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Edgerton et al.

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(54) **METHOD, APPARATUS AND SYSTEM FOR AUTOMATION OF BODY WEIGHT SUPPORT TRAINING (BWST) OF BIPED LOCOMOTION OVER A TREADMILL USING A PROGRAMMABLE STEPPER DEVICE (PSD) OPERATING LIKE AN EXOSKELETON DRIVE SYSTEM FROM A FIXED BASE**

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(22) Filed: **Aug. 21, 2000**

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(51) **Int. Cl.**^{7} **A61B 5/00**

(52) **U.S. Cl.** **600/587**; 600/595; 73/379.01

(58) **Field of Search** 482/1–9, 900–902; 600/587, 595; 73/379.01–379.03

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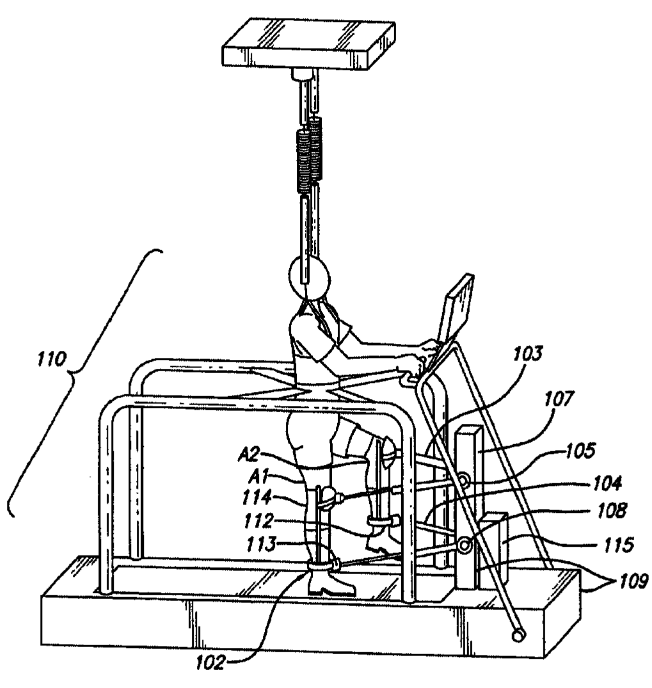
(57) **ABSTRACT**

A robotic exoskeleton and a control system for driving the robotic exoskeleton, including a method for making and using the robotic exoskeleton and its control system. The robotic exoskeleton has sensors embedded in it which provide feedback to the control system. Feedback is used from the motion of the legs themselves, as they deviate from a normal gait, to provide corrective pressure and guidance. The position versus time is sensed and compared to a normal gait profile. Various normal profiles are obtained based on studies of the population for age, weight, height and other variables.

