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(54) VARIABLE COMPLIANCE JOYSTICK WITH COMPENSATION ALGORITHMS

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(60) Division of application No. 11/068,655, filed on Feb. 25, 2005, now abandoned, and a continuation-in-part of application No. PCT/US03/27163, filed on Aug. 29, 2003.

(60) Provisional application No. 60/406,682, filed on Aug. 29, 2002.

(51) **Int. Cl.**
G06F 3/033 (2006.01)

(52) **U.S. Cl.** .... **345/161**; 463/38; 700/85; 74/471 XY

(58) **Field of Classification Search** 700/85
See application file for complete search history.

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Primary Examiner — Lixi C Simpson
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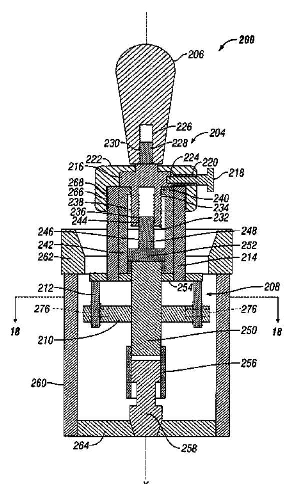
(57) **ABSTRACT**

The present invention provides variable compliance joysticks with mechanical and software customization, and with an integrated control capability, and a method of systematically determining the best mechanical settings and compensatory algorithms to embed in the joysticks to offer an individual with substantial upper extremity motor impairments a personal fit and maximum function. The joysticks may include components for varying the compliance and dampening of the joystick shaft. The method may include providing the user access to operate the joysticks, operatively connecting the joysticks to a driving simulator, displaying an icon on the driving simulator, controlling movement of the icon by the joysticks, evaluating performance of the user based upon the user's ability to control movement of the icon, and modifying hardware settings and software algorithms for the joysticks based upon the evaluation.

20 Claims, 11 Drawing Sheets



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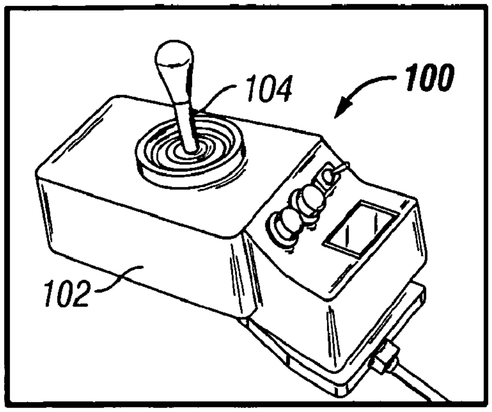


FIG. 1

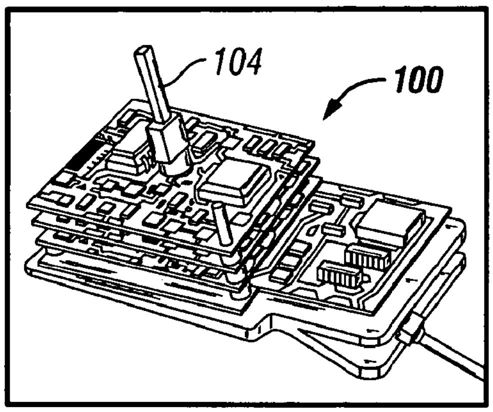


FIG. 2

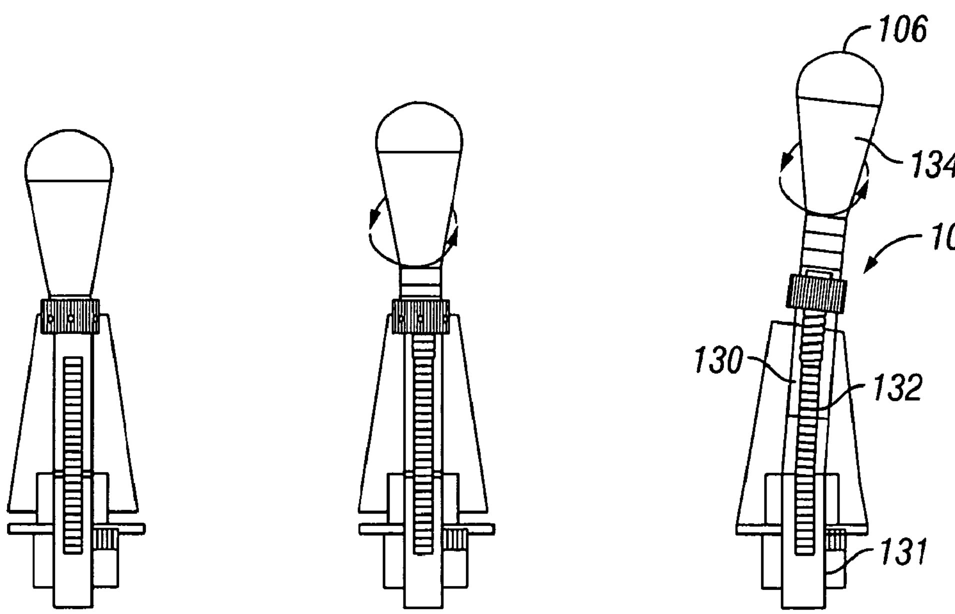


FIG. 3A FIG. 3B FIG. 3C

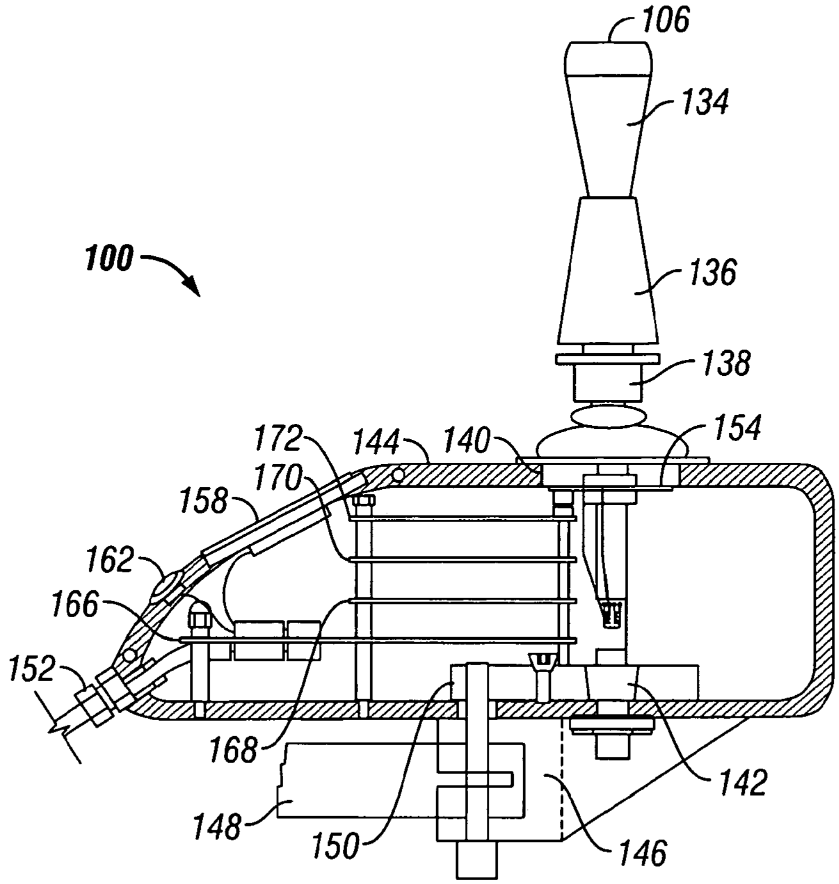

106
134
100
136
138
172
144
140
154
170
158
162
166
152
168
142
148
150
146

FIG. 3D

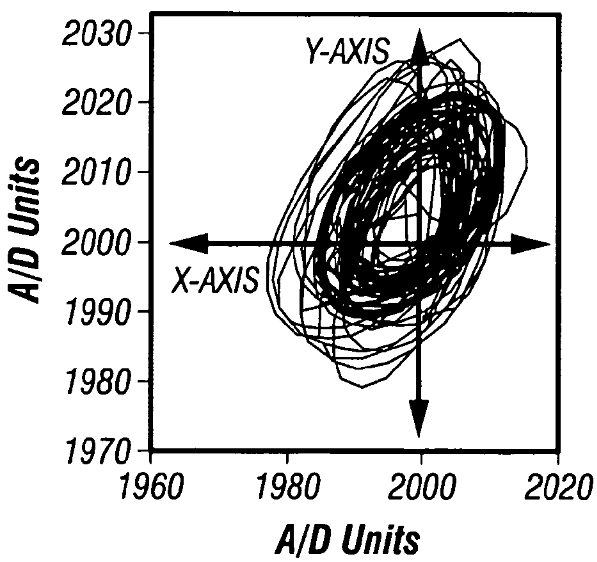
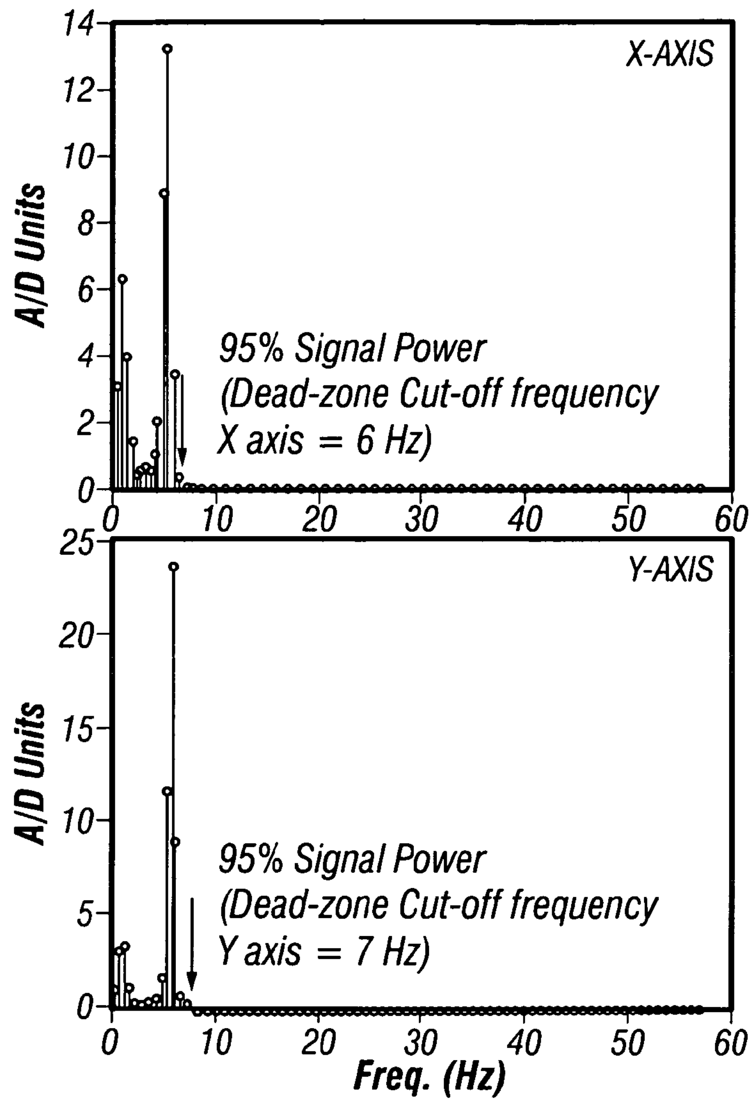
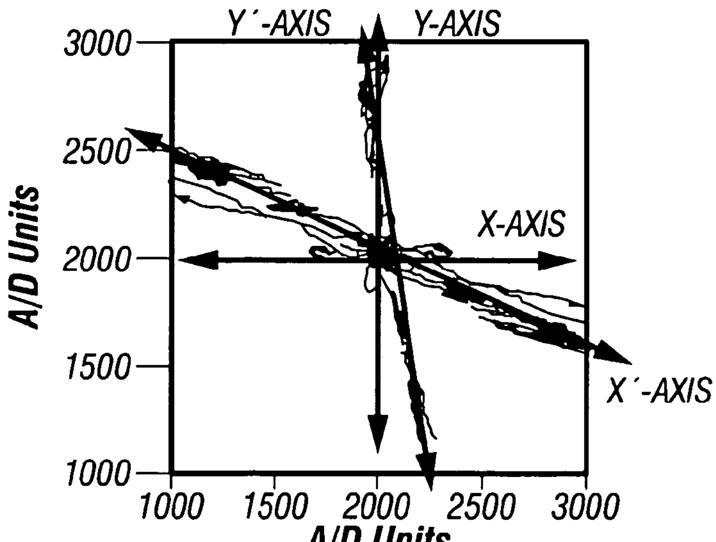

2030
2020
2010
2000
1990
1980
1970
Y-AXIS
X-AXIS
A/D Units
1960
1980
2000
2020
A/D Units

FIG. 4



X-AXIS
A/D Units
95% Signal Power
(Dead-zone Cut-off frequency
X axis = 6 Hz)
Y-AXIS
95% Signal Power
(Dead-zone Cut-off frequency
Y axis = 7 Hz)
Freq. (Hz)

FIG. 5



Y´-AXIS
Y-AXIS
X-AXIS
X´-AXIS
A/D Units
A/D Units

FIG. 6

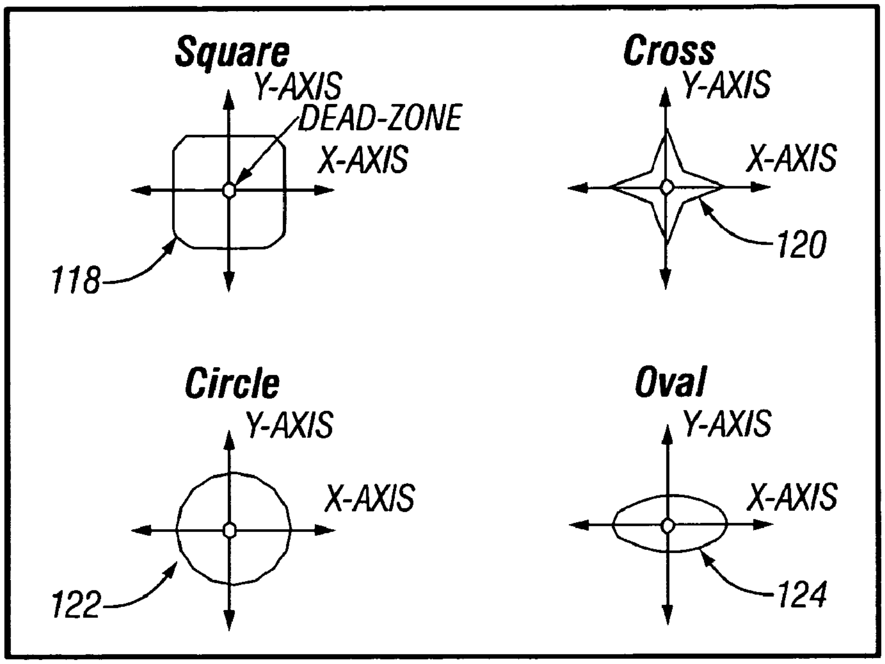

Square
Y-AXIS
DEAD-ZONE
X-AXIS
118
Cross
Y-AXIS
X-AXIS
120
Circle
Y-AXIS
X-AXIS
122
Oval
Y-AXIS
X-AXIS
124

