4** comprising:
said switches supporting the handle for slidable rotatable movement about its longitudinal axis;

a pair of lever actuated pushbutton switches mounted on the support means; and

a lever mounted on the handle between the pair of lever actuated switches for selectively actuating these switches as the handle is rotated about its longitudinal axis.

6. A controller as claimed in claim 5 comprising:

a toggle actuated double-throw switch means mounted on the support means adjacent the left end of the handle; and

a toggle operatively connected to the toggle actuated switch and located for finger operation of a hand grasping said handle.

7. A controller as claimed in claim 6 comprising:

first through seventh bidirectional power units each being connected in series across first and second electrical power sources of opposite polarities;

the right and left direction pushbutton switches being connected between the first power unit and respective electrical power sources;

the horizontally supporting pair of forward switches and pair of after switches being connected between the second power unit and respective electrical power sources;

the vertically supporting pair of upward switches and pair of downward switches being connected between the third power unit and respective electrical power sources;

a pair of switches at opposite ends of the handle, selected one from each of the vertically supporting pairs of upward and downward switches, and the remaining pair of switches of the vertically supporting pairs of upward and downward switches being connected between the fourth power unit and respective electrical power sources;

another pair of switches at opposite ends of the handle, selected one from each of the horizontally supporting pairs of forward and after switches, and the remaining pair of switches of the horizontally supporting pairs of upward and downward switches being connected between the fifth power unit and respective electrical power sources;

each of the lever actuated switches being connected between the sixth power unit and respective electrical power sources; and

each of the throws of the toggle actuated switch means being connected between the seventh power unit and respective electrical power sources.

8. A natural response manipulator apparatus including the elements of claim 7 and further comprising:

further support means;

a forearm and upper arm, the forearm being pivotally connected to the upper arm and the upper arm being rotatably connected to the further support means;

a wrist pivotally connected to the forearm;

a plurality of fingers, at least one of which is pivotally connected to said wrist; and

means connecting the power units to the forearm, upper arm, wrist, and fingers for natural movements with respect to hand control of the handle of said controller.