27 Claims, 8 Drawing Sheets



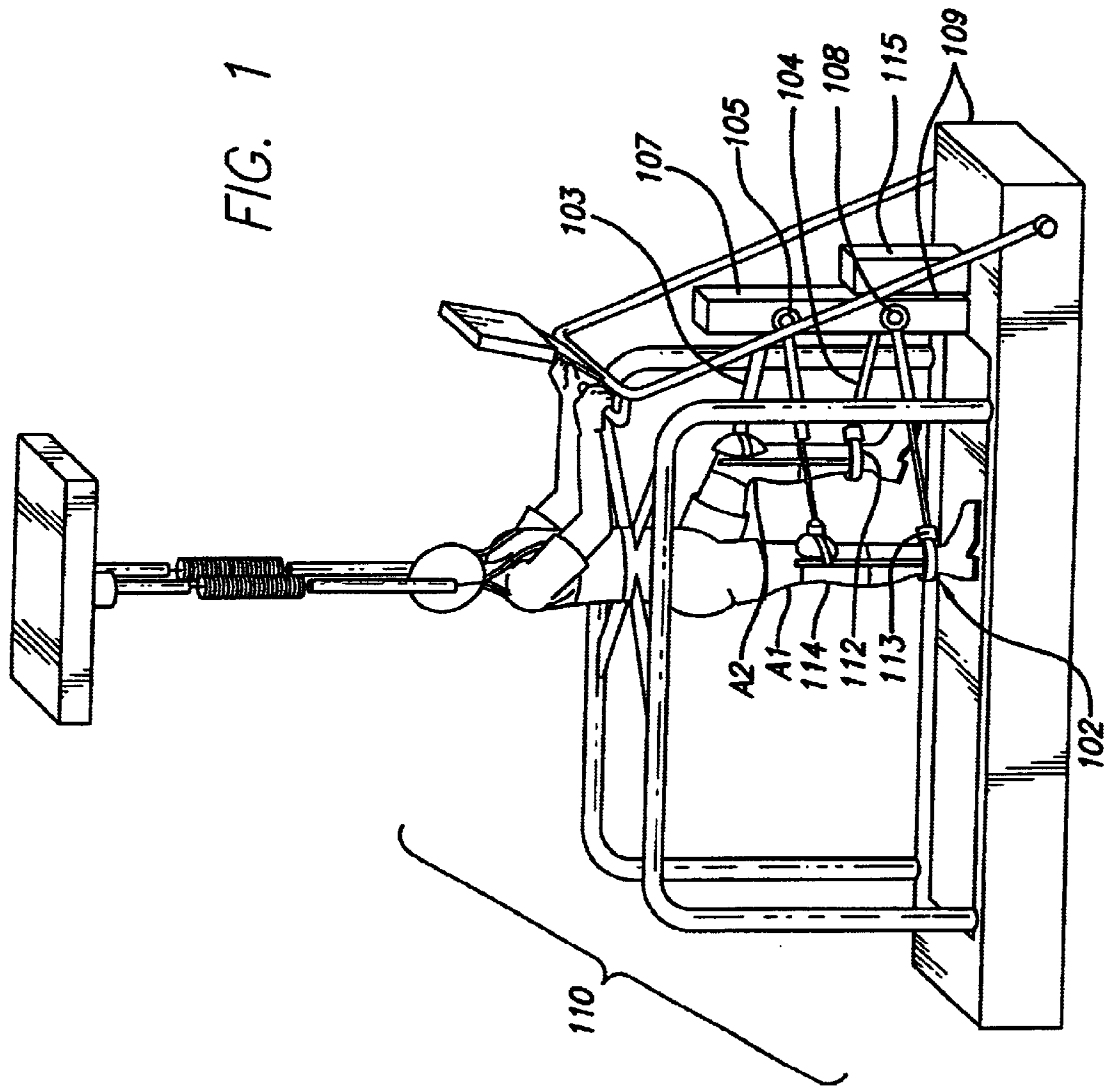


FIG. 1

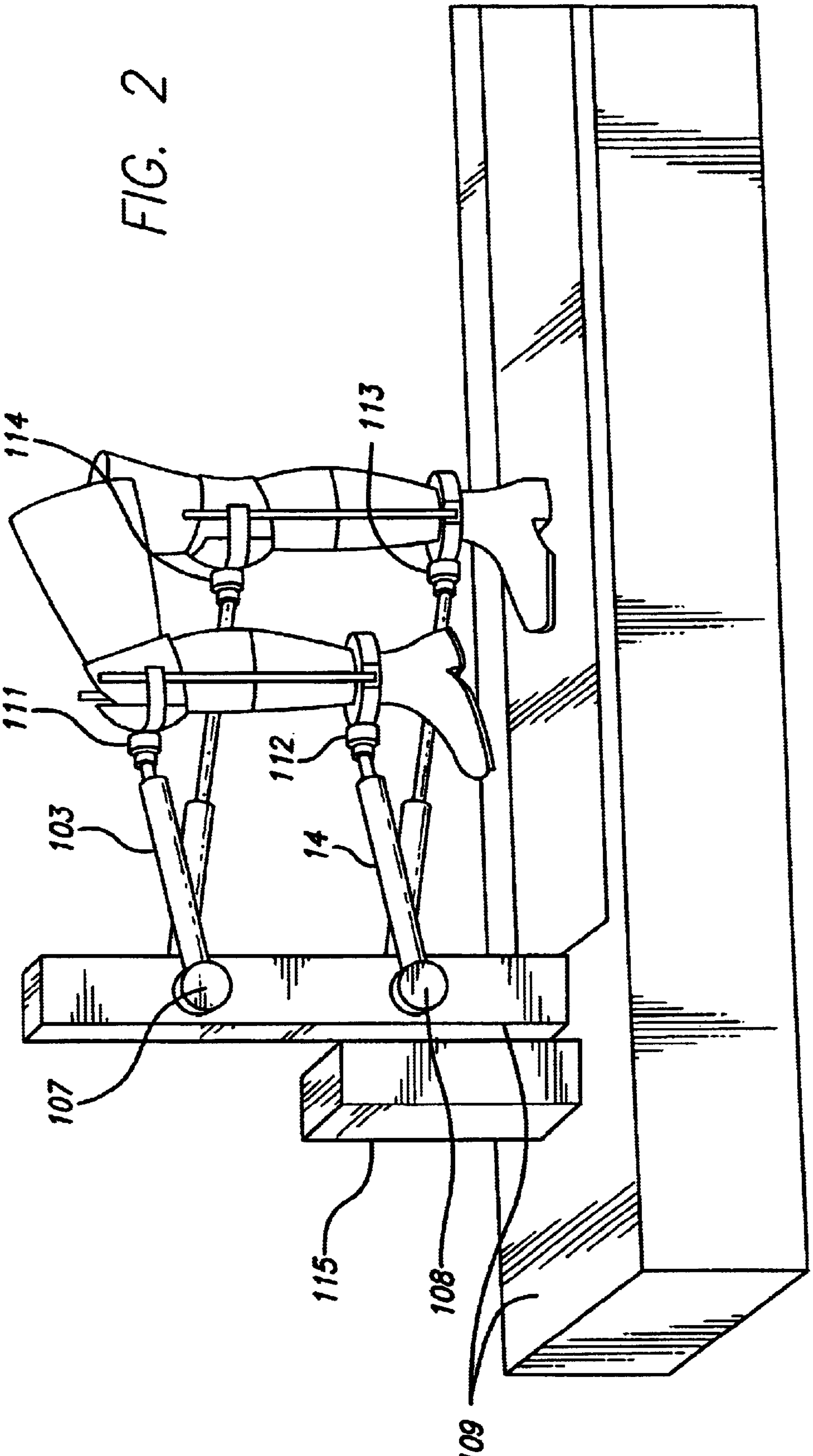


FIG. 2

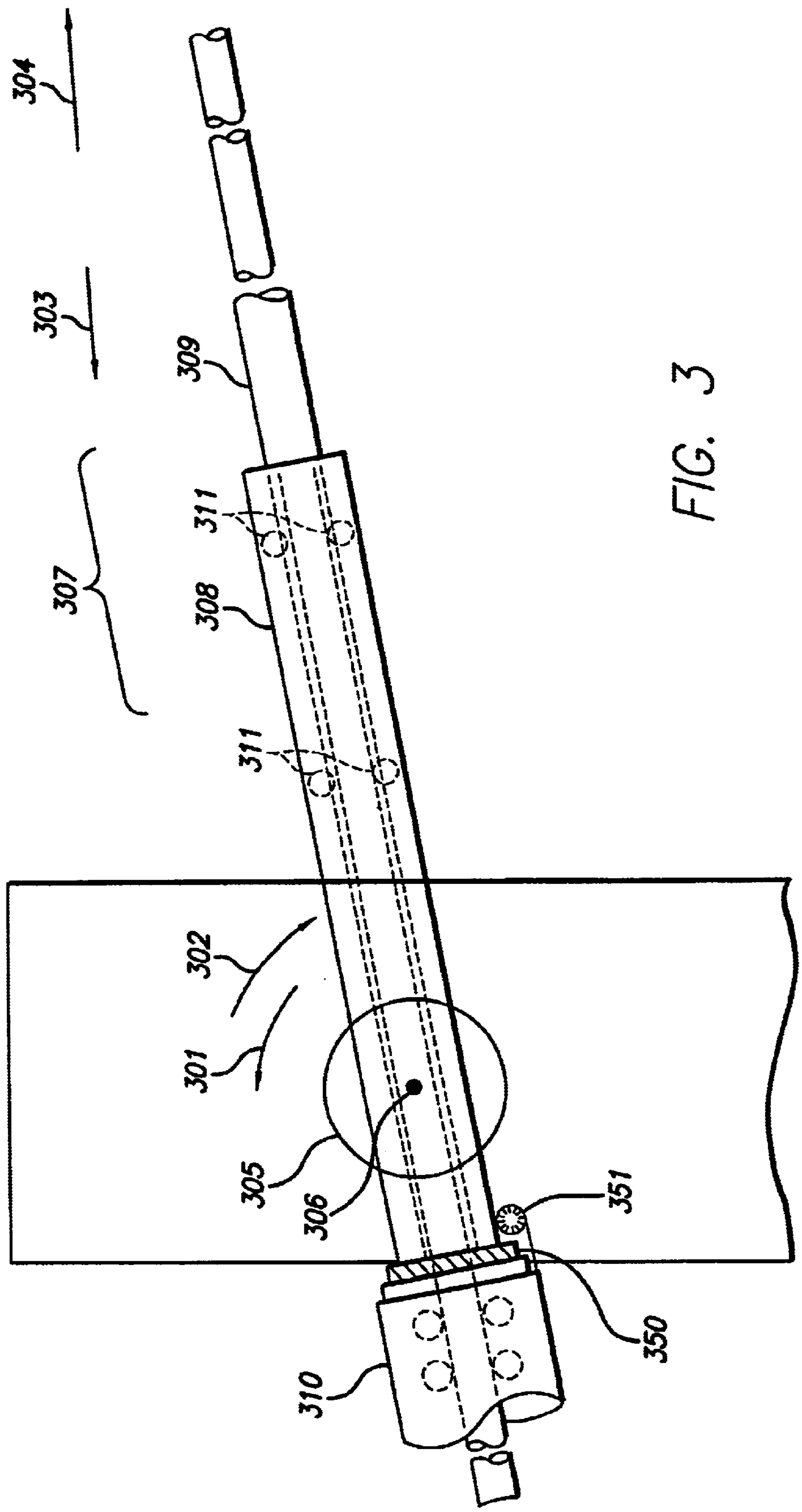


FIG. 3

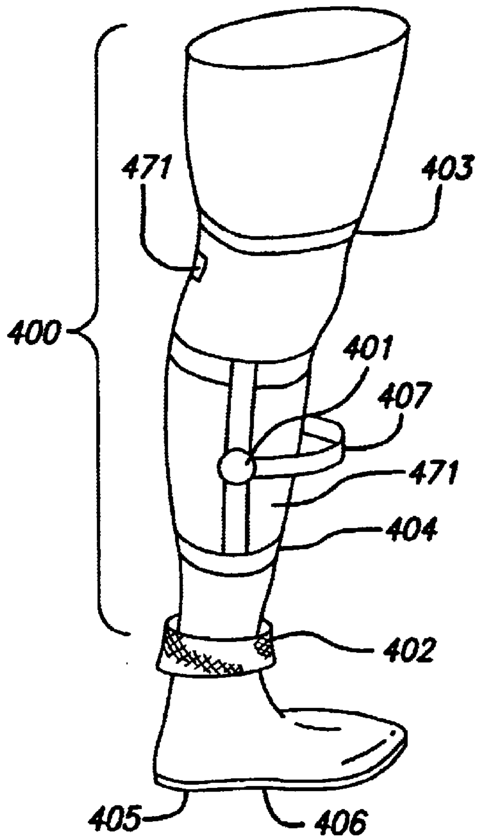

471
403
400
401
407
471
404
402
405
406

FIG. 4A

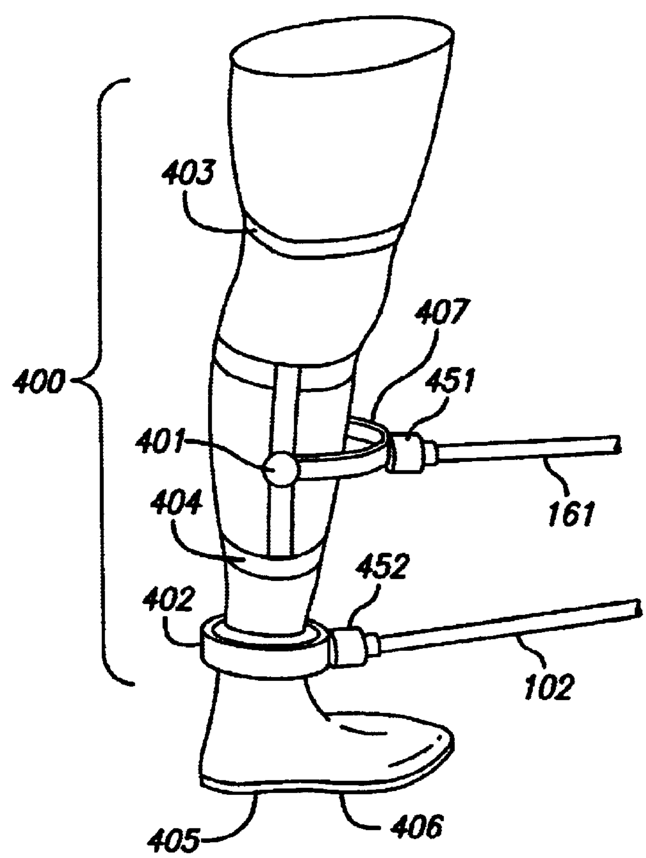

403
407
451
400
401
161
404
452
402
102
405
406

FIG. 4B

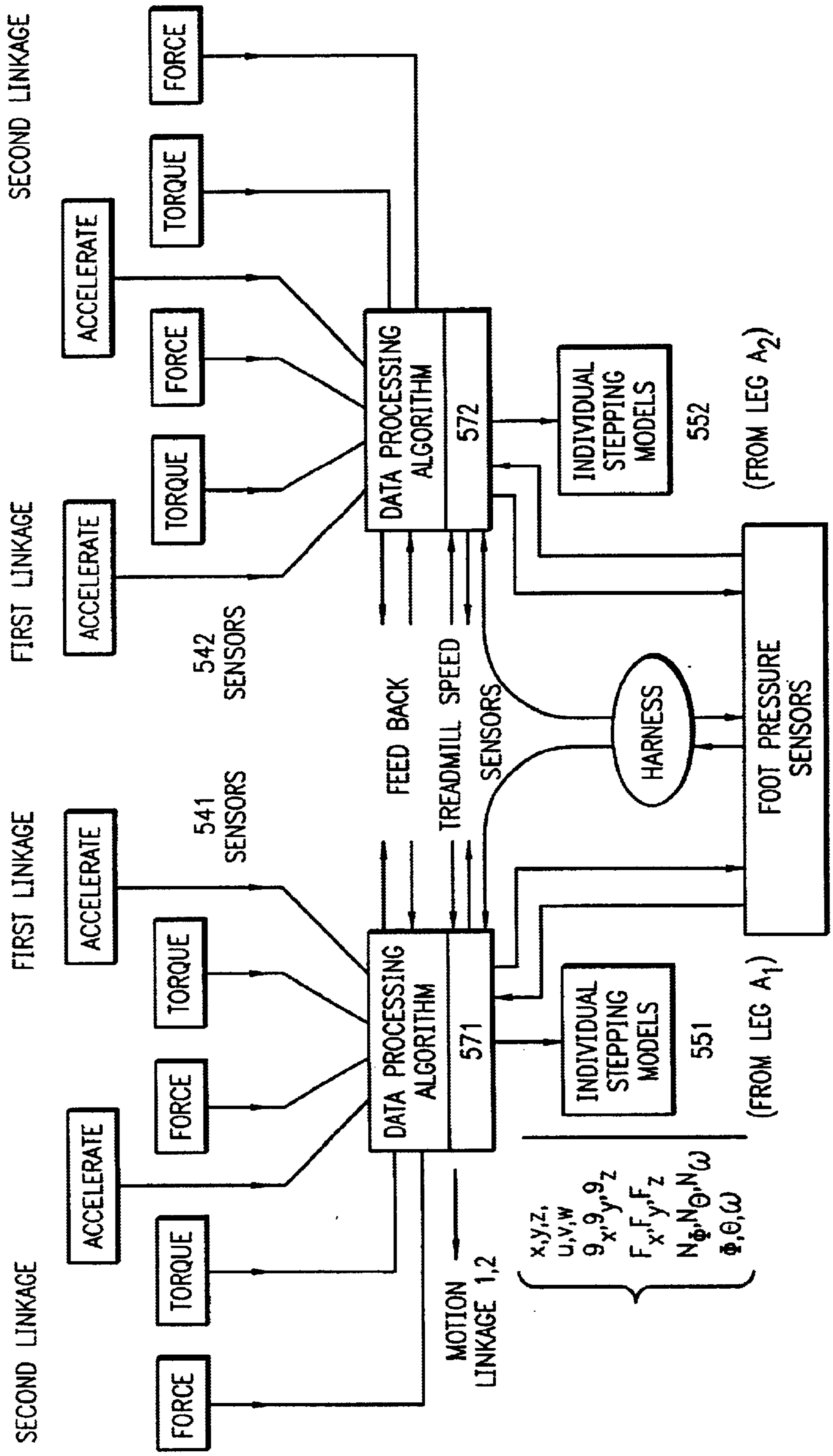

SECOND LINKAGE
FORCE
TORQUE
ACCELERATE
FIRST LINKAGE
FORCE
TORQUE
ACCELERATE
542 SENSORS
DATA PROCESSING ALGORITHM
572
INDIVIDUAL STEPPING MODELS
552
(FROM LEG A2)
FEED BACK
TREADMILL SPEED
SENSORS
HARNESS
FOOT PRESSURE SENSORS
FIRST LINKAGE
ACCELERATE
TORQUE
541 SENSORS
FORCE
ACCELERATE
SECOND LINKAGE
TORQUE
FORCE
DATA PROCESSING ALGORITHM
571
INDIVIDUAL STEPPING MODELS
551
(FROM LEG A1)
MOTION LINKAGE 1,2
x,y,z,
u,v,w
gx,gy,gz
Fx,Fy,Fz
NΦ,NΘ,Nω
Φ,Θ,ω