FIG. 7

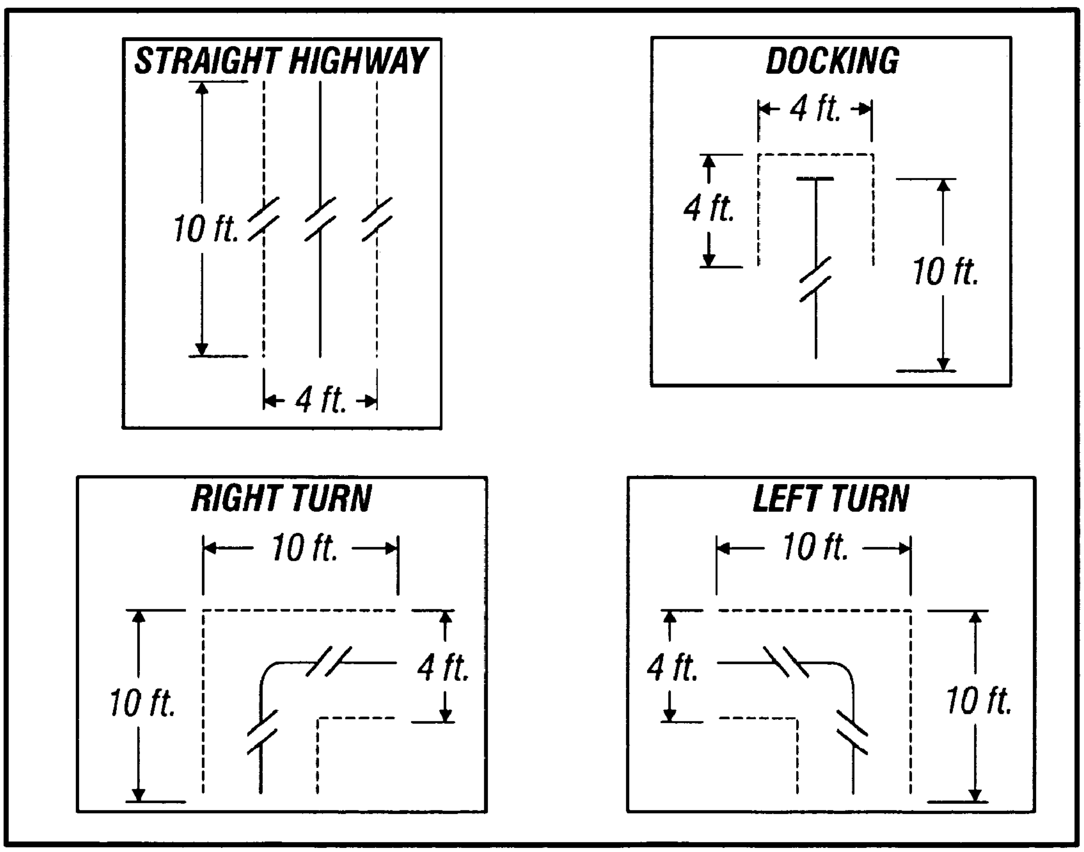

STRAIGHT HIGHWAY
10 ft.
4 ft.
DOCKING
4 ft.
4 ft.
10 ft.
RIGHT TURN
10 ft.
10 ft.
4 ft.
LEFT TURN
10 ft.
4 ft.
10 ft.

FIG. 8

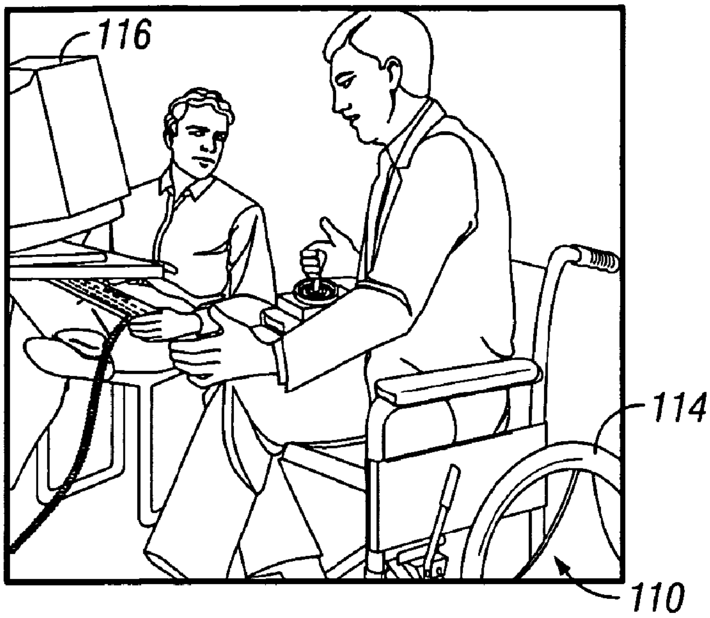


FIG. 9

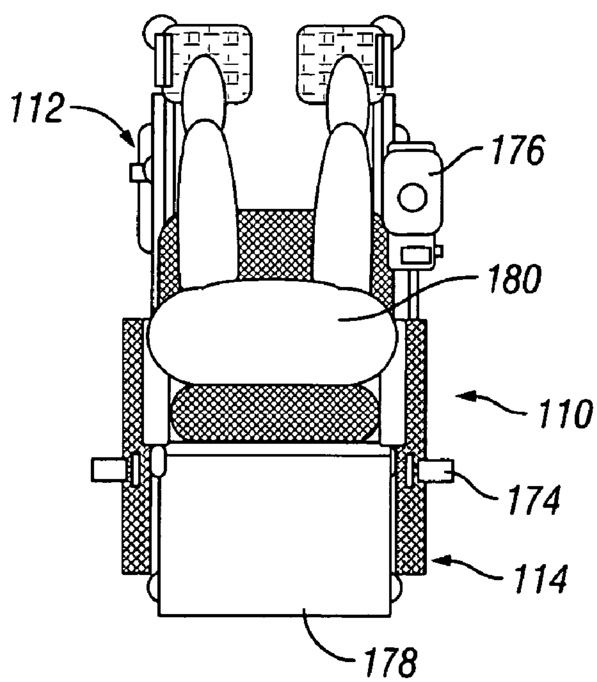


FIG. 10

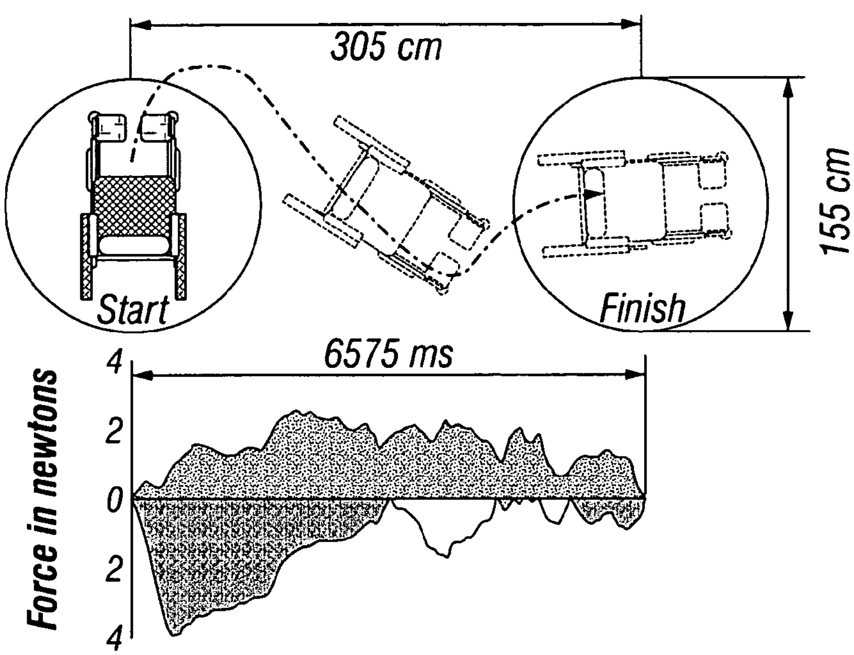


FIG. 11

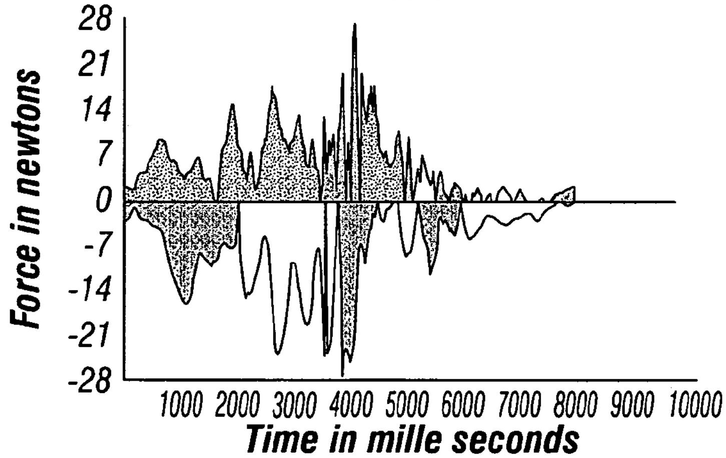


FIG. 12

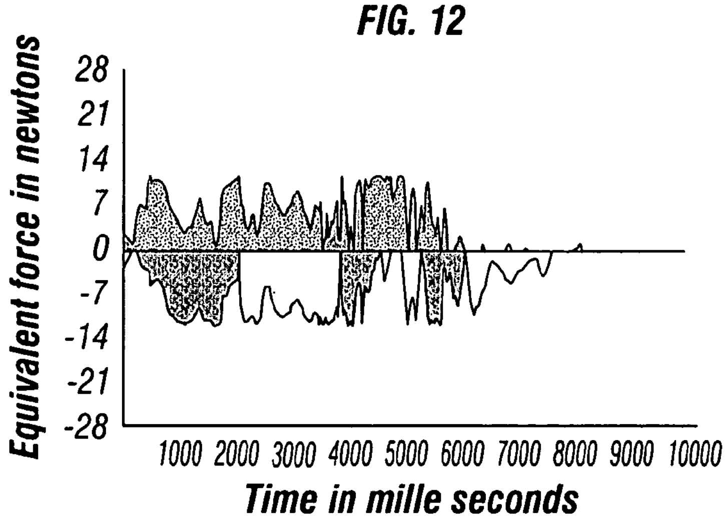


FIG. 13

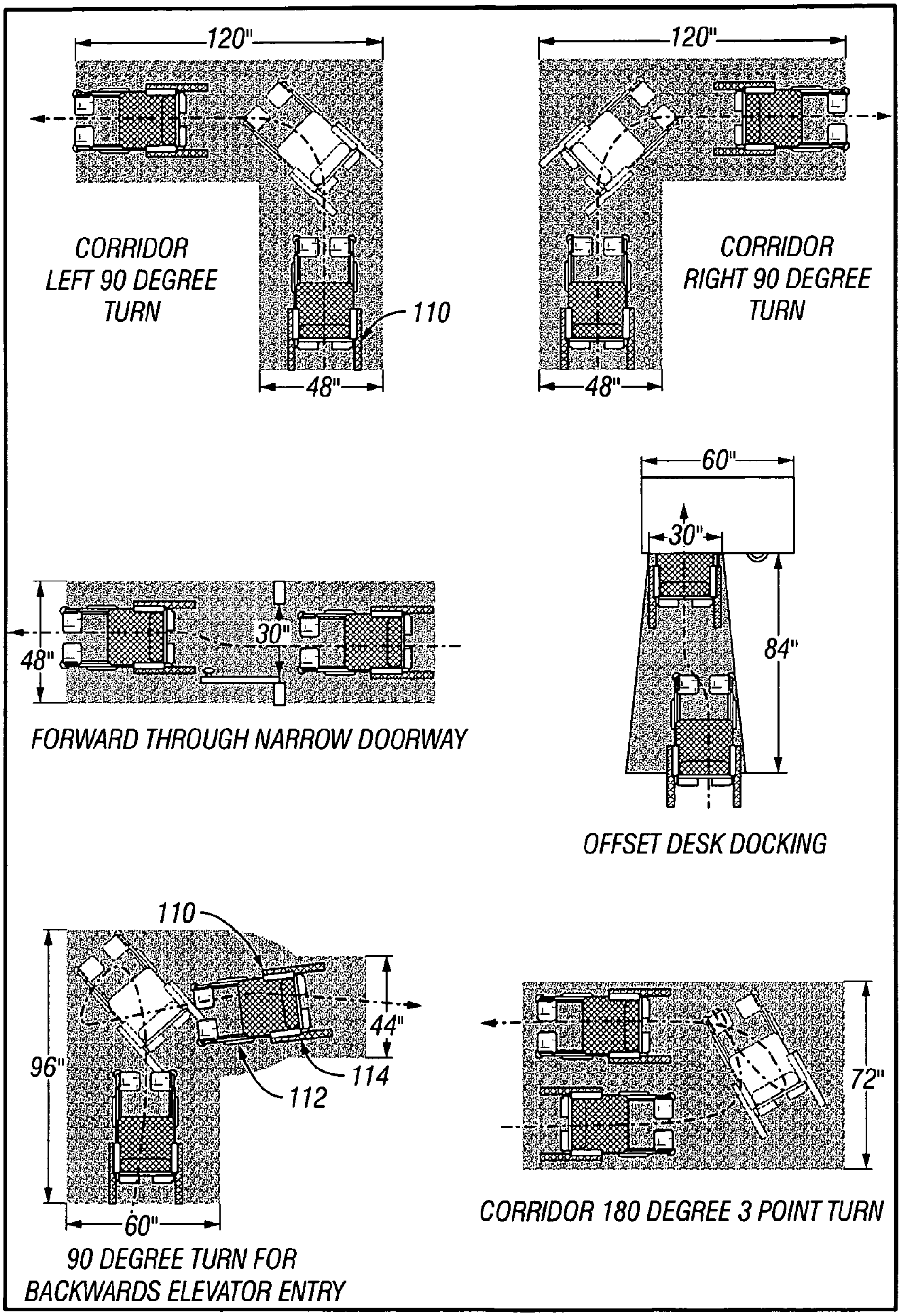

120"
CORRIDOR
LEFT 90 DEGREE
TURN
110
48"
120"
CORRIDOR
RIGHT 90 DEGREE
TURN
48"
60"
30"
84"
OFFSET DESK DOCKING
48"
30"
FORWARD THROUGH NARROW DOORWAY
110
96"
44"
114
112
60"
90 DEGREE TURN FOR
BACKWARDS ELEVATOR ENTRY
72"
CORRIDOR 180 DEGREE 3 POINT TURN

FIG. 14

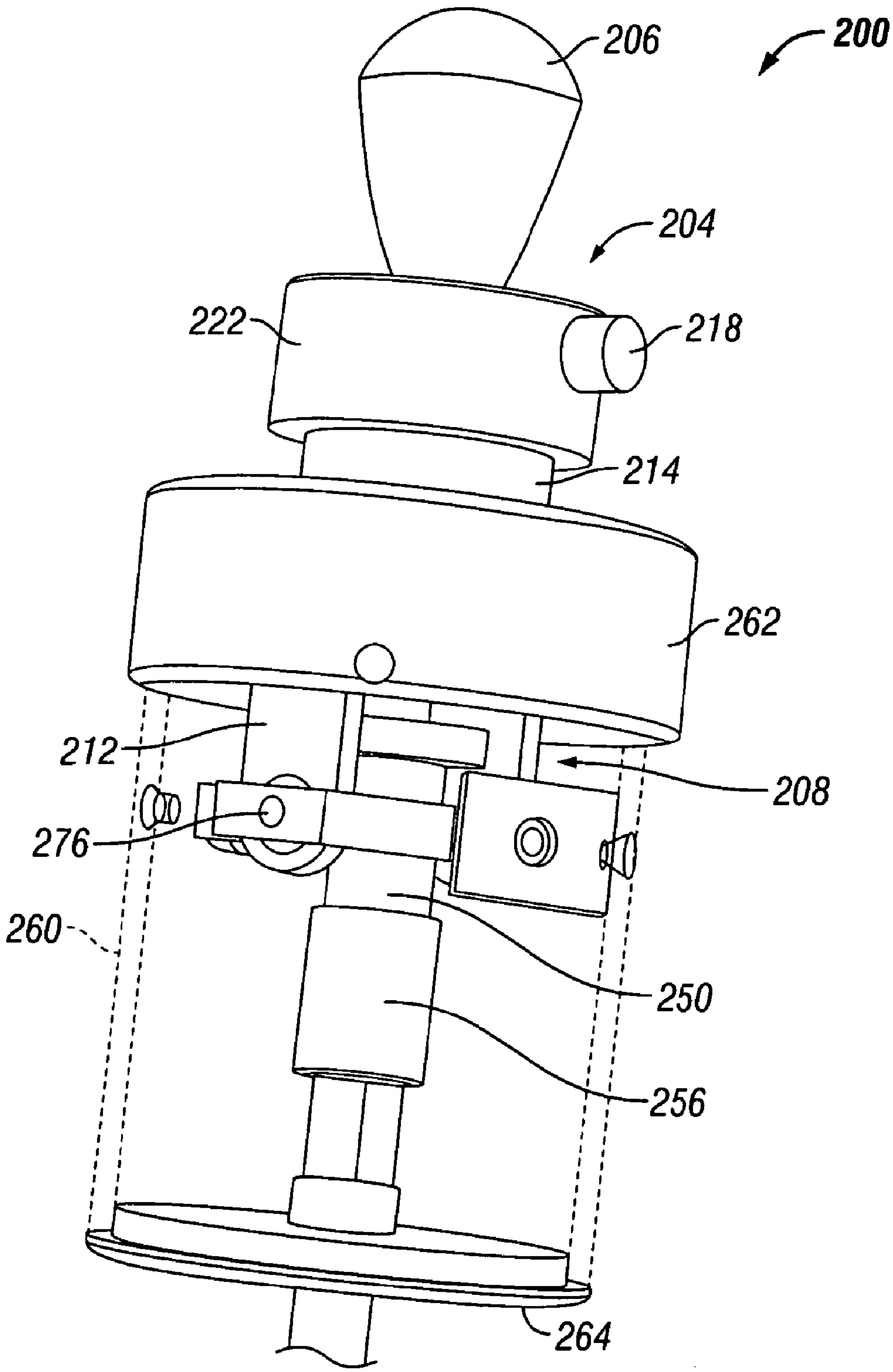
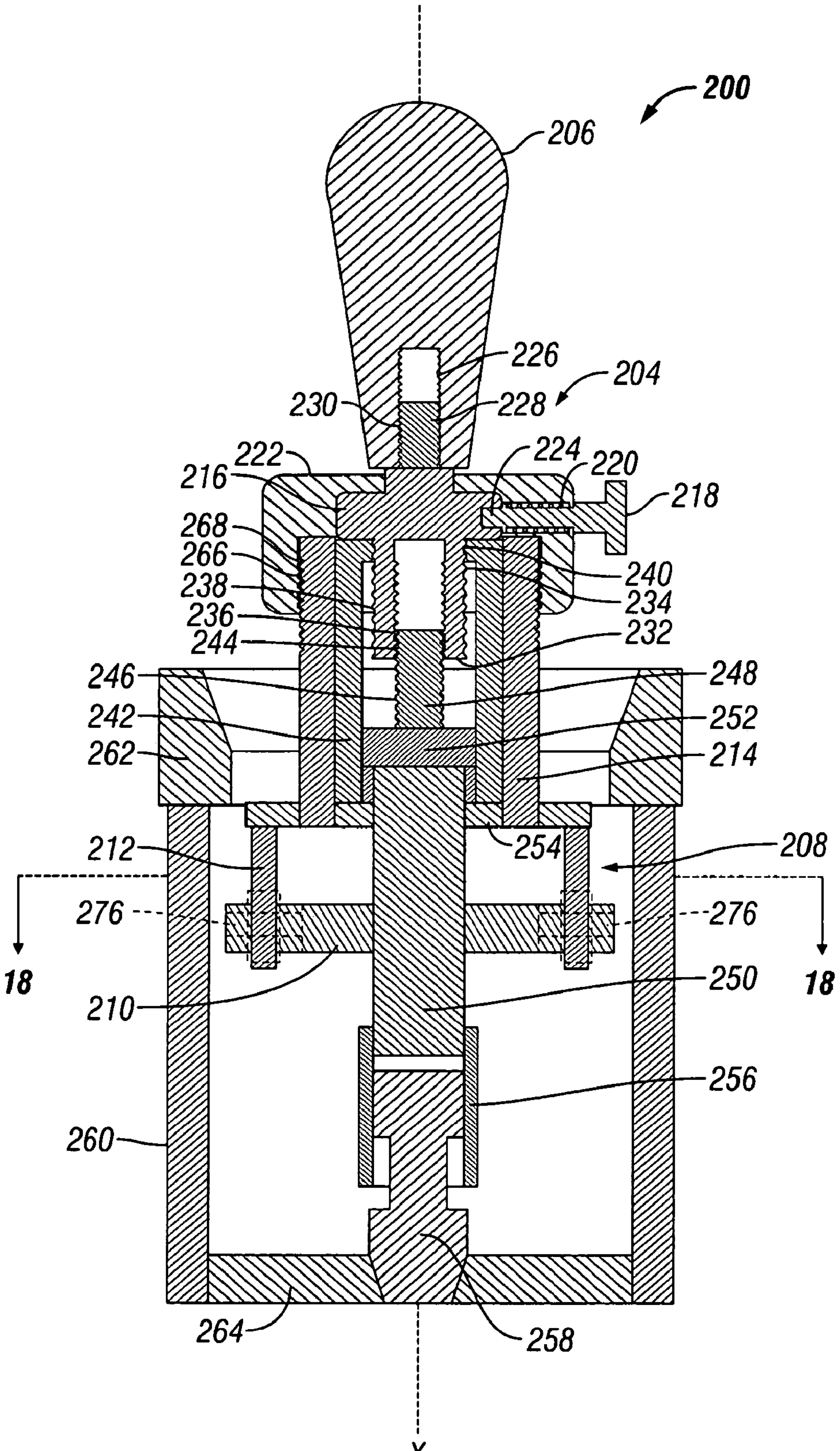


FIG. 15


200
206
226
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230
228
222
224
220
216
218
268
266
240
238
234
236
232
244
246
248
242
252
262
214
212
254
208
276
276
18
18
210
250
256
260
264
258
X