FIG. 5

FIG. 6

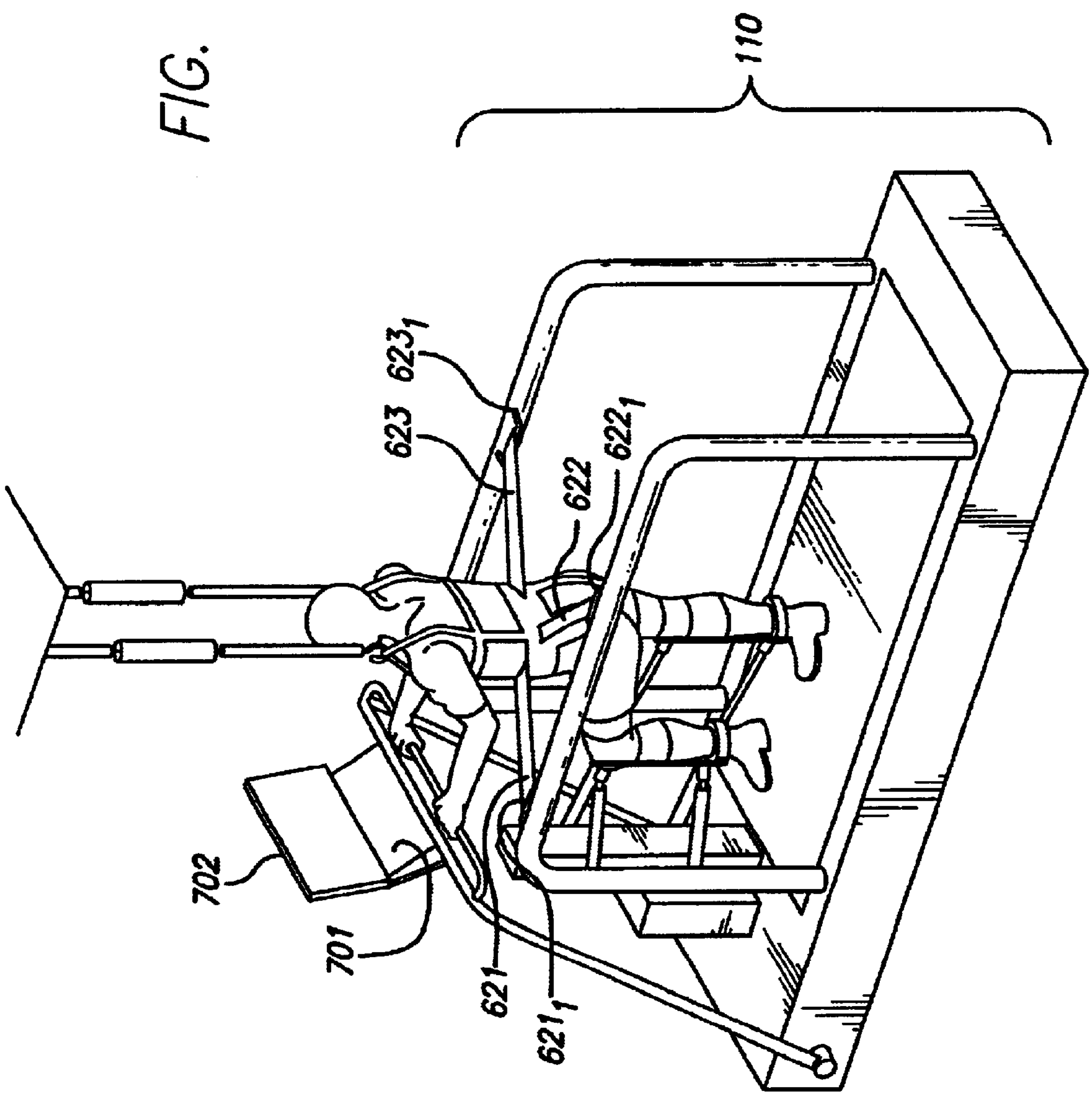
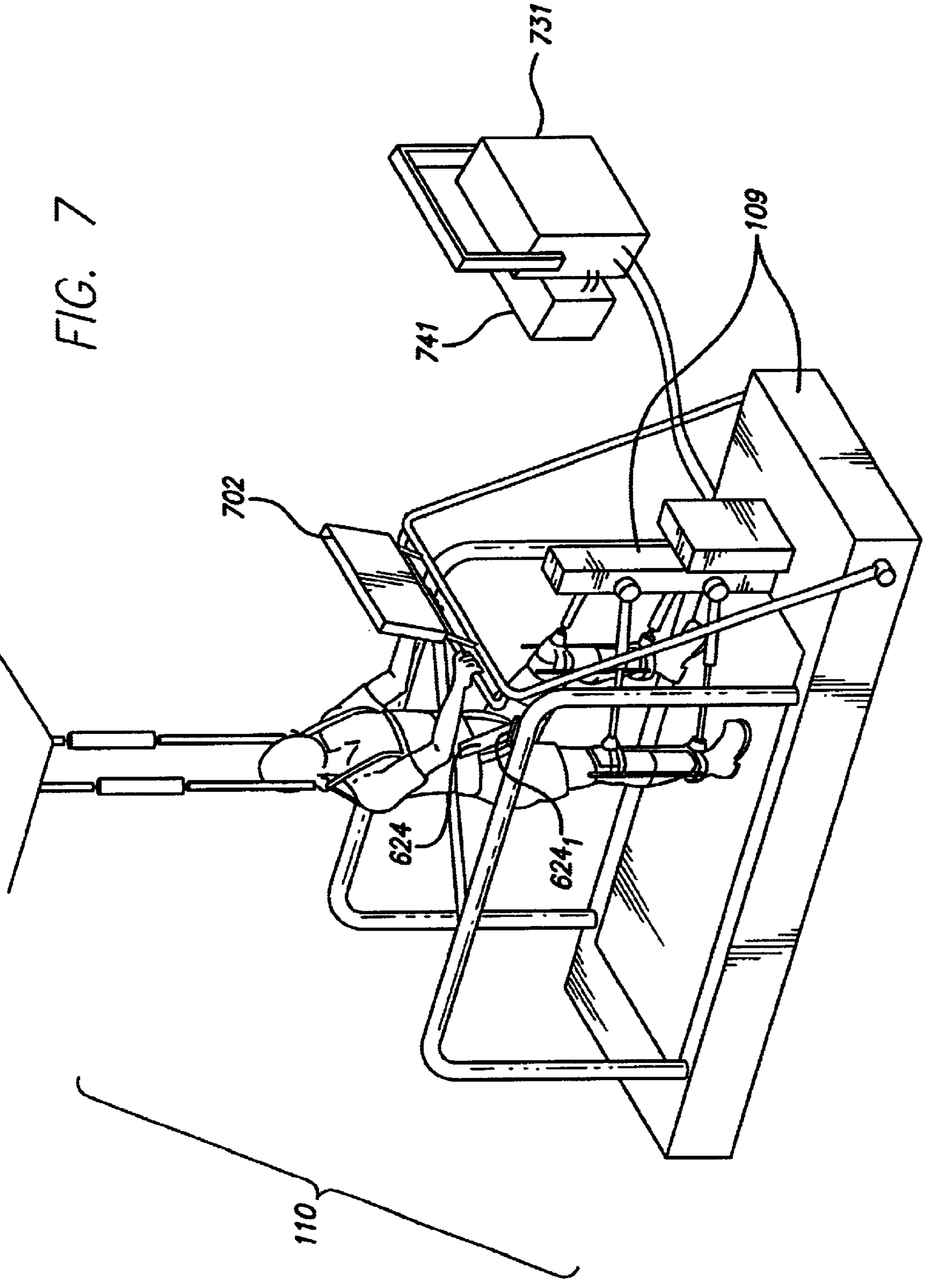


FIG. 7



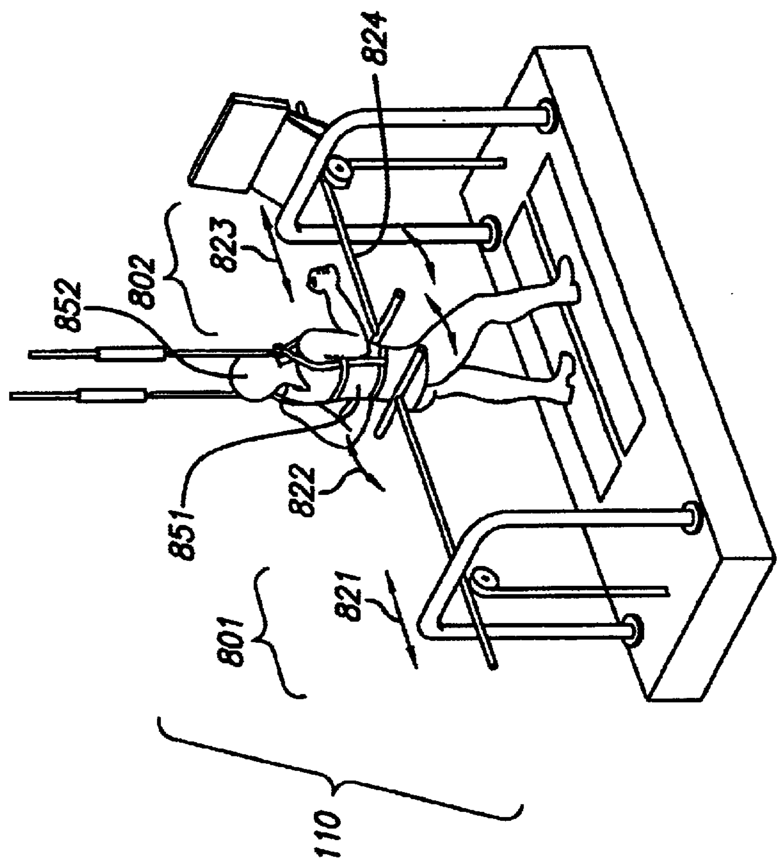
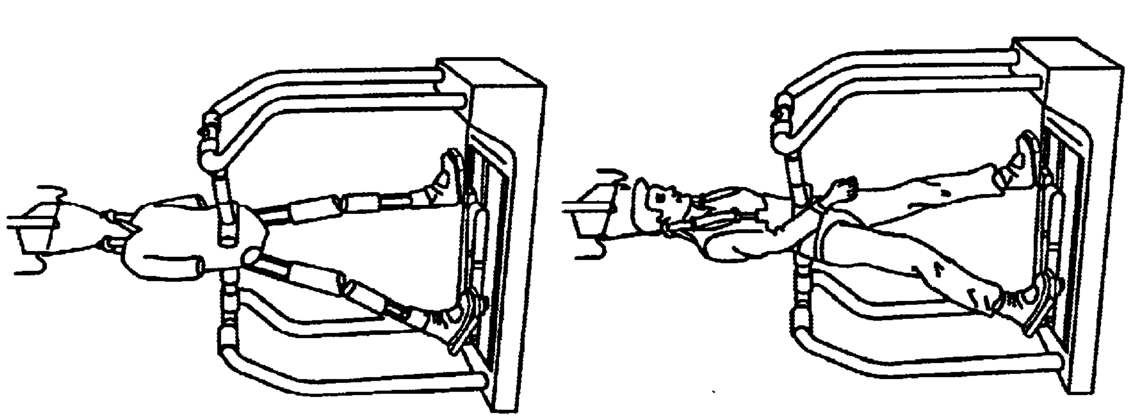


FIG. 8



METHOD, APPARATUS AND SYSTEM FOR AUTOMATION OF BODY WEIGHT SUPPORT TRAINING (BWST) OF BIPED LOCOMOTION OVER A TREADMILL USING A PROGRAMMABLE STEPPER DEVICE (PSD) OPERATING LIKE AN EXOSKELETON DRIVE SYSTEM FROM A FIXED BASE

This application claims the benefit of Ser. No. 60/150,085 (filed Aug. 20, 1999).

This invention was made with Government support under Grant. No. NS16333, awarded by the National Institutes of Health. The Government has certain rights in this invention.

FIELD OF INVENTION

The field of the invention is robotic devices to improve ambulation.