FIG. 16

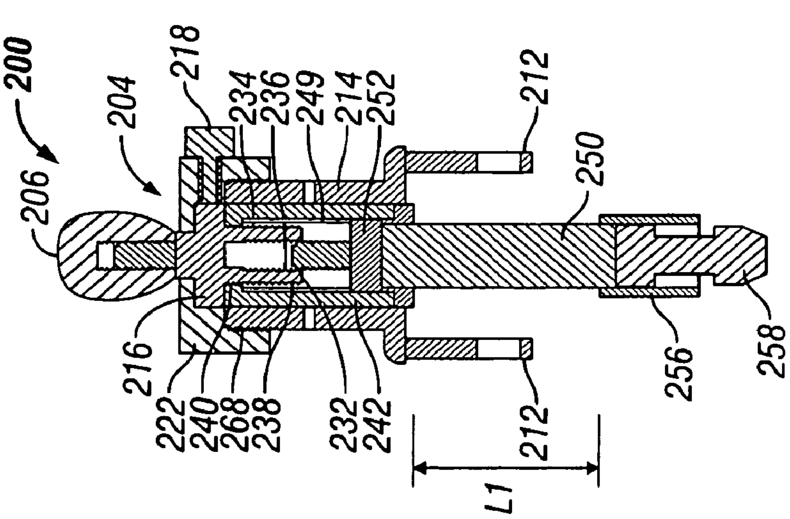

FIG. 17A

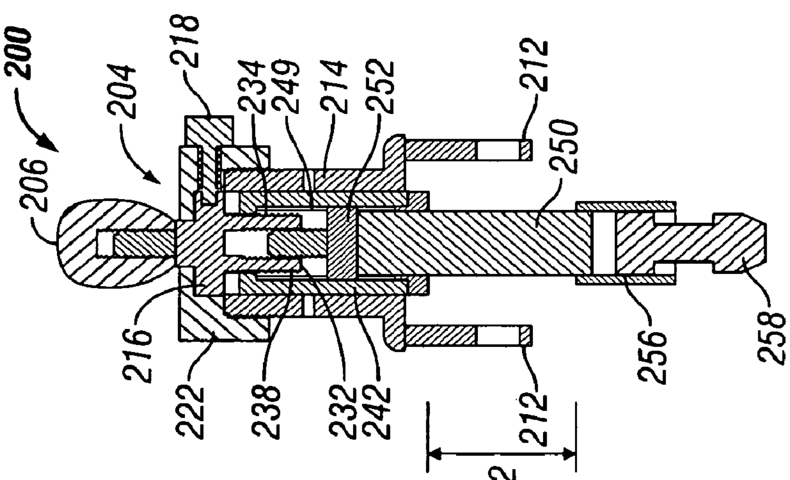

FIG. 17B

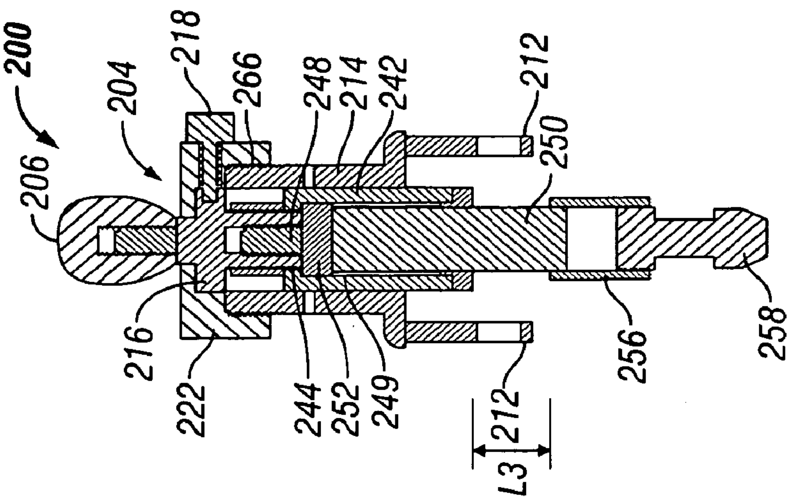

FIG. 17C

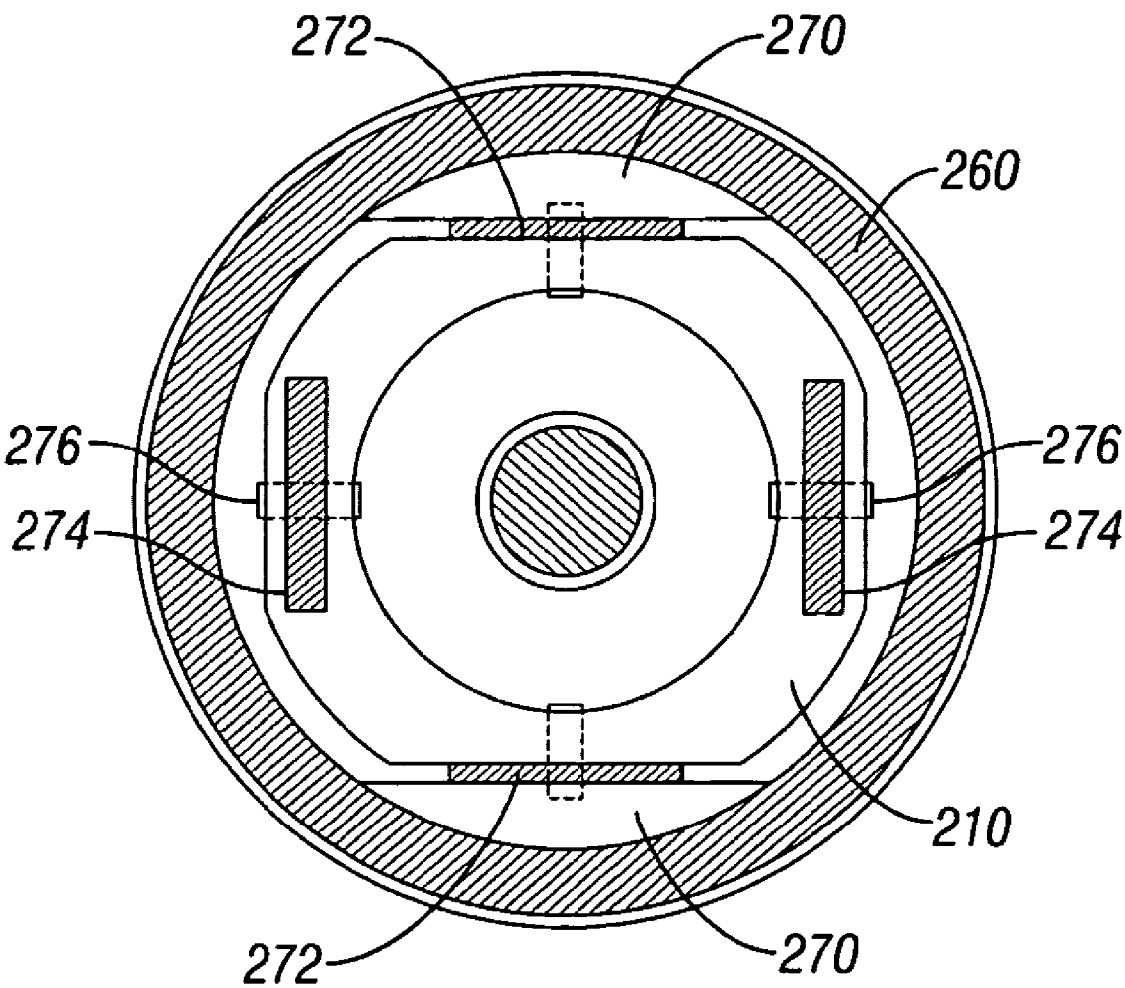

FIG. 18

VARIABLE COMPLIANCE JOYSTICK WITH COMPENSATION ALGORITHMS

RELATED APPLICATIONS

This application is a Divisional of U.S. application Ser. No. 11/068,655, filed Feb. 25, 2005 now abandoned and claims benefit of priority of Provisional Application Ser. No. 60/406,682, filed Aug. 29, 2002, and is a continuation-in-part of PCT App. Serial No. PCT/US03/27163, filed Aug. 29, 2003.

BACKGROUND OF INVENTION

a. Field of Invention

The invention relates generally to electric powered wheelchairs, and, more particularly to an apparatus and method for customized control of an electric powered wheelchair.

b. Description of Related Art

Position sensing devices are integral components of computing systems, the ubiquitous "mouse" being one of the best examples. Joysticks are also common, and find applications in computer games, medical devices, wheelchairs, robotics, aircraft, advanced vehicles, and other devices. Other examples of position sensing devices include trackballs and virtual reality equipment such as helmets, goggles, gloves, and foot pedals. The earliest joysticks were basically a simple arrangement of contact switches at four quadrants. Moving the joystick shaft away from its centered position closed one of the four switches, depending on the direction of movement. Springs connected to the joystick returned the device to a central position when the joystick was released. The resistance to motion, called compliance, that is provided by the springs could be provided or augmented by other means, such as having the joystick move through a viscous fluid.

An improvement to the contact switch joystick was made by development of the position sensing joystick. In this arrangement, the joystick was coupled to two potentiometers mounted at right angles. Motion of the joystick produced voltages from the potentiometers that indicated the position of the joystick. Later variations of position sensing joysticks employed optical encoders to determine the joystick position, replacing potentiometers. Further refinements of position sensing joysticks included the addition of tactile and force feedback. Tactile feedback is a simple vibration generated when provided position information falls within some desired region. Force feedback devices actually apply forces to the joystick shaft, for example, pushing against the operator induced motion. Force feedback may be used to indicate to a robotic operator that contact with an object has been made. The force sensing, or isometric, joystick used strain gauges to measure forces applied to the joystick with no motion of the joystick required. An example of such a joystick is the miniature isometric joystick used on laptop computer keyboards.

In view of the aforementioned developments, today's electric powered wheelchairs include several components for facilitating control of movement thereof, including proportional position sensing joysticks, electric powered wheelchair controllers, isometric joysticks, damped joystick controls, joysticks with corrective algorithms and integrated control features, and wheelchair driving simulators.

Proportional position sensing joysticks for electric powered wheelchairs are known in the art and generally allow individuals with impaired mobility to drive such wheelchairs. Position sensing joysticks produce speed and direction signals proportional to the joystick's directionality and angle of deflection. It has been shown that such joysticks are inadequate for as many as 40% of potential wheelchair users, partly because they are built on a "one size fits all" philosophy. For example, current clinical practice is to have a user try out various commercially available position sensing joystick controls, and then select a handle and mounting position most compatible with the user's residual hand function. Frequently, none of the commercial position sensing joystick controls are suitable and the user is often downgraded to single switch head arrays rather than a proportional control system. While single switch technology can be operated with limited and imprecise limb movement, the result is generally a slow and awkward wheelchair control system.

With regard to electric powered wheelchair controllers, such controllers generally include a power regulating circuit between the position sensing joystick and the wheelchair drive motors. Controllers translate the speed and direction signals from the user control (i.e. a joystick) into appropriate current levels that are applied to the drive motors of a wheelchair. Over the years, the improvement and perfection of such controllers has been a focus of the wheelchair industry. Early controllers generally included simple driving algorithms, an example of which includes a controller operated by a driver pushing a position sensing joystick to the right or left, at which time the controller decided whether to merely slow the wheel inside the turn or, in the event of a sharp, low speed turn, to run the inside wheel in reverse to produce a tighter turning circle. In more modern controllers, in order to safely match an electric powered wheelchair to different driving abilities of particular users, manufacturers provide several adjustments on their controllers that a vendor or clinician may set with a hand held programmer. An exemplary adjustment may include adjustment of the maximum velocity the wheelchair will achieve during straight ahead or turning maneuvers. Modern controllers also include advanced algorithms to stabilize a wheelchair in hazardous terrain, such as during climbing or descending steep grades, or when traversing a cross slope. Even in light of the aforementioned improvements in controllers, commercial controllers and position sensing joysticks are generally unable to recognize or in any way correct for an operator's unintentional hand movements. Another major disadvantage of currently available controllers is that they only serve the electric powered wheelchair, and do not support the control of any other associated device, such as personal computers or environmental control systems.

With regard to isometric joysticks, as discussed above, such joysticks are generally used with personal computers. A well-known example of an isometric joystick includes the "eraser head" mouse used on many laptop computers. While such joysticks are known in the industry, these joysticks have had limited application in the field of electric powered wheelchairs due to the associated limitations in the ability of user to adequately operate the joystick.

With regard to damped joystick control, while such a control methodology is known in the industry, damped control for joysticks has generally been used in the reduction of hand tremor. Moreover, the damped control methodology has primarily been used for position sensing, and not for control of electric powered wheelchairs.

Lastly, with regard to wheelchair driving simulators, while simulators have indeed found applications in the automotive field, as with automobile driving simulators, for example, such simulators are however not applicable to wheelchair driving. Moreover, no known driving simulators have been used to tune electric powered wheelchairs or associated joysticks.

Accordingly, there remains a need for a customizable and versatile control technology for electric powered wheelchairs. There also remains a need for a variable compliance joystick for electric powered wheelchair control and for facilitating the customization of the aforementioned technologies for users with various disabilities.

SUMMARY OF INVENTION

The invention solves the problems and overcomes the drawbacks and deficiencies of the prior art wheelchair control and simulation systems by providing an apparatus and method for customized control of electric powered wheelchairs.

Thus an exemplary aspect of the present invention is to provide variable compliance joysticks with mechanical and software customization, and with an integrated control capability.

Another aspect of the present invention is to provide a method of systematically determining the best mechanical settings and compensatory algorithms to embed in the joystick to offer an individual with substantial upper extremity motor impairments a personal fit and maximum function.

Yet another aspect of the present invention is to provide customized joysticks that can be closely matched to user needs by use of a simulator to optimize software and hardware characteristics of the joystick.

The present invention achieves the aforementioned exemplary aspects by providing first and second embodiments of a joystick apparatus. The first embodiment of the joystick apparatus according to the present invention includes a rigid shaft having a tip, and a flexible extension operatively connected to the shaft to vary the compliance of the shaft. The extension may be hollow and encircle the shaft, and may further include a frusto-conical cross-section. The extension may include a viscous substance disposed therein for dampening motion of the shaft. The shaft may include upper and lower shaft segments, the segments including a resilient member disposed between adjacent ends thereof and being adjustable to be spaced away from each other for varying the compliance of the shaft. The joystick may include integrated control capability for operating multiple assistive devices, and may be operatively mounted on an electric powered wheelchair for allowing a user to operate multiple assistive devices.

The joystick may further include compensation algorithms including an elliptical dead-zone representative of the joystick shaft at rest, the dead-zone representing a minimum range of forces which must be exceeded to produce motion of an electric powered wheelchair including the joystick mounted thereon, the dead-zone further representing a maximum range of forces which must not be exceeded to prevent movement of the wheelchair. The compensation algorithms may include a determination of an optimal bias axes gain for movement of the joystick shaft in left, right, forward and backward directions. The compensation algorithms may also include at least one software template for at least one of controlling bias of the joystick shaft, decreasing throw of the joystick shaft and reducing degrees of freedom of an output signal of the joystick shaft. The software template may be based upon the mathematics of super quadratics, and may be one of a square, circular, cross, elliptical and diamond shaped template. The compensation algorithms may also include filtering to reduce the effects of unwanted motions of the joystick shaft.

The second embodiment of the joystick apparatus according to the present invention includes a joystick shaft having a generally predetermined length, and including upper and lower joystick segments operatively connected to each other. The lower joystick segment may be substantially flexible and movable relative to the upper joystick segment to vary compliance of the joystick shaft without substantially changing the predetermined length.

For the second embodiment of the joystick apparatus described above, the upper joystick segment may include a longitudinal axis. The joystick may further include a gimbal assembly substantially surrounding a length of the lower joystick segment for generally maintaining the lower joystick segment in a predetermined extended orientation relative to the longitudinal axis. The upper joystick segment may include a handle mounted to an index bushing including internal threads along a length thereof. A drive stud may be operatively connected to the lower joystick segment and further include external threads operatively engaged with the internal threads such that rotation of the handle in first and second opposite rotational directions respectively moves the lower joystick segment toward and away from the upper joystick segment to vary the compliance of the shaft. The joystick apparatus may further include a spring biased locking plunger selectively engageable with the index bushing for allowing and preventing rotation of the index bushing when respectively disengaged from and engaged with the index bushing.

Alternatively, for the second embodiment of the joystick apparatus, the upper joystick segment may include a handle mounted to an index bushing including external threads along a length thereof. A chamber column including internal threads may be operatively engaged with the external threads such that rotation of the handle in first and second opposite rotational directions respectively moves the chamber column away from and toward the upper joystick segment to vary the compliance of the shaft by reducing a bendable length of the lower joystick segment.

Alternatively, in combination, the upper joystick segment may include a handle mounted to an index bushing including internal and external threads along a length thereof. A drive stud may be operatively connected to the lower joystick segment and further include external threads operatively engaged with the index bushing internal threads. A chamber column including internal threads may be operatively engaged with the index bushing external threads, such that rotation of the handle in first and second opposite rotational directions respectively moves the lower joystick segment toward and away from the upper joystick segment, and further respectively moves the chamber column away from and toward the upper joystick segment to vary the compliance of the shaft by reducing a bendable length of the lower joystick segment.

For the joystick described above, the gimbal assembly may include a gimbal ring operatively connected to the upper joystick segment. The gimbal ring may have the lower joystick segment disposed therethrough. The gimbal assembly may further be disposed within an enclosure for limiting pivotal movement of the joystick shaft by substantially enclosing the upper joystick segment within an opening in the enclosure. The gimbal ring may be pivotally mounted within the enclosure for pivotal movement about a first axis of rotation. The upper joystick segment may be pivotally mounted to the gimbal ring by at least two yoke legs for rotation about a second axis of rotation substantially orthogonal to the first axis of rotation for thereby enabling substantially universal pivotal movement of the upper joystick segment relative to the lower joystick segment. The lower joystick segment may be slidably connected to an isometric post, for controlling the joystick, by a sleeve fixedly mounted to the lower joystick segment and further slidably disposed around the isometric post.

As discussed above for the first embodiment, the second embodiment of the joystick apparatus may likewise include a joystick having integrated control capability for operating multiple assistive devices, and the joystick may be operatively mounted on an electric powered wheelchair for allowing a user to operate multiple assistive devices. The joystick may further include compensation algorithms including an elliptical dead-zone representative of the joystick shaft at rest, the dead-zone representing a minimum range of forces which must be exceeded to produce motion of an electric powered wheelchair including the joystick mounted thereon, the dead-zone further representing a maximum range of forces which must not be exceeded to prevent movement of the wheelchair. The compensation algorithms may include a determination of an optimal bias axes gain for movement of the joystick shaft in left, right, forward and backward directions. The compensation algorithms may also include at least one software template for at least one of controlling bias of the joystick shaft, decreasing throw of the joystick shaft and reducing degrees of freedom of an output signal of the joystick shaft. The software template may be based upon the mathematics of super quadratics, and may be one of a square, circular, cross, elliptical and diamond shaped template. The compensation algorithms may also include filtering to reduce the effects of unwanted motions of the joystick shaft. The upper joystick segment may be detachable from the lower joystick segment for facilitating replacement of the lower joystick segment.

The invention yet further provides a method for systematically determining the best mechanical settings and compensatory algorithms to embed in a joystick to offer a user a personal fit and maximum function. The method includes providing the user access to operate the joystick, operatively connecting the joystick to a driving simulator, displaying an icon on the driving simulator, controlling movement of the icon by the joystick, evaluating performance of the user based upon the user's ability to control movement of the icon, and modifying hardware settings and software algorithms for the joystick based upon the evaluation.