BACKGROUND

There is a need to train patients who have had spinal cord injuries or strokes to walk again. The underlying scientific basis for this approach is the observation that after a complete thoracic spinal cord transection, the hindlimbs of cats can be trained to fully support their weight, rhythmically step in response to a moving treadmill and adjust their walking speed to that of a treadmill. See for example, Edgerton et al., Recovery of full weight-supporting locomotion of the hindlimbs after complete thoracic spinalization of adult and neonatal cats. In: *Restorative Neurology, Plasticity of Motoneuronal Connections*. New York, Elsevier Publishers, 1991, pp. 405–418; Edgerton, et al., Does motor learning occur in the spinal cord? *Neuroscientist* 3:287–294, 1997b; Hodgson, et al., Can the mammalian lumbar spinal cord learn a motor task? *Med. Sci. Sports Exerc*. 26:1491–1497, 1994.

Relatively recently, a new rehabilitative strategy, locomotor training of locomotion impaired subjects using Body Weight Support Training (BWST) technique over a treadmill has been introduced and investigated as a novel intervention to improve ambulation following neurologic injuries. Results from several laboratories throughout the world suggest that locomotor training with a BWST technique over a treadmill significantly can improve locomotor capabilities of both acute and chronic incomplete spinal cord injured (SCI) patients.

Current BWST techniques rely on manual assistance of several therapists during therapy sessions. Therapists provide manual assistance to the legs to generate the swing phase of stepping and to stabilize the knee during stance. This manual assistance has several important scientific and functional limitations. First, the manual assistance provided can vary greatly between therapists and sessions. The patients' ability to step on a treadmill is highly dependent upon the skill level of the persons conducting the training. Second, the therapists can only provide a crude estimate of the required force torque and acceleration necessary for a prescribed and desired stepping performance. To date all studies and evaluations of step training using BWST technique over a treadmill have been limited by the inability to quantify the joint torques and kinematics of the lower limbs during training. This information is critical to fully assess the changes and progress attributable to step training with BWST technique over a treadmill. Third, the manual method can require up to three or four physical therapists to assist the patient during each training. session. This labor-intensive protocol is too costly and impractical for widespread clinical applications.

There is a need for a mechanized system with sensor-based automatic feedback control exists to assist the rehabilitation of neurally damaged people to relearn the walking capability using the BWST technique over a treadmill. Such a system could alleviate the deficiencies implied in the currently employed manual assistance of therapists. A programmable stepper device would utilize robotic arms instead of three physical therapists. It would provide rapid quantitative measurements of the dynamics and kinematics of stepping. It would also better replicate the normal motion of walking for the patients, with consistency.

SUMMARY OF THE INVENTION

The invention is a robotic exoskeleton and a control system for driving the robotic exoskeleton. It includes the method for making and using the robotic exoskeleton and its control system. The robotic exoskeleton has sensors embedded in it which provide feedback to the control system.

The invention utilizes feedback from the motion of the legs themselves, as they deviate from a normal gait, to provide corrective pressure and guidance. The position versus time is sensed and compared to a normal gait profile. There are various normal profiles based on studies of the population for age, weight, height and other variables. While the portion of the legs is driven according to a realistic model human gait, additional mechanical assistance is applied to flexor and extensor muscles and tendons at an appropriate time in the gait motion of the legs in order to stimulate the recovery of afferent-efferent nerve pathways located in the lower limbs and in the spinal cord. The driving forces applied to move the legs are positioned to induce activations of these nerve pathways in the lower limbs that activate the major flexor and extensor muscle groups and tendons, rather than lifting from the bottom of the feet.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages. of the invention will be more apparent from the following detailed description wherein:

FIG. **1** shows the patient in a body weight suspension training (BWST) modality over a treadmill attached to two pairs of robotic arms, with sensors, which are computer controlled and are directed to train the patient to walk again;

FIG. **2** shows another view of the legs of the patient attached to the robotic arms which have the acceleration and force/torque sensors in them;

FIG. **3** shows a detail of one of the robotic arms with its rotary and telescopic motions;

FIG. **4**A shows, the detail of the ankle and upper leg attachments, as well as a special shoe with pressure sensors in it, and also shown are stimulation means for flexor and extensor muscle groups and tendons;

FIG. **4**B shows a detail of corresponding to FIG. **4**A, except that the robotic arms and the position of the sensor units are shown, attached between the arms and the ankle and knee attachments to the leg;

FIG. **5** shows a diagrammatic representation of the interactions of the sensors, treadmill speed, individual stepping models, and the computational and other algorithms which form the operating control with feedback part of the system;

FIG. **6** shows the system of FIG. **1** from a rear three-quarter view showing details of the keyboard, display, and hip harness system, both passive and active;

FIG. **7** shows the front three-quarter view corresponding to FIGS. **1** and **6**, showing other detail of the hip control, system and the off-treadmill recording, display, and off-treadmill control part of the system;

FIG. **8** shows a dual t-bar method for on-treadmill control of hip and body position.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

The following description is of the best mode presently contemplated for carrying out the invention. This description is not to be taken in a limiting sense, but is merely made for the purpose of describing the general principles of the invention. The scope of the invention should be determined with reference to the claims.

The solution to the above problem is an individually adjustable and automated BWST technique using a Programmable Stepping Device (PSD) with model and sensing based control operating like an exoskeleton on the patients' legs from a fixed base on the treadmill (i) to replace the active and continuous participation of currently needing several highly and specifically trained therapists to conduct the retraining sessions, (ii) to provide a consistent training performance, and (iii) to establish a quantified data base for evaluating patient's progress during locomotor. training.

The system serves the purpose of assisting and easing the rehabilitation of spinal cord, stroke and traumatic brain injured people (as well as others with injury affecting locomotion) to regain, walking capabilities. The overall system uses an individually adjustable and sensing based automation of body weight support training (BWST) to train standing and locomotion of impaired patients. The system helps them to relearn how to walk on a treadmill which then facilitates relearning to walk overground. It uses an individually adjustable and sensing based automation of body weight support training (BWST) approach to train standing and locomotion of impaired patients by helping them to relearn how to walk on a treadmill which then facilitates relearning to walk overground.

FIG. **1** and FIG. **2** show two pairs of motor-driven mechanical linkage units, each unit with two mechanical degrees-of-freedom, are connected with their drive elements to the fixed base of the treadmill while the linkages' free ends are attached to the patient's lower extremities. Two pairs of motor-driven mechanical linkage units **101**, **102**, **103**, **104** each unit with two mechanical degrees-of-freedom, are connected with their drive elements **105**, **106**, **107**, **108** to the fixed base **109** of the treadmill **110** while the linkages' free ends **111**, **112**, **113**, **114** are attached to the patient's lower extremities (legs) A1, A2 at two locations at each leg so that one linkage pair **101**, **102** serves one leg A1 and the other linkage pair **103**,**104** serves the other leg A2 in the sagittal plane of bipedal locomotion.

Thus, this linkage system arrangement **101**, **102**, **103**, **104** is capable of reproducing the profile of bipedal locomotion and standing in the sagittal plane from a fixed base **109** which is external to the act of bipedal locomotion and standing on a treadmill **110**.

The exoskeleton linkage system together with its passive compliant elements are adjustable to the geometry and dynamic needs of individual patients.

This individual adjustment is implemented in this embodiment with the control of the linkage system of the programmable stepper device (PSD) computer **115** based, referenced to individual stepping models, treadmill **110** speed, and force/torque and acceleration data (sensors located at **111**, **112**, **113**, **114**) sensed at the linkages' exoskeleton contact area with each of the patient's legs **111**, **112**, **113**, **114**.

As seen in FIG. **2** the system concept is built on the use of special two degree-of-freedom (d.o.f) robot arms **101**, **103**, **102**, **104** connected to the fixed base of the treadmill where their drive system is located, while the free end of the robot arms **111**, **112**, **113**, **114** is connected to the patient's legs like an exoskeleton attachment.

As shown in FIG. **3**, the first (or base) d.o.f (degree of freedom, or, joint) of the robot arms is rotational **301**, **302**, and the second (or subsequent) d.o.f, or, joint is linear of telescoping nature **303**, **304**. The rotational drive elements **105**, **106**, **107**, **108** are represented by **305** in FIG. **3**. The angular rotational motion indicated by the arrows **301** and **302** take place around a pivot point **306**. This motion is driven by a motor **307** which is located perpendicular to the plane of rotation **301**, **302** of the telescoping arm **307**, in this aspect of this embodiment. The telescoping arm comprises an outer sleeve part **308** and an inner sleeve part **309**. In addition a motor **310** for moving the inner sleeve relative **309** to the outer sleeve **308**, which in this aspect of this embodiment is fixed to the rotating element **305**. It should be noted that there are other ways, old in the art, of achieving the two dimensional motion in a plane which the rotating **301**, **302**, telescoping **303**, **304** arm, as just described, which may form a different embodiment as herein presented, but which is equally good at providing the required (motor driven) degrees of freedom.