For the method described above, modifying hardware settings may include substituting different flexible extensions for varying compliance of a joystick shaft, the extensions being operatively connected to the shaft to encircle the shaft, the extensions further including a frusto-conical cross-section. Modifying the software algorithms may include computing an elliptical dead-zone representative of a joystick shaft at rest, the dead-zone representing a minimum range of forces which must be exceeded to produce motion of an electric powered wheelchair including the joystick mounted thereon, the dead-zone further representing a maximum range of forces which must not be exceeded to prevent movement of the wheelchair. Modifying the software algorithms may include determining an optimal bias axes gain for movement of a joystick shaft in left, right, forward and backward directions. Modifying the software algorithms may include providing at least one software template for at least one of controlling bias of a joystick shaft, decreasing throw of the joystick shaft and reducing degrees of freedom of an output signal of the joystick shaft. The software template may be based upon the mathematics of super quadratics, and may be one of a square, circular, cross, elliptical and diamond shaped template. Modifying at least one of the hardware settings and software algorithms may include obtaining a plurality of joystick shaft inputs corresponding to driving performance of an electric powered wheelchair having the joystick mounted thereon.

Additional features, advantages, and embodiments of the invention may be set forth or apparent from consideration of the following detailed description, drawings, and claims. Moreover, it is to be understood that both the foregoing summary of the invention and the following detailed description are exemplary and intended to provide further explanation without limiting the scope of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate preferred embodiments of the invention and together with the detail description serve to explain the principles of the invention. In the drawings:

FIG. **1** is an illustration of a first embodiment of a variable compliance joystick according to the present invention;

FIG. **2** is an illustration of the variable compliance joystick of FIG. **1**, with the outer housing removed to show the internal components;

FIGS. **3A-3D** are enlarged views of the compliance and dampening components for the variable compliance joystick of FIG. **1**;

FIG. **4** is a graph illustrating sample data for dead-zone calculation with an ellipse superimposed;

FIG. **5** is a graph illustrating power spectral density estimates from data collected while the hand of a user is resting on the shaft of the variable compliance joystick of FIG. **1**, the low-pass filter frequency being shown for both axes;

FIG. **6** illustrates bias axes (x', y') for a particular case in which the bias axes were not orthogonal;

FIG. **7** illustrates sample software templates, with the square template being the default template for the variable compliance joystick of FIG. **1**;

FIG. **8** illustrates virtual driving tasks performed by a user, with the desired path indicated in solid lines and the virtual walls being represented by dashed lines;

FIG. **9** illustrates a user driving an electric powered wheelchair through a virtual environment for the wheelchair driving simulator according to the present invention;

FIG. **10** illustrates a setup for collecting modeling data;

FIG. **11** illustrates an example of a driving task and the corresponding motor graph (unimpaired hand control);

FIG. **12** illustrates a motor graph of the same maneuver of FIG. **11** performed by an individual with cerebral palsy;

FIG. **13** illustrates an output signal produced by the variable gain algorithm;

FIG. **14** illustrates another example of virtual driving tasks performed by a user;

FIG. **15** is an illustration of a second embodiment of a variable compliance joystick according to the present invention;

FIG. **16** is a illustrative sectional view of the variable compliance joystick of FIG. **15**, illustrating the various internal components of the joystick;

FIGS. **17A-17C** are views of the compliance and dampening components for the variable compliance joystick of FIG. **15**; and

FIG. **18** is a cross-sectional view substantially along line **18-18** in FIG. **16**, illustrating the mounting arrangement for the gimbal ring.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings wherein like reference numerals designate corresponding parts throughout the several views, FIGS. **1-14** illustrate components and features of a first embodiment of variable compliance joystick **100** and associated systems according to the present invention, and FIGS. **15-18** illustrate components and features of a second embodiment of variable compliance joystick **200** according to the present invention.

The first embodiment of variable compliance joystick **100** will now be described in detail.

Specifically, as illustrated in FIGS. **1-14**, the present invention provides a variable compliance joystick **100** with mechanical and software customization, and with an integrated control capability, and a method of systematically determining the best mechanical settings and compensatory algorithms to embed in joystick **100** to offer an individual with substantial upper extremity motor impairments a personal fit and maximum function. Generally, variable compliance joystick **100** may be used for driving Electric Powered Wheelchairs, for controlling additional rehabilitation technology, and for other related operations as discussed in detail below.

The aforementioned features of variable compliance joystick **100** and the method of systematically determining the best mechanical settings and compensatory algorithms to embed in joystick **100** will first be broadly described.

With regard to mechanical customization, as discussed in greater detail below, variable compliance joystick **100** may generally be an isometric (force sensing) joystick, and contain an internal micro controller and memory. Joystick **100** may be operable in full isometric mode (no shaft movement), or alternatively, a flexible extension (i.e. a conical elastimer sheathe) may be added to the joystick shaft to create various levels of compliance (motion with spring return). If the flexible extension is hollow and filled with a viscous substance such as stiff modeling clay, a dampening effect may be included as well.

With regard to software customization, as discussed in greater detail below, variable compliance joystick **100** may generally include a reprogrammable internal micro controller for intercepting and modifying the transducer signals generated by the joystick shaft. These transformations will hereinafter be referred to as "compensatory algorithms".

With regard to integrated control capability, as discussed in greater detail below, variable compliance joystick **100** may generally have the ability to operate a personal computer by functioning as a cordless joystick mouse. For example, most current wheelchair joysticks only drive the wheelchair, and separate interfaces must be purchased and mounted if an individual wishes to operate other devices such as a personal computer. Moreover, individuals with impaired hand use may only be able to reach and operate a single control interface, thus forcing them to obtain assistance when changing between devices. Therefore, by providing joystick **100** with the ability to operate a personal computer, in addition to wheelchair driving and computer access, joystick **100** may also be used to access devices such as voice output communication aids, environmental control systems etc.

Lastly, with regard to the method of systematically determining the best mechanical settings and compensatory algorithms to embed in joystick **100** to offer an individual with substantial upper extremity motor impairments a personal fit and maximum function, as discussed in greater detail below, variable compliance joystick **100** may include a Wheelchair-Driving Simulator for determining the best joystick settings. For example, current clinical practice for setting up an Electric Powered Wheelchair joystick is to mechanically mount the joystick on the side of the chair within the user's reach and then have the user practice driving around the clinic floor space. Based solely upon visual observation, the clinician makes changes to the wheelchair controller settings to improve wheelchair manageability. The Wheelchair-Driving Simulator for determining the best joystick settings may generally consist of a stationary wheelchair positioned in front of a large screen computer monitor. While practicing with joystick **100**, the user may "drive" an onscreen wheelchair icon or "sprite" through a series of close-quarter maneuvers. The simulator program running on a desktop PC may monitor the sprite's path and score the driver's maneuvering skill. During the evaluation phase, both the hardware settings and software algorithms of the joystick **100** may be modified to improve the client's driving ability. Hardware compliance and dampening adjustments may be achieved by substituting different extension shafts on joystick **100**. Compensatory algorithms may be invoked by selecting options contained on menus in the driving simulator program. In this manner, a therapist may rapidly try out a variety of mechanical and algorithm settings. The simulator may immediately stage a fresh sprite-driving task and objectively score the benefit of a particular mechanical setting or algorithm. Through this iterative process, the therapist may "fine tune" joystick **100** to the user's motor pattern. When the most useful customizations have been determined, the final extension shaft may remain with the joystick and the final compensatory algorithms may be cross-compiled and downloaded into the joystick's internal micro controller memory, thus providing a user with a personalized joystick.

Variable compliance joystick **100** and the method for systematically determining the best mechanical settings and compensatory algorithms to embed in joystick **100**, will now be described in detail in reference to FIGS. **1-14**.

Specifically, as shown in FIGS. **1** and **2**, variable compliance joystick **100** may be designed such that it would appear similar to a conventional joystick and use commercial mounting and positioning hardware for an electric powered wheelchair. Joystick **100** may be used in full isometric mode or in a variable compliance mode, and include a housing **102** having a shaft **104** including a joystick tip **106** disposed on a top end thereof for operation by a user's fingertip. Shaft **104** may couple joystick tip **106** to an actuator plate fixed to a lower end of the shaft. The actuator plate may include horizontal arms extending radially from shaft **104**, with the number of arms generally equaling the number of discrete force sensors (not shown), with each arm overlying a corresponding sensor.

Joystick **100** may produce a voltage output proportional to the force exerted on shaft **104** by a user, and include printed circuit board **154** designed to fit within housing **102** for providing voltage regulation, bridging direct current excitation, bridging output signal amplification and low-pass filtering of the strain gage bridge signal. Joystick **100** may be operatively connected to an electric powered wheelchair **110**. As with conventional electric powered wheelchairs, wheelchair **110** may operate on a 24 V dc system and use electromechanical parking brakes (not shown) that are normally closed (i.e. fully active) that release when power is applied to the motors. In the embodiment of FIG. **1**, joystick **100** may obtain its power from batteries (not shown) and run on 12 V dc, or half the bus voltage. The output signal may include level shifting in order to be compatible with commercial analog electric powered wheelchair controllers. Alternatively, for digital electric powered wheelchair controllers, joystick **100** may include a serial or parallel port. Joystick **100** may contain an internal microcontroller with memory which uses compensatory algorithms to modify signals generated by the joystick forces on each strain gauge.

In operation, a forward directed force on shaft **104** produces a forward motion of wheelchair **110** with speed proportional to the magnitude of the force. Likewise, a rearward directed force on shaft **104** produces a rearward motion of wheelchair **110** with speed proportional to the magnitude of the force. Left and right forces on shaft **104** are used to turn wheelchair **110** in the direction of the applied force with the rate of turning being proportional to the magnitude of the force. A digital low-pass filter with a cut-off frequency of 6 Hz, for example, may be implemented as the default setting to reduce the effects of vibration and tremor. Joystick **100** may be designed for electric powered wheelchairs that use differential wheel speed to provide directional control. In such wheelchairs, front casters **112** may swivel as wheelchair **110** turns in response to changes in the speed of rear wheels **114**.

As discussed above, joystick **100** may generally include variable compliance and dampening which can be modified to enhance operator control. Variable compliance, which refers to the movement ease and springiness of shaft **104**, generally refers to the spectrum of force versus motion. For example, standard position-sensing joysticks produce output signals proportional to shaft directionality and angle of deflection. These joysticks move freely as no significant spring tension (other than a return spring) is supplied. Examples of common controls that sense position are computer trackballs, sliding volume controls on stereos and doorknobs, all of which are essentially movement driven. A separate set of control technologies exist that respond to force with little or no displacement. As discussed above, these devices are collectively called isometric controls, one of which is the common "eraser head" mouse, which appears in the center of the keyboard on many laptop computers. Another example is the membrane keypad used on microwave ovens to simplify cleaning, in which traditional push buttons are replaced with sealed force-sensing switches. What is not obvious is that position sensing and force-sensing controls merely represent the endpoints of a continuum of control designs. Thus the term variable compliance is used when referring to this spectrum of force vs. motion. For example, mid compliance controls are not common in the home, but are frequently found on motor vehicles. Examples of mid compliance controls include the brake and accelerator pedals on automobiles, or the control stick on an aircraft. Mid range compliance is designed into these controls to provide proprioceptive feedback (tactile sensation through pressure). This is especially important in situations where the operator must visually scan the surroundings and cannot observe the position of the control.

The variable compliance mode for joystick **100** allows motion of shaft **104** with mechanical resistance and spring return to restore shaft **104** to a central position when the operating force is removed. As shown in FIGS. **3A-3D**, compliance may be achieved by adding a flexible extension **136** to joystick shaft **104**. Compliance provides tactile feedback which gives the operator an indication of joystick position, freeing the use of vision for maneuvering wheelchair **110**. While conventional movement sensing and isometric joysticks are actually endpoints of a spectrum, such joysticks contain a continuum of movement/force ratios ranging from low compliance, (high force with very little movement), to high compliance, (low force with substantial movement). Accordingly, variable compliance joystick **100** may include shaft **104** including upper and lower shaft segments **130**, **131**, respectively, joined by a closed coil spring **132**. The upper shaft segment **130** may be drilled and threaded to match the spring wire gage. Therefore, by turning handle **134** counterclockwise, progressively more of spring **132** may be exposed to increase the compliance. For example, as shown in FIG. **3A**, in the full isometric setting, the ends of the two shaft segments **130**, **131** are in contact and fully constrained by the backing flange, thus the spring having no effect. To select a mid range compliance, as shown in FIG. **3B**, the upper shaft segment **130** may be turned several revolutions, thus allowing spring **132** to buckle under load for increasing the amount of movement associated with a given force. Lastly, for the high compliance setting shown in FIG. **3C**, additional spring length may been exposed by further turning handle **134** to allow upper shaft **130** to buckle relative to lower shaft segment **131**. It should be noted that shaft **104** becomes longer as compliance is increased. This increase in length can be compensated by machining a long threaded hole (not shown) inside handle **134** and counter rotating the handle to correct for the length increase.

Dampening refers to the introduction of friction, which varies with the velocity of shaft **104**. Dampening provides an additional mechanical modification that may improve proportional control, especially for individuals with athetoid cerebral palsy. For example, an athetoid movement disorder is characterized by incessant, uncontrolled writhing motions, frequently accompanied by involuntary, explosive bursts of extreme muscular exertion. Accordingly, if an individual with athetosis attempts to operate a conventional proportional joystick, he will uncontrollably slam the stick hard against the stop ring. A damper, as shown in FIG. **3D**, is a frictional device in which the coefficient of friction increases with the velocity of the joystick. If a tremor or athetoid movement is characterized by a higher frequency than volitional movement, a damper will tend to attenuate the unwanted movement while preserving the volitional movement, thus providing a means of increasing the signal to noise ratio. Dampening may be accomplished with pneumatics, viscous fluids, electrorheological fluids, or by electric particle brakes.

In the embodiment of FIG. **3D**, flexible extension **136** (i.e. an elastimer sheathe) disposed around shaft **104** may be provided to act as a variable damper. Flexible extension **136** may provide both compliance and dampening for movement of shaft **104**. For example, in the mid range compliance region for FIG. **3B**, the cross section of extension **136** may be relatively thick and provide the heavier dampening required for the higher spring tension. Variable compliance joystick **100** may further include an elastimer backing flange **138**, a clearance hole **140** and a tapered locking base **142**. An enclosure **144** may be used to encase the various components of joystick **100**. Joystick **100** may further include the following components, including an interface block **146** to mounting tube **148**, an anchor plate **150** for joystick shaft **104**, a cable **152** connectable to a power wheelchair controller (not shown), a printed circuit board **154** for strain gages, user status LCD panel **158**, joystick power switch (push on-push off) **162**, controller interface and user controls printed circuit board **166**, an analog signal conditioning printed circuit board **168**, a digital signal processing printed circuit board **170** and a computer mouse interface printed circuit board **172**. Alternatively, additional dampening may be achieved by filling extension **136** with a viscous substance (such as stiff modeling clay) for providing mechanical dampening of motion.