The mechanical part of the system uses four such robot arms. (**101**, **102**), (**103**, **104**), two for assisting each. leg of a patient in bipedal locomotion. The two arms are located above each other in a vertical plane coinciding with the sagittal plane of bipedal locomotion.

The rotational axis of the first joint **305** is perpendicular to the vertical (sagittal) plane while the linear (telescoping) axis **307** of the second joint is parallel to the vertical (sagittal) plane. Thus, the free end of each arm **111**, **112**, **113**, **114** can move up-down and in-out. These motion capabilities are needed for each arm to jointly reproduce the profile of bipedal locomotion in the sagittal plane from a fixed treadmill **110** base **109** which is external to the act of bipedal locomotion on a treadmill **110**.

FIG. **4** shows the patients leg A1. A leg support brace **400** is attached to the part of the leg A1 which is above **403** the knee and to the part of the leg below **404** the knee. As shown there is a freely pivoting pivot joint **401** corresponding the motion of the knee. The leg brace may correspond to a modified commercially available brace such as the C180 PCL (posterior tibial translation) support offered by Innovation Sports, with a modification. The modification to the leg support brace is shown as **407**. The ankle has a padded custom-made attachment. In addition, a special shoe **405** containing pressure sensors **406** is used on the foot to provide feedback information to the main computer **115**.

The arms **101** and **102** attach respectively for patient's leg A1 at the sensor **451** at the knee via the modification **407** and to the ankle area sensor **452**. The exoskeleton supports and moves each leg so as to provide pressure on extensor surface during stance and flexor surface during swing. The extensor pressure is applied inferior to the patella in the vicinity of the patella tendon which helps locks the knee so as to aid "stance" position of the leg. The flexor pressure is applied in the vicinity of the hamstring muscles and associated tendons, on the back of the upper leg just above the rear crease of the knee, aiding in the "swing" part of the step motion.

An important additional feature is the continuous recording of the electrical activity of the muscles in the form of electromyograms (EMGs). These are real-time recordings of the electrical activity of the muscles measured with surface electrodes, or, optionally, with fine wire electrodes, or with a mix of electrode types.

The two arms **101, 102** assisting one leg are connected to the leg so that the lower arm is attached to the lower limb slightly above the ankle while the upper arm is attached to the leg near and slightly below the knee. This robot arm arrangement closely imitates a therapist's two-handed interaction with a patient's one leg **A1** during locomotor training on a treadmill. Implied in this robot arm arrangement is the fact that the lower arm **102** is mostly responsible for the control of the lower limb while the upper arm **101** is mostly responsible for the upper limb control, though in a coordinated manner, complying with the profile of bipedal locomotion in the sagittal plane as seen from the front.

At the front end of each robot arm **101, 102, 103, 104** near the exoskeleton connection to the leg a combined force/torque and acceleration sensor **451, 452** (other two sensors of this type not shown) is mounted which measures the robot arm's interaction with the leg. Potentiometers **350** measuring the arm's position are installed at the drive motors at the base of the robot arms. Alternative methods, old in the art, also may be used, including but not limited to, a digitally-read rotating optical disk **351**.

The mechanical elements necessary to properly connect to a variety of legs are adjustable to the geometry of individual patients, including the compliant elements of the system. The described four-arm architecture permits all active drive elements of each arm (motors, electronics, computer) to be housed on the front end of the treadmill **110** in a safe arrangement and safe operation modality. Aspects of the safe operation modality include limiting switches on the range of motion of the telescoping movements and in the rotating movements of the arms, emergency cut-off switches for both a monitoring therapist and for the patient. In addition, the leg brace **400** is constructed so that the pivoting joint **401** cannot be bent back so as to hyperextend the knee and destroy it. The overall construction of the leg brace **400** is such that it can resist a chosen safety factor, such as four times (4×), the maximum amount of force which the robotic arms with all their motors, can exert to buckle the knee, i.e., the constructed knee joint (for the C180, it is a four bar linkage), which protects the knee from hyperextension.

The range of kinematic and dynamic parameters associated with the programmable stepping device (PSD) operation are determined from actual measurements of the therapists' interaction with the legs of various patients during training and from the ideal models, FIG. **5, 551, 552** of corresponding healthy persons' bipedal locomotion. The system can monitor and control each leg independently.

The control system (FIG. **5, 500**) of the PSD is not wired to patients body but rather gets feedback from sensors in the vicinity of the ankles (FIG. 4B) **452**, the knees **451** and from the (dynamic) pressure sensors **406** in the "shoes" of the apparatus.

The control system (FIG. **5, 500**) is computer based and referenced to (i) individual stepping models **551, 552**, (ii) treadmill speed **561**, and (iii) force/torque/accelerometer sensor data **541 542** measured at the output end of each robot arm. The control software architecture **571, 572** is "intelligent" in the sense that it can distinguish between the force/torque generated by the patient's muscles, by the treadmill **110**, and by the robot arms' drive motors **310** (others not shown) in order to maintain programed normal stepping on the treadmill.

The patient's contact force with the revolving treadmill belt is pre-adjustable through the BEST harness (FIG. **6**, FIG. **7, 600**) dependent upon body weight and size. The proper adjustment can be automatically maintained during motion by utilizing a proper force/pressure system on the harness **600**. The harness system may be passive with respect to the hip placement of the patient, in so far as it provides for constraint via somewhat elastic belts, or cords, (FIG. **6**) **621, 622, 623**; (FIG. **7**) **624**. A more active adjustment system is also used, in a different aspect of an embodiment of this invention. FIG. **8** shows the use of dual T-bars **801** and **802** where the T-bars are adjustable, as shown by the curved and straight arrows, by controlled motors **821, 822, 823, 824**. Other active methods of control of the hips, utilize stepping, or other, motors on the belts (FIG. **6**) **621, 622, 623**, as **6211, 6221, 6231**) and (FIG. **7**) **624** as **6241**. The use of special sensor **406** shoes **405** also provides feedback for the adjustment of body weight in contact with the treadmill **110**. The overall control system operates in E wireless configuration relative to the patient's body. The algorithms for the system include, in some aspects of an embodiment of the invention, neural network algorithms, in software and/or in hardware implementation, to "learn" aspects of the patient's gait, either when strictly mediated by the robotic system, or, when therapists move the patient through the "proper motions" while the robotic system is acting passively, except for measurements being made by sensors **406** and **451** and **452** and the electromyogram (EMG)s and the corresponding sensors on the other leg (not shown).

A keyboard (FIG. **6, 701**) and monitor (FIGS. **6, 7**) **702** attached to the treadmill **110** enables the user to input selected kinematic and dynamic stepping parameters to the computer-based control and performance monitor system. The term user, here, covers the patient and/or a therapist and/or a physician and/or an assistant. The user interface to the system is implemented by a keybord/monitor setup **701, 702** attached to the front of the treadmill **110**, easily reachable by the patient, as long as the patient has enough use of upper limbs. It enables the user (therapist or patient) to input selected kinematic and dynamic stepping parameters and treadmill speed to the control and monitor system. A condensed stepping performance can also be viewed on this monitor interface in real time, based on preselected performance parameters.

An externally located digital monitor system **731** displays the patient's stepping performance in selected details in real time.

A data recording system **741** enables the storage of all training related and time based and time coordinated data, including electromyogram (EMG) signals, for off-line diagnostic analysis. The architecture of the data recording part of the system enables the storage of all training related and time based and time coordinated data, including electromyogram (EMG), torque and position signals, for off-line diagnostic analysis of patient motion, dependencies and strengths, in order to provide a comparison to expected patterns of nondisabled subjects. The system will be capable of adjusting or correcting for measured abnormalities in the patient's motion.

An important part of this embodiment of the invention is the provision for the extra-stimulation of designated and associated tendon group areas. For example, when the leg is being raised, flexor and associated tendons in the lower hamstring area on the back of the leg are optionally subject to vibration or another type of extra-stimulation.(See FIG. **4A**, **471**, **472**) This is thought to strengthen the desired nerve pathways to allow the patient to develop toward overground locomotion. Therapeutic stimulators **471**, **472**, which may be vibrators, is shown in FIG. **4A**.

The overall system is designed to minimize the external mechanical load acting on the patient while maximizing the work performed by the patient to generate effective stepping and standing during treadmill training.

Operation safety is assured by proper stop conditions implemented in the control software and in the electrical and mechanical control hardware. The patient's embarkment to and disembarkment from the Programmable Stepping Device (PSD) is a manual operation in all cases.

While the invention herein disclosed has been described by means of specific embodiments and applications thereof, numerous modifications and variations could be made thereto by those skilled in the art without departing from the scope of the invention set forth in the claims.

What is claimed is:

1. A system for assisting and easing the rehabilitation of spinal cord, stroke and traumatic brain injured people (as well as others with injury affecting locomotion) to regain walking capabilities comprising

(a) an individually adjustable automated body weight suspension training system;

(b) multiple sensors wherein said sensors provide feedback to adjust the automated body weight suspension training system.

2. The system of claim **1** further comprising:

(a) two pairs of motor-driven mechanical linkage units;

(b) each of said units with two mechanical degrees-of-freedom;

(c) said units connected with their drive elements to a fixed base of a treadmill;

(d) said linkages' free ends wherein said free ends are attachable to the patient's legs at two locations at each leg; wherein one linkage pair serves one leg in the sagittal plane of bipedal locomotion; and wherein the other linkage pair serves the other leg in the sagittal plane of bipedal locomotion.

3. The system of claim **1** further comprising:

(a) an exoskeleton linkage system with its passive compliant elements wherein said exoskeleton linkage system with its passive compliant elements are adjustable to an individual patient's geometry and dynamics.

4. The system of claim **3** further comprising: said linkage system arrangement wherein said linkage system arrangement is capable of reproducing the profile of bipedal locomotion and standing in the sagittal plane, from a fixed base.

5. The system of claim **1** further comprising:

(a) a control system for a programmable stepping device;

(b) said computer based control system of a linkage system of the programmable stepping device;

(c) said control system referenced to individual stepping models, treadmill speed, and force, torque, electromyogram (EMG) and acceleration data;

(d) said data sensed at the linkages' exoskeleton contact area with each of the patient's legs.

6. The system of claim **1** further comprising:

(a) control algorithms of the exoskeleton linkages' computer control system

(b) said control algorithms being "intelligent" control for biped locomotion wherein said algorithms distinguish between the amount and direction of the force/torque generated by the patient, by the feet's contact with the treadmill, and by the action of the programmable stepping device;

(c) said control system monitoring and controlling each leg independently.

7. The system of claim **1** further comprising:

said control system operating by way of feedback through sensors for force, torque, acceleration, and pressure located at various points on or in the exoskeleton system; wherein no wires are required to go to the human body.

8. The system of claim **1** further comprising:

a keyboard attached to the treadmill wherein the user, one or more, selected from the group consisting of patient, therapist, physician and assistant can input selected kinematic and dynamic stepping parameters to said computer-based control system.

9. The system of claim **1** further comprising:

an externally located digital monitor system wherein the patient's stepping performance is selectively displayed in real time.

10. The system of claim **1** further comprising:

a data recording system wherein the storage of all training related and time based and time coordinated data, including electromyogram (EMG) signals, for off-line diagnostic analysis is enabled.

11. The system of claim **1** further comprising:

(a) a minimized external mechanical load acting on the patient;

(b) a maximized work performed by the patient in generating effective stepping and standing during treadmill training.

12. The system of claim **1** further comprising:

(a) a stimulator for applying stimulation to selected flexor muscles and associated tendons;

(b) a stimulator for applying stimulation to selected extensor muscles and associated tendons.

13. The system of claim **12** wherein said stimulators for applying stimulation to selected flexor and extensor muscles and associated tendons are vibrating stimulators.

14. The system of claim **1** further comprising:

an active system for positioning the hips.

15. The system of claim **14** further comprising:

said active system wherein controlled dual T-bars position the hips.

16. The system of claim **14** further comprising:

said active system wherein motorized semi-elastic belts position the hips.

17. An apparatus for rehabilitation of spinal cord, stroke and traumatic brain injured people (as well as others with injury affecting locomotion) to regain walking capabilities comprising:

(a) an individually adjustable automated body weight suspension training apparatus;

(b) multiple sensors wherein said sensors provide feedback to adjust the automated body weight suspension training apparatus;

(c) two pairs of motor-driven mechanical linkage units;

(d) each of said units with two mechanical degrees-of-freedom;

(e) said units connected with their drive elements to a fixed base of a treadmill;

(f) said linkages' free ends wherein said free ends are attachable to the patient's legs at two locations at each leg; wherein one linkage pair serves one leg in the sagittal plane of bipedal locomotion; and wherein the other linkage pair serves the other leg in the sagittal plane of bipedal locomotion.

18. The apparatus of claim **17** further comprising:

(a) an exoskeleton linkage system with its passive compliant elements wherein said exoskeleton linkage system with its passive compliant elements are adjustable to an individual patient's geometry and dynamics;

(b) said linkage system arrangement wherein said linkage system arrangement is capable of reproducing the profile of bipedal locomotion and standing in the sagittal plane, from a fixed base.

19. The apparatus of claim **17** further comprising:

(a) a control system for a programmable stepping device;

(b) said computer based control system of a linkage system of the programmable stepping device;

(c) said control system referenced to individual stepping models, treadmill speed, and force, torque, electromyogram (EMG) and acceleration data;

(d) said data sensed at the linkages' exoskeleton contact area with each of the patient's legs.

20. The apparatus of claim **17** further comprising:

(a) control algorithms of the exoskeleton linkages' computer control system

(b) said control algorithms being "intelligent" control for biped locomotion wherein said algorithms distinguish between the amount and direction of the force/torque generated by the patient, by the feet's contact with the treadmill, and by the action of the programmable stepping device;

(c) said control system monitoring and controlling each leg independently;

(d) said control system operating by way of feedback through sensors for force, torque, electromyogram (EMG), acceleration, and pressure located at various points on or in the exoskeleton system; wherein no wires are required to go to the human body.

21. The apparatus of claim **17** further comprising:

(a) a keyboard attached to the treadmill wherein the user, one or more, selected from the group consisting of patient, therapist, physician and assistant, can input selected kinematic and dynamic stepping parameters to said computer-based control system;

(b) an externally located digital monitor system wherein the patient's stepping performance is selectively displayed in real time;

(c) a data recording system wherein the storage of all training related and time based and time coordinated data, including electromyogram (EMG) signals, for off-line diagnostic analysis is enabled.

22. The apparatus of claim **17** further comprising:

(a) a minimized external mechanical load acting on the patient;

(b) a maximized work performed by the patient in generating effective stepping and standing during treadmill training.

23. The system of claim **17** further comprising:

(a) a stimulator for applying stimulation to selected flexor and associated tendons;

(b) a stimulator for applying stimulation to selected extensor muscles and associated tendons.

24. The system of claim **23** wherein said stimulators for applying stimulation to selected flexor and extensor muscles are vibrating stimulators.

25. The apparatus of claim **17** further comprising:

an active system for positioning the hips.

26. The apparatus of claim **25** further comprising:

said active system wherein controlled dual T-bars position the hips.

27. The apparatus of claim **25** further comprising:

said active system wherein motorized semi-elastic belts position the hips.

* * * * *

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(12) United States Patent
Agrawal et al.

(10) **Patent No.:** **US 8,147,436 B2**

(45) **Date of Patent:** **Apr. 3, 2012**

(54) **POWERED ORTHOSIS**

(75) Inventors: **Sunil Agrawal**, Newark, DE (US); **Sai Banala**, Hamden, CT (US)

(73) Assignee: **University of Delaware**, Newark, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1034 days.

(21) Appl. No.: **12/062,903**

(22) Filed: **Apr. 4, 2008**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**
A61F 5/00 (2006.01)

(52) **U.S. Cl.** **602/16**; 602/23

(58) **Field of Classification Search** 602/16, 602/23, 26–28, 19, 32–36; 128/882
See application file for complete search history.

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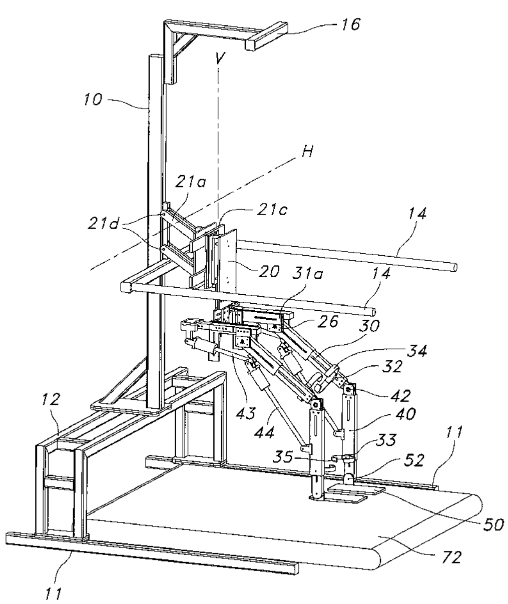
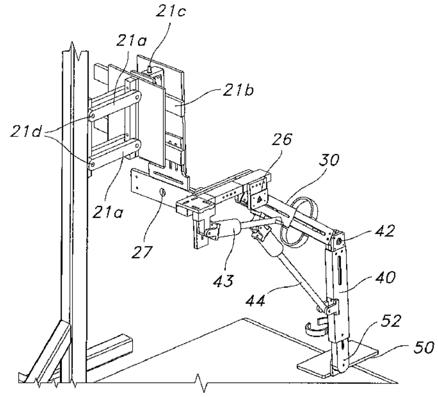
(74) *Attorney, Agent, or Firm* — RatnerPrestia

(57) **ABSTRACT**

A powered orthosis, adapted to be secured to a corresponding body portion of the user for guiding motion of a user, the orthosis comprising a plurality of structural members and one or more joints adjoining adjacent structural members, each joint having one or more degrees of freedom and a range of joint angles. One or more of the joints each comprise at least one back-drivable actuator governed by a controller for controlling the joint angle. The plurality of joint controllers are synchronized to cause the corresponding actuators to generate forces for assisting the user to move the orthosis at least in part under the user's power along a desired trajectory within an allowed tolerance. One embodiment comprises force-field controllers that define a virtual tunnel for movement of the orthosis, in which the forces applied to the orthosis for assisting the user may be proportional to deviation from the desired trajectory.