In operation, as handle **134** is turned counterclockwise toward higher compliances (movement sensing region), as shown in FIG. **3C**, the spring tension decreases. At this stage, the thinner region of flexible extension **136** is engaged and less dampening is imposed on shaft **104**.

As shown in FIG. **3C**, a scale similar to a micrometer thimble may be affixed above flexible extension **136**. Upper shaft **130** may be engraved with ring rulings and a single longitudinal line (not shown) to allow reading and replicating compliance settings. By combining this physically adjustable compliance with the different gain and filter settings discussed below, a variety of unique joystick characteristics may be created.

The method of systematically determining the optimal settings for variable compliance joystick **100** by means of a wheelchair driving simulator will next be described in detail in reference to FIGS. **4-14**. The wheelchair driving simulator illustrated in FIG. **9**, may be used to evaluate the operational characteristics of a user and to adjust software and mechanical parameters of joystick **100** to determine the optimal driving configuration. As discussed in greater detail below, the simulator may use a computer generated rendition of a wheelchair course displayed on a large-screen computer monitor and a stationary wheelchair placed before the monitor. The wheelchair may be fitted with a joystick, but instead of the joystick controlling motion of the wheelchair, the joystick may control the motion of a wheelchair icon on the monitor. The user may guide the wheelchair icon through a series of close-quarter maneuvers. The program may have the ability to load various compensatory algorithms and driving tasks. The therapist running the simulation may add compliance and dampening to the test by attaching different extension shafts to joystick **100**. The simulator may score each driving task, enabling the therapist to determine the optimal mechanical and software configuration for the user. The compensation algorithms may include dead-zone computation joystick at rest). This section includes low-pass filtering to reduce effects of tremor-like motion. The compensation algorithms may further include a determination of optimal bias axes (i.e. left-right, forward-backward), gain for each axis, determining wheelchair speed in each direction, and software templates (i.e. mathematically generated, to control bias, complex shapes generated by changing a single parameter).

Software compensation algorithms may be applied to the signals emanating from the joystick transducers. These can be either an alternative or an addition to the aforementioned mechanical variable compliance or dampening intervention techniques discussed previously.

The three phases (i.e. Phase One, Phase Two and Phase Three) for the optimization of variable compliance joystick **100** will now be described.

Generally, for Phase One, because the fitting of joystick **100** is carried out in a virtual setting, an empirical kinematics database (EKD) of the user's current or "to be prescribed" electric powered wheelchair is preferably obtained and loaded onto the virtual driving system. An EKD characterizes the movement behavior of an electric powered wheelchair as various joystick signals are applied. This data is needed so that the virtual wheelchair image on the simulator can be made to accelerate, decelerate and turn in the same manner as the actual vehicle. For Phase Two, a virtual driving simulator may be used to train the user to effectively control the electric powered wheelchair through an iterative process. The user may be observed driving the virtual wheelchair while performing virtual tasks and the physical (compliance and dampening) and algorithmic (software compensation) parameters of the joystick may be adjusted to maximize the user's driving capability. For Phase Three, the final control parameters chosen during simulation may be embedded into joystick **100** mounted on an actual electric powered wheelchair. The user may be observed driving the physical wheelchair in a wheelchair activities driving laboratory to confirm that the parameters chosen carry over to real world driving.

Specifically, for Phase One, a control fitting evaluation may be conducted using a virtual (computer simulated) environment. The benefits for virtual fitting include opportunities for practice without injury risk, rapid adjustment of control parameters and the ability for a computer to record accurate performance data. The accuracy of the user's driving may be graphically displayed by generating "Motor Graphs" from the computer's stored time-series data.

For Motor Graphs, joystick input forces and movements may be continuously recorded as time-series data while the user drives. As illustrated in FIG. **11**, for the graphical method for displaying these data, the forward and reverse joystick axes are plotted above the graph centerline. The region below the centerline may be used for plotting left and right turns. The height of any plotted segment may represent the magnitude of the force/movement being applied at that moment. Since forward and reverse data, as well as left and right data are mutually exclusive, there is no overlap in the graphs. Graphs, as shown in FIG. **11**, reveal much about an individual's joystick interaction.

Specifically, FIG. **11** illustrates an exemplary driving trial taken from an actual study. During the particular trial for FIG. **11**, an electric powered wheelchair **110** was driven from the starting position to a target 305 centimeters to the right. The user begins by applying strong forward and right forces to joystick **100** to quickly turn the chair about 130 degrees to the right. Approximately halfway through the maneuver, some left turn force was applied to straighten out the chair path and during the last third, forward power was decreased to halt the chair. This particular user had a lumbar spinal cord injury and very little hand impairment.

FIG. **12**, illustrates the control patterns generated by an individual with athetoid cerebral palsy while performing the same trial as for FIG. **11**. The raw signal recorded for FIG. **12** illustrates the many transients are apparent as the user drives. In prior studies where only the motion of the entire wheelchair was tracked, these transient signals would be hidden by the inertia of the chair and driver.

Lastly, FIG. **13** shows the same trial time-series after processing with a basic, variable gain algorithm, where the weaker signals have gain applied and the sharply spiked transients have been substantially attenuated, resulting in considerably smoother driving. It should be noted that this attenuation is not a fixed cut-off value but one that tracks the contours of the operator's original input. This improved signal is sent to the electric powered wheelchair controller. It should also be noted that any of the driving tasks illustrated herein may have motor graphs generated as they are performed. To judge whether a user is able to drive more accurately following an adjustment to one of his compensation algorithms, the user's motor graph may be compared to a graph generated by an electric powered wheelchair driver without movement disorders performing the same maneuver.

In order for the virtual fitting for Phase One to be meaningful, it is essential that an accurate kinematics model of the actual mobility vehicle be obtained. The steering response, acceleration and deceleration of the virtual vehicle must closely match the prescribed real world vehicle.

In order to create an Empirical Kinematics Database for a personal mobility vehicle, the onscreen chair must accelerate, turn and decelerate consistent with the user's actual test chair. As shown in FIG. **10**, the user's chair may be characterized by temporarily mounting friction driven shaft encoders **174** on the drive wheels, a joystick signal generator **176** and a laptop computer **178**. A manikin **180** approximately equal to the user's weight may be strapped into the chair seat. Joystick signal generator **176** may then be activated to execute a prerecorded set of joystick signals covering representative directions and magnitudes. Computer **178** on the rear of chair **110** may record the joystick signals and the encoder data representing the chair's movement responses. From this session, an empirical kinematic database may be calculated.

The onscreen wheelchair image used for virtual driving may be defined with variables to allow the drive wheel diameters, drive wheel span, caster diameters, wheelbase and caster fork offset values to be assigned. To interpret a joystick action entered during virtual driving, the joystick signal may be matched to the two nearest records in the EKD and the shaft encoder data fields read. The virtual motion may be interpolated from these two records.

Continuing with Phase One, kinematic models of popular wheelchairs and scooters may be provided as part of the virtual software, the only adjustment needed would be to correct for the user's weight and possibly a different floor surface, i.e. the user may live in a home with wall to wall carpet.

Thus, for Phase One, a series of basic joystick inputs without feedback as to driving performance in electric powered wheelchair **110** may be optimized. In order to accomplish this, a user may be asked to rest his or her hand comfortably on shaft **104** of joystick **100**. Thereafter, force data in the x and y directions may be collected for a predetermined interval (i.e. 30 seconds) while the user's hand is at rest on the joystick (i.e. no attempt to drive will be made). The user may then be asked to push shaft **104** in the y-direction (i.e. straight ahead) with a light push and hold, moderate push and hold, and maximum push and hold for a minimum period (i.e. 10 seconds each), during which time the forces in the x and y direction may be recorded. The user may then repeat these tasks by pulling in the minus y-direction (i.e. straight back). The user may also be asked to push shaft **104** forward for a predetermined interval (i.e. two minutes) at a force that is comfortable. Next, the user may be asked to exert a force in the plus and minus x-direction (i.e. left and right). The user may be asked to push or pull lightly and hold, moderately and hold, and maximally and hold, in each direction for a predetermined interval (i.e. 10 seconds). The user may also exert a force at a comfortable level in both the left and right directions, each for a predetermined interval (i.e. two minutes). This force data may be used to determine the bias axes, maximum force frequency in the x and y directions, and to set the speed sensitivity. Based upon the force measurements recorded, the optimization software may calibrate the joystick software variables.

As briefly discussed above, the optimization of the variable compliance joystick **100** thus consists of five steps, which involve a series of basic joystick inputs without feedback as to driving performance in the electric powered wheelchair. The steps being, dead-zone calibration, filter frequency determination, bias axis adjustment, software template determination, and fatigue compensation, will now be described in detail.

Specifically, for step one, the resting force data may be used to set the "dead-zone" (i.e. the minimum range of x and y forces that need to be exceeded in order to produce motion of the wheelchair). The dead-zone may be calculated by the following equations:

$$DZ = \underset{a,b}{\operatorname{argmin}}(af_x^2 + bf_y^2) = r^2 \qquad \text{Equation-1}$$

$$f_y^2(k\Delta T) = \theta^T u + e(k\Delta T) \qquad \text{Equation-2}$$

where:

-continued

$$\theta^T = \begin{bmatrix} \frac{a}{b} & \frac{r^2}{b} \end{bmatrix} u = \begin{bmatrix} f_x^2(k_1\Delta T)\ldots & f_x^2(k_N\Delta T) \\ 1\ldots & 1 \end{bmatrix} \qquad \text{Equation-3}$$

Using the least squares criteria:

$$\theta = R^{-1} \times P \qquad \text{Equation-4}$$

where:

$$R = [uu^T] P = [\mu^T f^2{}_y(k\Delta T)] \qquad \text{Equation-5}$$

The variables definitions for Equations 1-5 are listed in Table-1.

Referring to FIG. **4**, the aforementioned equations may be used in an algorithm to calculate the parameters to define an elliptical dead-zone fitted from the data for each user. The parameters that define the ellipse may be increased by 20%, for example, in order to ensure that there is no unintended input to the wheelchair controller, and to ensure that the power wheelchair brakes fully engage when the forces on shaft **104** are within the dead-zone. If the forces on shaft **104** are outside the dead-zone upon start-up of the controller, wheelchair **110** may not move and an error signal may be provided to the user. The user must restart the controller while the forces are in the dead-zone (i.e. lower forces or remove hand from shaft **104**) for the controller to start. This would be a safety feature designed to prevent the wheelchair from lunging when powered-up.

For step two, the data from the resting forces, fore-aft forces, and left-right forces may be used to determine the low-pass filter frequency, for example due to tremor or athetoid motion, in the x and y directions. Independent filters for the x and y forces may use second order digital Butterworth Filters having the following filter frequency:

$$F_y(\text{Hz}) = \min[F_{stop_y}(\text{Hz}), F_{forward_y}(\text{Hz}), F_{reverse_y}(\text{Hz}), F_{left_y}(\text{Hz}), F_{right_y}(\text{Hz})]$$

$$F_x(\text{Hz}) = \min[F_{stop_x}(\text{Hz}), F_{forward_x}(\text{Hz}), F_{reverse_x}(\text{Hz}), F_{left_x}(\text{Hz}), F_{right_x}(\text{Hz})]$$

The variables definitions for the above-identified filter frequency are listed in Table-2.

The optimal cut-off frequencies for the x and y force filters may be chosen as the minimum of the 95% power frequency for each of the test cases. Referring to FIG. **5**, a sample data set displaying the y-directional force in the frequency domain along with the boundary frequency at 95% is displayed. People with upper extremity impairments often have better control in a direction other than the orientation of the joystick axis. Limited ability to accommodate individual bias may be provided by using specialized mounting hardware and an iterative process to determine the most appropriate angle at which to position joystick **100**. Joystick **100** may automatically calculate the bias axes and adjust the force outputs in software.

An additional advantage of the joystick **100** is that the x and y axes do not need to be orthogonal as with current joysticks, hence, individual bias axes may be calculated for the forward and turning axes of wheelchair **110**. Therefore, for step three, the bias axes may be calculated using the following equations, and thereafter adjusted:

Straight Test (forward and reverse):

$$\hat{f}_y(k\Delta T) = m_{straight} f_x(k\Delta T) \qquad \text{Equation-6}$$

Turning Test (left and right):

$$\hat{f}_x(k\Delta T) = m_{turn} f_y(k\Delta T) \qquad \text{Equation-7}$$

Test to measure if axes are orthogonal:

$$C = \frac{\hat{f}(k\Delta T)}{\|\hat{f}_y(k\Delta T)\|} \cdot \frac{\hat{f}_x(k\Delta T)}{|\hat{f}_x(k\Delta T)\|} \qquad \text{Equation-8}$$

The variables definitions for Equations 6-8 are listed in Table-3.

Referring to FIG. **6**, in the above-identified method of calculating the bias axes, the constant C is the dot product of the unit vectors along the direction of the forward-reverse and left-right bias axes. If the bias axis analysis provides viable solutions, software may transform the forward and turning axes for the wheelchair to be aligned with the bias axes. The bias axes may be calculated from the force data obtained when subjects are asked to exert forces fore, aft, left and right at low, moderate, and high levels.

For present isometric joysticks, subjects have reported experiencing fatigue after driving for several minutes with an isometric joystick, due to the individual pushing much harder than is required to attain maximum speed or rate of turning. This problem is most prevalent among people who are fully capable of operating a position-sensing joystick. Therefore, gains may be set by using the mean of the force values in the x and y direction, respectively, during the middle minute (30 seconds to 90 seconds) of the aforementioned two minute session of applying a force at a comfortable level. Gains may be calculated using the following equations:

Initiating the x and y gains:

$$\text{Gain}_y = \frac{\text{Range}_{y_{controller\_input}}}{f_{y_{comfort}} - f_{y_{dead\text{-}zone}}} \qquad \text{Equation-9}$$

$$\text{Gain}_y = \frac{\text{Range}_{x_{controller\_input}}}{f_{x_{comfort}} - f_{x_{dead\text{-}zone}}} \qquad \text{Equation-10}$$

The variables definitions for Equations 9 and 10 are listed in Table-3.

In order to initiate the x and y gains, a linear gain may be used from the joystick forces, along the bias axes, to the wheelchair controller input signals. Alternatively, a non-linear gain function may be used. The gains may be initiated using Equations 9 and 10 above. The software used to tune joystick **100** may permit adjusting the limits for forward and reverse speed, and left and right rate turning by using a sliding bar with a range of 10% to 150% of the initial value.

For step four, software Templates are typically stamped or machined pieces of metal placed over joystick housing **102** to restrict the motion of shaft **104**. Essentially, shaft **104** hits the wall of the template and is restricted from moving further. Templates may be used to control bias, decrease the throw of shaft **104**, or reduce the degrees of freedom of movement thereof. Software templates may be incorporated into joystick **100**, and may be based on the mathematics of super quadratics.

Super quadratics use mathematical equations to describe complex shapes. The math behind super quadratics has its origin in computer graphics and data compression. The benefit of super quadratics is that a sliding bar (i.e. adjusting a single parameter) can be used to adjust the software template shape from a square, circle, cross, ellipse or diamond. Hence, complex templates can be generated for each user of joystick **100** in a simple understandable manner. For the exemplary templates illustrated in FIG. **7**, as the position of the sliding bar changes, the shape of the template may be displayed on a computer screen. A clinician may be allowed to rotate the axes of the template via a sliding bar to improve the user's performance. After the desired template has been selected, it may be downloaded into the memory of joystick **100**. In the exemplary embodiment of FIG. **7**, square, cross, circular and oval templates **118**, **120**, **122** and **124**, respectively, may be used.

Thus for step four, as shown in FIG. **9**, a computer monitor **116** may be moved in front of the user and positioned for optimum viewing. The user may be instructed to track a pseudo-randomly-moving 10 mm square object. The computer may record the user's hand forces/movements and convert them into motor performance graphs. By comparing these graphs, algorithm changes may be selected by the therapist, transformed into the appropriate micro code, and flashed onto the embedded processor's EEPROM memory. The calibration cycle may be repeated up to four times during a during a period of 90 minutes.

Additionally, for step four, the user may perform virtual driving with two different joysticks, each joystick being presented on a separate visit. Joysticks may be selected from a standard movement sensing joystick, a force sensing joystick with a standard algorithm known as Variable Gain Algorithm, variable compliance joystick **100** with the movement sensing personally fitted algorithm and the movement-sensing joystick with the movement sensing personally fitted algorithm. One of the four joystick-algorithm combinations may be randomly selected and mounted. The virtual driving program on the computer may be started, with an investigator presenting selected onscreen driving tasks to the user using a balanced randomization scheme. The computer may track the edge of the virtual electric powered wheelchair silhouette and beep if the user attempts to exceed the boundary. The exemplary tasks may be chosen from the ones illustrated in FIG. **14**. The correct procedure for executing each task may be explained, and the user may be allowed to drive each maneuver with the joystick three times at a relaxed pace for familiarization. The user may be instructed to perform each maneuver as fast as practical without letting the onscreen chair stray over the gray boundary, with the investigator advising the user that driving accuracy is more important than completion speed. The intended path for the onscreen chair may be marked with a dotted line. Using automated data collection software, the computer may record the virtual chair's position and the forces or motions applied

TABLE 5

Gain Scheduling Control Algorithm

$$K = \begin{cases} K_1 = K_{max} - (K_{max} - K_{min})e^{-\alpha T} & F > F_{dead\text{-}zone} \\ K_2 = K_{min} - (K_1 - K_{min})e^{-\beta T} & F \le F_{dead\text{-}zone} \end{cases}$$

Variables	Description
F	The time-varying force sensed by the joystick
$F_{dead\text{-}zone}$	Largest force within the dead-zone
$F > F_{dead\text{-}zone}$	Joystick is being used actively (use eq. K_1)
$F < F_{dead\text{-}zone}$	Joystick is inactive (use eq. K_2)
α	Fatigue rate tuned for individual user, the rate of increase when the joystick is active
β	Recovery rate tuned for individual user
K_{max}	Maximum gain set for individual user
K_{min}	Baseline gain; no fatigue compensation.
T	Recovery time, duration while joystick is inactive.

by the user to the joysticks may be recorded. Additionally, time required to complete each maneuver in milliseconds and the number of boundary violations may be recorded. Users may perform forty eight trials, for example, for data collection in a session lasting about seventy minutes (i.e. one joystick, times six driving maneuvers, times eight presentations of each maneuver).

Thereafter, for step five, some diseases and disorders result in substantial changes in motor strength and control during the course of a day. Thus, another advantage of a micro controller managed joystick, is that in addition to employing corrective algorithms to compensate for movement disorders, a change in sensitivity may be programmed to take place over time. To determine the changes brought on by fatigue, users may be asked to repeat the virtual driving testing protocol at 10:00 am, 12:00 pm, and 2:00 pm, for three sessions in a virtual laboratory.

As users perform the virtual tasks for Phase Two above, those prone to fatigue would be expected to exhibit progressively "flatter" motor graphs in the later task iterations. The joystick's microcontroller may be used to log cumulative force-time activity (a cumulative integral) as a user performs successive trials. All forces may be logged as absolute values. For each user, parameters alpha and beta for the fatigue-scheduling algorithm depicted in Table-5 may be established.

This would constitute the gain intervention, which may be superimposed on the user's other algorithm compensation. As the amount of uninterrupted joystick usage accumulates, the gain may be increased until a point of diminishing returns occurs (K_{max}). If the gain is raised too high, tremor or other unintentional movement may be amplified to the point of becoming the limiting factor. A fatigue recovery algorithm may also be included based on the assumption that if the user stops driving and receives a rest break, the gain can be backed off. After a specified period, i.e. eight hours of inactivity, the fatigue gain compensation may be reset and only the customized algorithms used. By logging the accumulated force-time integral and including a recovery algorithm, individuals may be able to drive in the community in the future with an optimum gain setting throughout the day.

Lastly, for Phase Three, a user may drive his/her personal electric powered wheelchair in an indoor and outdoor driving course known as The Wheelchair Driving Activities Laboratory (WDAL). The WDAL has been used in several previous studies performed herein to effectively evaluate new assistive technologies, especially wheelchairs and wheelchair controls, prior to evaluation in the "real-world". The WDAL includes indoor driving skills for driving in environments including as tile flooring, carpeting, a door threshold, a doorway, a hallway, model bathroom, and model kitchen. The WDAL outdoor driving tasks include an ADA ramp, bus docking area, curb-cut, sidewalk, and decking material. Users may be tested on all of these activities. Each user may be given the opportunity to practice each of the driving tasks, but not to practice the test course. After a maximum of one-half hour of practice in the WDAL, users may undergo the testing protocol. A study clinician may be given the option to tune the algorithms during the respective practice sessions using the same procedure as in Phase Two. At the completion of a practice session, a study therapist or rehabilitation engineer may rate each user as being either safe or unsafe in performing each driving task. If a user performs all of the driving tasks safely, than they would progress to the testing phase. Users who are judged unsafe may have a maximum of two, one-hour remedial training sessions prior to testing, otherwise they may be discontinued.

The hardware for implementing the aforementioned method of systematically determining the optimal settings for variable compliance joystick **100** will next be described in detail. Specifically, the setup for algorithm optimization for joystick **100** may include a computer monitor **116**, for displaying virtual driving tasks on a wheelchair dynamometer. The driving tasks may be presented on monitor **116**, and users may receive real-time feedback of their driving by viewing the sprite on the monitor screen. The motion of the sprite may be proportional to the actual rotation of the wheelchair wheels on the dynamometer.

Referring to FIG. **8**, the sprite may flash and change color when it contacts a wall, and a running total of wall hits may be displayed on the screen of monitor **116**. The driving tasks may be performed while driving forwards and then repeated while driving backwards for a total of eight driving trials (i.e. 4 tasks×2 orientations). The driving tasks may be presented in the following order: (1) straight hallway, (2) left turn, (3) right turn, and (4) docking. Based upon previous studies, these tasks are preferred since they have been demonstrated to elicit differences in the driving performance of a wheelchair. The driving task order may be selected to allow user to learn with simple tasks and progress to more complex tasks.

Joystick **100** may start with the software in the default setting (all speed and directional setting at their minimum, and the virtual template set as a cross aligned with the x and y axes). While users are performing the driving tasks with joystick **100**, a study investigator may tune joystick **100** parameters (i.e. speed limits, turning limits, and the shape and orientation of the software template) to optimize each user's performance. A licensed therapist specializing in Assistive Technology or a rehabilitation engineer may observe each user while driving in the virtual environment. At the completion of each task, a study therapist may rate each user as either being safe or unsafe in performing the task. Users may move into the performance analysis process once they are able to perform all of the virtual driving tasks safely. If a user is unable to perform all of the virtual driving tasks with a safe rating within a predetermined time period (i.e. 30 minutes), the optimization process may be suspended. In order to determine the safety of joystick **100**, the joystick may be tested for compliance ISO 7176-14, a regulation for specifying the operation of control devices for use on electric powered wheelchairs. Both normal operation and foreseeable misuse may be tested in ISO 7176-14. This standard includes bench tests (i.e. low voltage operation, over voltage protection, connector quality) and driving performance tests (i.e., braking, acceleration).

In order to compare the virtual driving to driving in a controlled environment, a computerized tracking system may be used to evaluate the use of devices for control of electric powered wheelchair **110**. In a clinical study conducted herein, joystick **100** including compensation algorithms was compared to a conventional position-sensing joystick. The manual performance of each joystick was measured for five inexperienced electric powered wheelchair users and five experienced electric powered wheelchair users who have tetraplegia. The users with tetraplegia, aged 32 to 50, had spinal cord injuries or dysfunctions at level C4-C6. Each used an electric powered wheelchair **110** as their primary means of mobility, using a position sensing joystick by hand. Each joystick had a similar housing and handle, and each joystick was mounted in a position preferred by the user. A computer (not shown) recorded the speed of each wheel, computed the virtual position and orientation, and displayed this information on the screen in real-time. All users used conventional handles except for one user with tetraplegia, who used a

T-shaped handle since he was unable to use the knot handle. The users used an electric powered wheelchair while stationary on a wheelchair dynamometer to simulate inertial effects. Operating the electric powered wheelchair with each joystick, the users followed two-dimensional driving tasks displayed on a computer monitor. A moving sprite displayed virtual motions of the electric powered wheelchair. The root mean square error (rmse) was computed as users followed a series of driving tasks while following a pre-defined desired path. A paired t-test ($p<0.05$) showed no significant differences in the root mean square error between the two joysticks. Each user demonstrated acceptable, comparable tracking performance using each joystick. Ten unimpaired users and ten users with tetraplegia, who used position sensing joystick controlled electric powered wheelchairs for their mobility, participated in a clinical study to compare the use of a conventional position-sensing joystick and variable compliance joystick **100**. Using each joystick, tracking errors were measured while users perform computerized tracking and actual driving. Results indicated that joystick **100** and the conventional position-sensing joystick provide statistically comparable electric powered wheelchair control for both groups during both virtual driving and driving activities laboratory tasks.

Prior to developing the compensation algorithms, joystick **100** with Compensation Algorithms was tested against existing wheelchair standards, and compared to a commercial position sensing joystick. When averaged across all users (both controls and impaired users), the root mean square tracking error and time to complete the driving course constructed on a level asphalt parking lot were not significantly different (i.e. $p<0.05$) for the two joysticks. Results within a user, however, did show significance. Across all users, nevertheless, joystick **100** was superior to the conventional position sensing joystick for two tasks: driving straight and driving in a circle.

In another study performed herein, Fitts' Law for target acquisition was extended to a continuously updated target. The extended Fitts' Law was used to examine electric powered wheelchair driving with a conventional position sensing joystick and variable compliance joystick **100**. The test results showed significant differences ($p<0.05$) among the two types of joysticks for selected measures of information processing capacity, movement time, root mean square error, and average velocity while performing turning maneuvers. The mean values indicated that variable compliance joystick **100** provides superior turning and close quarter (i.e. indoor) performance.

In summarizing variable compliance joystick **100** described above may be mechanically configurable and include variable compliance to full isometric to be adapted for best use by a user, and/or include dampening to reduce effects of unwanted motion. Joystick **100** may incorporate compensation algorithms, including a dead-zone for determining an elliptical area where joystick **100** ignores input, and filtering to reduce effects of tremors and other spurious motions. Moreover, the axes of motion need not be orthogonal, thus enabling the finding of the best directions for forward, reverse, left and right directions. Joystick **100** may also include software templates of various shapes generated with a single parameter. Joystick **100** may be used with the wheelchair simulator discussed above for facilitating the matching of joystick mechanical and software parameters to individual users.

One of ordinary skill in the art will appreciate in view of this disclosure that the wheelchair simulator disclosed herein may have application to other vehicles, such as cars, scooters, remotely controlled vehicles and for robotics.

The second embodiment of variable compliance joystick **200** will now be described in detail with reference to FIGS. **15-18**. It should be noted that the features and methods discussed above with reference to FIGS. **4-14** for joystick **100** are likewise applicable to joystick **200**, as would be readily apparent to those skilled in the art.

Turning now to FIGS. **15-18**, joystick **200** may include a housing (not shown) similar to housing **102**, and shaft **204** having a handle **206** at an upper end thereof. An open center gimbal **208** may be provided for further stabilizing the bending of flexible extension **250** (similar to flexible extension **136** of the first embodiment). Gimbal **208** may include hollow gimbal ring **210**, including pivotally mounted yoke legs **212** at pivot pins **276**; the yoke legs being further affixed to circular yoke column **214**. As shown in FIG. **18**, yoke legs **212** may be disposed in suitable apertures **274** in ring **210**. Gimbal ring **210** may be further pivotally mounted on bushings **272** whose journals **270** may be permanently attached to the walls of enclosure **260**. As also illustrated in FIG. **18**, journals **270** may be crescent shaped. Consequently, gimbal ring **210** pivots about bushings **272** and yoke legs **212** pivot on pins **276**, thus creating a universal joint arrangement for pivotal movement of joystick shaft **204**. An index bushing **216** may be rotatably affixed to handle **206** for adjusting the compliance of joystick **200**, as will be discussed in greater detail below.

A locking spring plunger **218** may be biased into the engaged configuration illustrated in FIG. **16** by means of spring **220** to lock rotatable index bushing **216** with yoke cap **222**, and thus prevent joystick compliance adjustment. As illustrated in FIG. **16**, plunger **218** may include a pin **224** disposable within a complementary hole (not shown) in index bushing **216** to operatively connect yoke cap **222** with index bushing **216** and thereby prevent rotation of index bushing **216**.

Handle **206** may include a bore having internal threads **226** for mounting onto externally threaded stud **228**, which includes complementary threads **230** for engagement with threads **226** and is fixedly mounted to index bushing **216**. Handle **206** may thus rotate index bushing **216** via the fixed mounting thereof to stud **228**.

Index bushing **216** may include a bottom index adjustment section **232** including an externally threaded section **234** and internally threaded section **236**. Threads **238** of externally threaded section **234** may be disposed in engagement with complementary threads **240** of cylindrical chamber column **242**, which may axially translate relative to yoke column **214**. Threads **244** of internally threaded section **236** may be disposed in engagement with complementary threads **246** of drive stud **248**. Threads **238** and **244** may be configured such that rotation of handle **206** in a clock-wise direction (when viewed from the top of the joystick) allows for upwards axial translation of stud **248** and downwards translation of chamber column **242**, and vice-versa for opposite rotation of handle **206**. As shown in FIG. **17A**, axially extending splines **249** may be provided on the internal wall of column **242** for engagement with complementary axial grooves (not shown) in the outer wall of retainer **252** for preventing either column **242** or the retainer **252** from rotating relative to each other, while allowing relative axial translation of column **242** and retainer **252**.

In the particular embodiment illustrated, index bushing **216** may include male threads **238** in the form of ½"×20 left hand threads for mating with complementary female threads **240** of column **242**. Further, index bushing **216** may include female threads **244** in the form of ¼"×20 right hand threads for mating with complementary male threads **246** of drive stud **248**.

Stud **248** may be fixedly affixed to flexible extension **250** disposed at a lower end of the shaft. Extension **250** may be made of an elastimeric or polyurethane material. As illustrated in FIG. **16**, extension **250** may be mounted at a first end thereof to stud **248** by means of retainer **252** and held within bushing **254** for controlling the bending thereof. Extension **250** may be bonded, or otherwise fixedly attached, at its second opposite end to sleeve **256**. Sleeve **256** may be dimensioned to closely fit but slide freely over isometric post **258**.

The entire assembly including gimbal assembly **208**, yoke column **214**, extension **250** and isometric post **258**, including the various sub-components operable therewith, may be substantially enclosed within enclosure **260**, which includes internally tapered stop ring **262** at an upper end thereof and further includes an enclosure base **264** at a lower end thereof. Stop ring **262** essentially limits the extent of pivotal movement of the joystick shaft **204** by virtue of its engagement with the outer surface of yoke column **214**. Isometric post **258** may be utilized for controlling joystick **200** in a similar manner as joystick **100**.

In operation, referring to FIGS. **16-17**, as briefly discussed above, compliance of joystick **200** may be adjusted by first disengaging locking spring plunger **218** from index bushing **216** by pulling plunger **218** to retract pin **224** from the hole in bushing **216**. Handle **206** may now be rotated to vary the compliance of joystick **200**.

Specifically, as shown in FIG. **17**A, joystick **200** is illustrated in a maximum compliance configuration, as opposed to medium compliance for FIG. **17**B and minimum compliance for FIG. **17**C. In the maximum compliance configuration of FIG. **17**A, handle **206** may be rotated counter-clockwise (when viewed from the top of the joystick) to its maximum counter-clockwise rotatable position to provide maximum downwards axial translation of stud **248** and maximum upwards translation of chamber column **242**. Concurrently with the translation of stud **248** and column **242**, sleeve **256** may likewise travel relative to isometric post **258**, and in the particular embodiment illustrated, extension **250** may be disposed in contiguous engagement with post **258**. Further, in the particular embodiment illustrated, the position of FIG. **17**A provides an exposed extension length L1 of approximately 1.0". Thus as extension **250** is disposed outside of the chamber defined by column **242**, the maximum amount of extension **250** is available for bending. In the position of FIG. **17**A, it can be seen that enclosure **260** having gimbal assembly **208** disposed therein limits pivotal movement of joystick shaft **204**, thus providing an additional means for controlling bending of extension **250**.

In order to reduce the compliance of joystick **200**, referring to FIG. **17**B, handle **206** may be rotated clockwise (when viewed from the top of the joystick) to an intermediate rotatable position to allow upwards axial translation of stud **248** and downwards translation of chamber column **242**. Concurrently with the translation of stud **248** and column **242**, sleeve **256** may likewise travel upwards relative to isometric post **258**, such that extension **250** is no longer in contiguous engagement with post **258**. In the particular embodiment illustrated, the position of FIG. **17**B provides an exposed extension length L2 of approximately 0.650". As extension **250** is now disposed within the chamber defined by column **242**, a smaller amount of the exposed extension is available for bending.

Lastly, in order to further reduce the compliance of joystick **200**, referring to FIG. **17**C, handle **206** may be rotated clockwise (when viewed from the top of the joystick) to a maximum clockwise rotatable position to provide maximum upwards axial translation of stud **248** and maximum downwards translation of chamber column **242**. In this arrangement, the top surface of retainer **252** is disposed in contact with the inwardly facing section of column **242**, as shown in FIG. **17**C. Concurrently with the translation of stud **248** and column **242**, sleeve **256** may likewise travel upwards relative to isometric post **258**. In the particular embodiment illustrated, the position of FIG. **17**C provides an exposed extension length L3 of approximately 0.40". As the maximum length of extension **250** is now disposed within the chamber defined by column **242**, the smallest amount of the exposed extension is available for bending, while still providing compliance for joystick **200**.

For the embodiments of FIGS. **14-17**, compared to joystick **100** of the first embodiment, joystick **200** allows extension **250** to generally remain centered about the pivot axis X of gimbal **208** through the entire compliance adjustment thereof, as well as during subsequent use. Further, yoke cap **222**, which includes internal threads **266** engaged with complementary threads **268** of yoke column **214**, can be simply screwn onto column **214** for assembly and further unscrewn from column **214** for replacement of the entire assembly for extension **250** with a polyurethane rod of different durometer. This replacement feature extends the potential range of compliance options for joystick **200**.

In summarizing, variable compliance joystick **200** described above may be mechanically configurable and include variable compliance to full isometric to be adapted for best use by a user, and/or include dampening to reduce effects of unwanted motion. As discussed above for joystick **100**, joystick **200** may incorporate compensation algorithms, including a dead-zone for determining an elliptical area where joystick **200** ignores input, and filtering to reduce effects of tremors and other spurious motions. Moreover, the axes of motion need not be orthogonal, thus enabling the finding of the best directions for forward, reverse, left and right directions. Joystick **200** may also include software templates of various shapes generated with a single parameter. Joystick **200** may be used with the wheelchair simulator discussed above for facilitating the matching of joystick mechanical and software parameters to individual users.

Joystick **200** is further beneficial in that virtually all bending takes place at the center of flexible extension **250**, and the center of extension **250** is consistently maintained at the mechanical center (i.e. the intersection) of the gimbal axis X. It should be noted that while an index bushing **216** including internal/external threads is illustrated in operative engagement with threaded stud **248** and column **242**, any mechanism may be employed so as to change the length of flexible extension **250** while simultaneously longitudinally displacing extension **250** so that the center of the altered extension length remains centered with the intersection of the gimbal axis X. Such mechanisms may include a variety of gear/worm arrangements, or other automatic means for displacing extension **250** and column **242**. The present invention thus provides a mechanical means of adjusting extension **250** with concurrent realignment to provide a continuous range of elastic compliance while maintaining a balanced buckling extension.

One of ordinary skill in the art will appreciate in view of this disclosure that the wheelchair simulator disclosed herein may have application to other vehicles, such as cars, scooters, remotely controlled vehicles and for robotics. As evident for joystick **100**, joystick **200** may likewise be used for wheelchair control, as discussed above, or for control of other applications such as for computer pointing application (mouse). Although particular embodiments of the invention have been described in detail herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to those particular embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention as defined in the appended claims.

TABLE 1

Dead Zone Algorithm

Symbol	Definition
DZ	Dead Zone
fy	Force in the Y direction
fx	Force in the X direction
a	Regression parameter derived for subject along X-axis
b	Regression parameter derived for subject along X-axis
r	Virtual radius
k	Count 1, 2, 3, 4 . . . N
T	Sampling rate

TABLE 2

Filter Frequency Algorithm

Symbol	Definition
Hz	Frequency in Hertz
Fx	Force amplitude in the frequency domain
Fy	Force amplitude in the frequency domain
F_{stop_x}	Conditions when data was
$F_{forward_x}$	collected - X-axis
$F_{reverse_x}$	
F_{left_x}	
F_{right_x}	
F_{stop_y}	Conditions when data was
$F_{forward_y}$	collected - Y-axis
$F_{reverse_y}$	
F_{left_y}	
F_{right_y}	

TABLE 3

Bias Axis Algorithm

Symbol	Definition
$\hat{f}_y$	Regression line for F_y on Y-axis
$\tilde{f}_x$	Regression line for F_x on X-axis
$m_{straight}$	Regression constant for straight test
m_{turn}	Regression constant for turn test
C	Result of the dot product of the skewed axes
$\frac{\hat{f}_x(k\Delta T)}{\|\hat{f}_x(k\Delta T)\|}$	Unit vector along skewed X-axis
$\frac{\hat{f}_y(k\Delta T)}{\|\hat{f}_y(k\Delta T)\|}$	Unit vector along skewed Y axis

TABLE 4

Gain Algorithm

Symbol	Definition
$f_{x_{comfort}}$	User specific level of comfortable effort X-axis
$f_{y_{comfort}}$	User specific level of comfortable effort Y-axis

TABLE 4-continued

Gain Algorithm

Symbol	Definition
$Range_{x_{controller\_input}}$	Range of signal the A/D accepts on X-axis
$Range_{y_{controller\_input}}$	Range of signal the A/D accepts on Y axis
$f_{x\ dead\text{-}zone}$	Maximum of the X-axis dead zone
$f_{y\ dead\text{-}zone}$	Maximum of the Y-axis dead zone

What is claimed is:

1. A joystick apparatus comprising:

a joystick shaft having a predetermined length, and including upper and lower joystick segments operatively connected to each other, said lower joystick segment being substantially flexible and movable relative to said upper joystick segment to vary compliance of said joystick shaft without substantially changing said predetermined length.

2. A joystick according to claim **1**, wherein said upper joystick segment having a longitudinal axis, said joystick further comprising a gimbal assembly substantially surrounding a length of said lower joystick segment for generally maintaining said lower joystick segment in a predetermined extended orientation relative to said longitudinal axis.

3. A joystick according to claim **1**, wherein said upper joystick segment includes a handle mounted to an index bushing including internal threads along a length thereof, a drive stud operatively connected to said lower joystick segment and further including external threads operatively engaged with said internal threads such that rotation of said handle in first and second opposite rotational directions respectively moves said lower joystick segment toward and away from said upper joystick segment to vary the compliance of said shaft.

4. A joystick according to claim **1**, wherein said upper joystick segment includes a handle mounted to an index bushing including external threads along a length thereof, a chamber column including internal threads operatively engaged with said external threads such that rotation of said handle in first and second opposite rotational directions respectively moves said chamber column away from and toward said upper joystick segment to vary the compliance of said shaft by reducing a bendable length of said lower joystick segment.

5. A joystick according to claim **1**, wherein said upper joystick segment includes a handle mounted to an index bushing including internal and external threads along a length thereof, a drive stud operatively connected to said lower joystick segment and further including external threads operatively engaged with said index bushing internal threads, and a chamber column including internal threads operatively engaged with said index bushing external threads, such that rotation of said handle in first and second opposite rotational directions respectively moves said lower joystick segment toward and away from said upper joystick segment, and further respectively moves said chamber column away from and toward said upper joystick segment to vary the compliance of said shaft by reducing a bendable length of said lower joystick segment.

6. A joystick according to claim **5**, further comprising a spring biased locking plunger selectively engageable with said index bushing for allowing and preventing rotation of said index bushing when respectively disengaged from and engaged with said index bushing.

7. A joystick according to claim **1**, wherein said upper joystick segment includes index bushing means operatively connected to drive stud means such that rotation of a handle of said upper joystick segment in first and second opposite rotational directions respectively moves said lower joystick segment toward and away from said upper joystick segment to vary the compliance of said shaft.

8. A joystick according to claim **1**, wherein said upper joystick segment includes index bushing means operatively connected to chamber column means such that rotation of a handle of said upper joystick segment in first and second opposite rotational directions respectively moves said chamber column means away from and toward said upper joystick segment to vary the compliance of said shaft by reducing a bendable length of said lower joystick segment.

9. A joystick according to claim **2**, wherein said gimbal assembly includes a gimbal ring operatively connected to said upper joystick segment, said gimbal ring having said lower joystick segment disposed therethrough, said gimbal assembly further being disposed within an enclosure for limiting pivotal movement of said joystick shaft by substantially enclosing said upper joystick segment within an opening in said enclosure.

10. A joystick according to claim **9**, wherein said gimbal ring being pivotally mounted within said enclosure for pivotal movement about a first axis of rotation, said upper joystick segment being pivotally mounted to said gimbal ring by at least two yoke legs for rotation about a second axis of rotation substantially orthogonal to said first axis of rotation for thereby enabling substantially universal pivotal movement of said upper joystick segment relative to said lower joystick segment.

11. A joystick according to claim **1**, wherein said lower joystick segment being slidably connected to an isometric post, for controlling said joystick, by a sleeve fixedly mounted to said lower joystick segment and further slidably disposed around said isometric post.

12. A joystick according to claim **1**, wherein said joystick includes integrated control capability for operating multiple assistive devices.

13. A joystick according to claim **1**, wherein said joystick is operatively mounted on an electric powered wheelchair for allowing a user to operate multiple assistive devices.

14. A joystick according to claim **1**, further comprising compensation algorithms including an elliptical dead-zone representative of said joystick shaft at rest, said dead-zone representing a minimum range of forces which must be exceeded to produce motion of an electric powered wheelchair including the joystick mounted thereon, said dead-zone further representing a maximum range of forces which must not be exceeded to prevent movement of the wheelchair.

15. A joystick according to claim **1**, further comprising compensation algorithms including a determination of an optimal bias axes gain for movement of said joystick shaft in left, right, forward and backward directions.

16. A joystick according to claim **1**, further comprising compensation algorithms including at least one software template for at least one of controlling bias of said joystick shaft, decreasing throw of said joystick shaft and reducing degrees of freedom of an output signal of said joystick shaft.

17. A joystick according to claim **16**, wherein said software template is based upon the mathematics of super quadratics.

18. A joystick according to claim **17**, wherein said software template is one of a square, circular, cross, elliptical and diamond shaped template.

19. A joystick according to claim **1**, further comprising compensation algorithms including filtering to reduce the effects of unwanted motions of said joystick shaft.

20. A joystick according to claim **1**, wherein said upper joystick segment is detachable from said lower joystick segment for facilitating replacement of said lower joystick segment.

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