18 Claims, 11 Drawing Sheets





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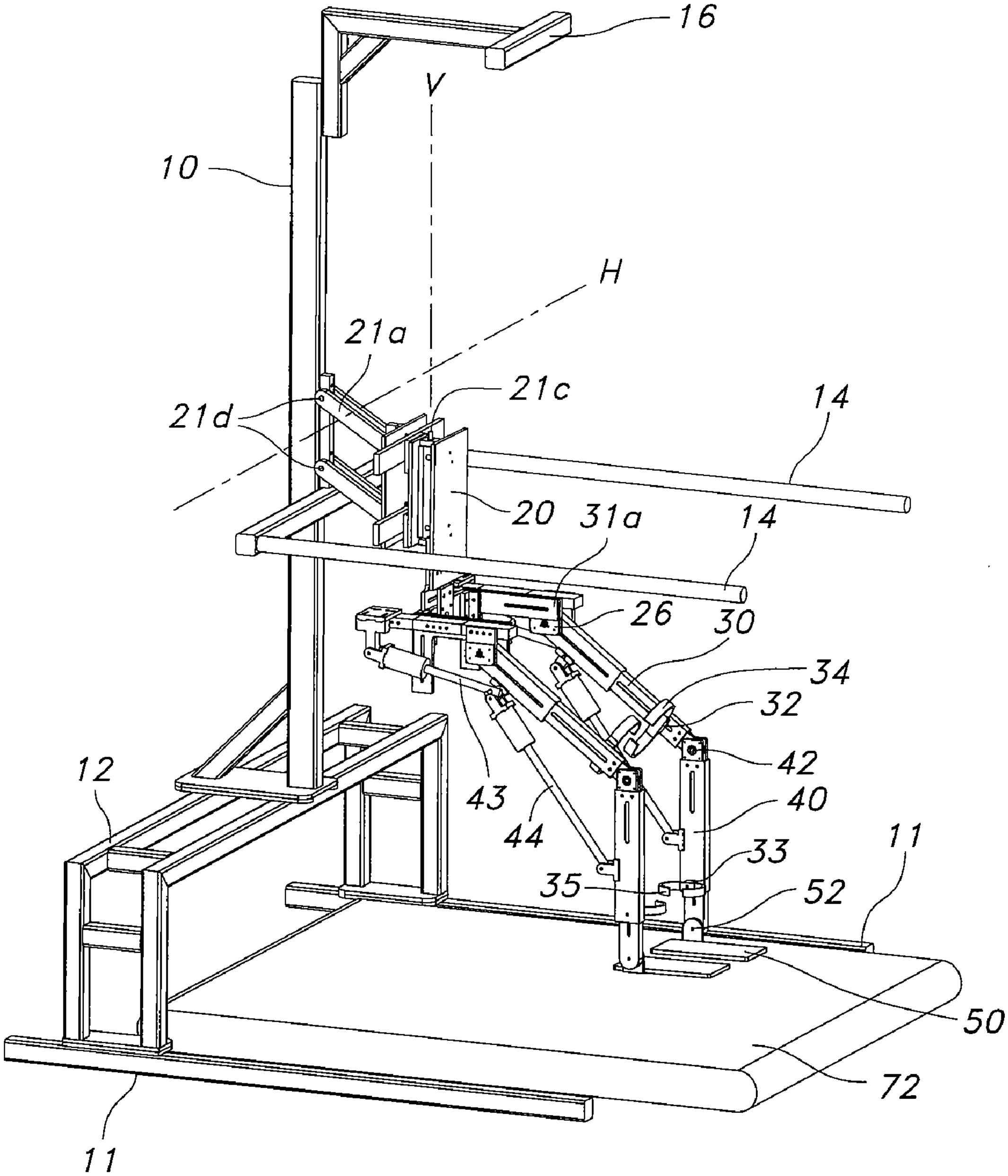
16
V
10
H
21a
21c
21d
14
20
31a
14
26
30
34
32
42
40
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44
12
11
33
35
52
50
72
11

FIG. 1A

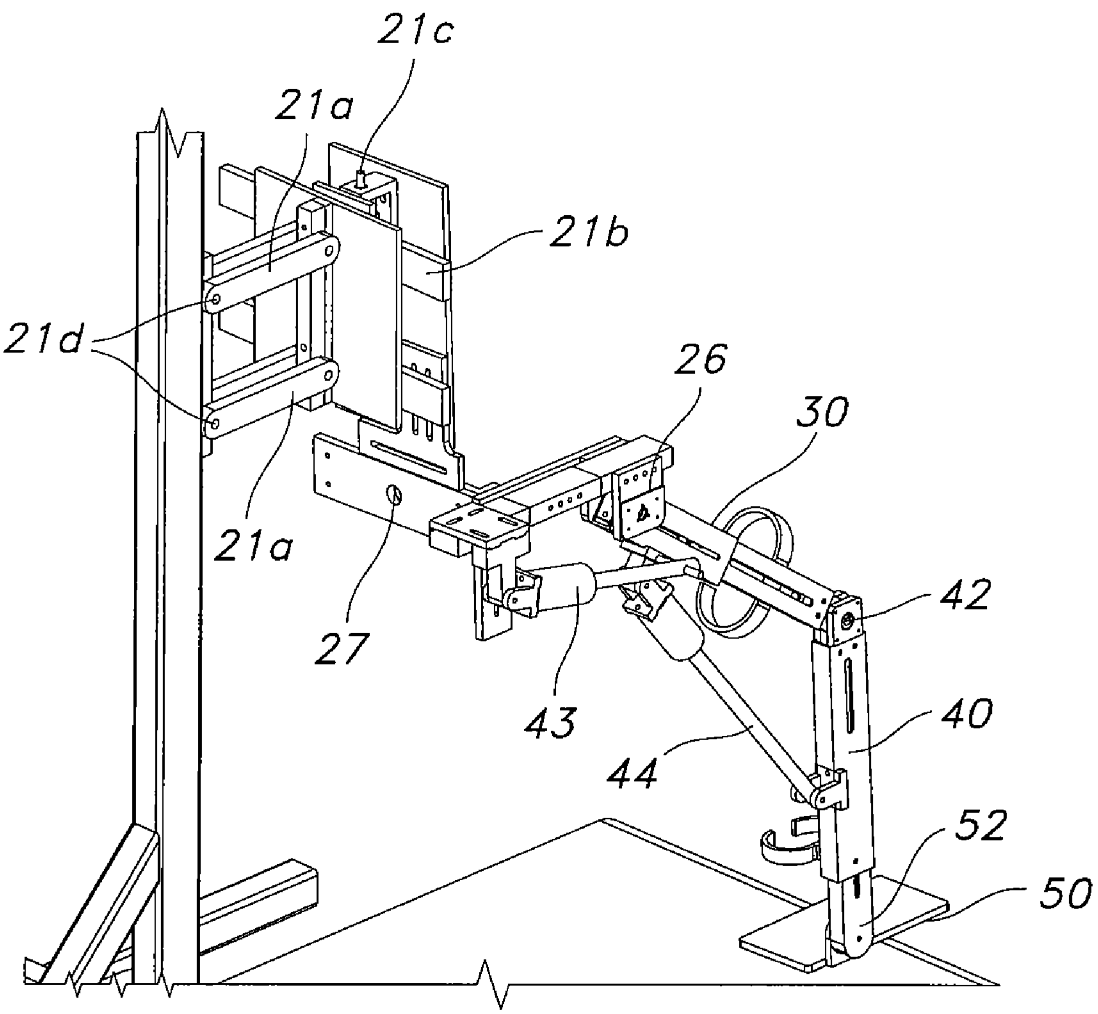

FIG. 1B

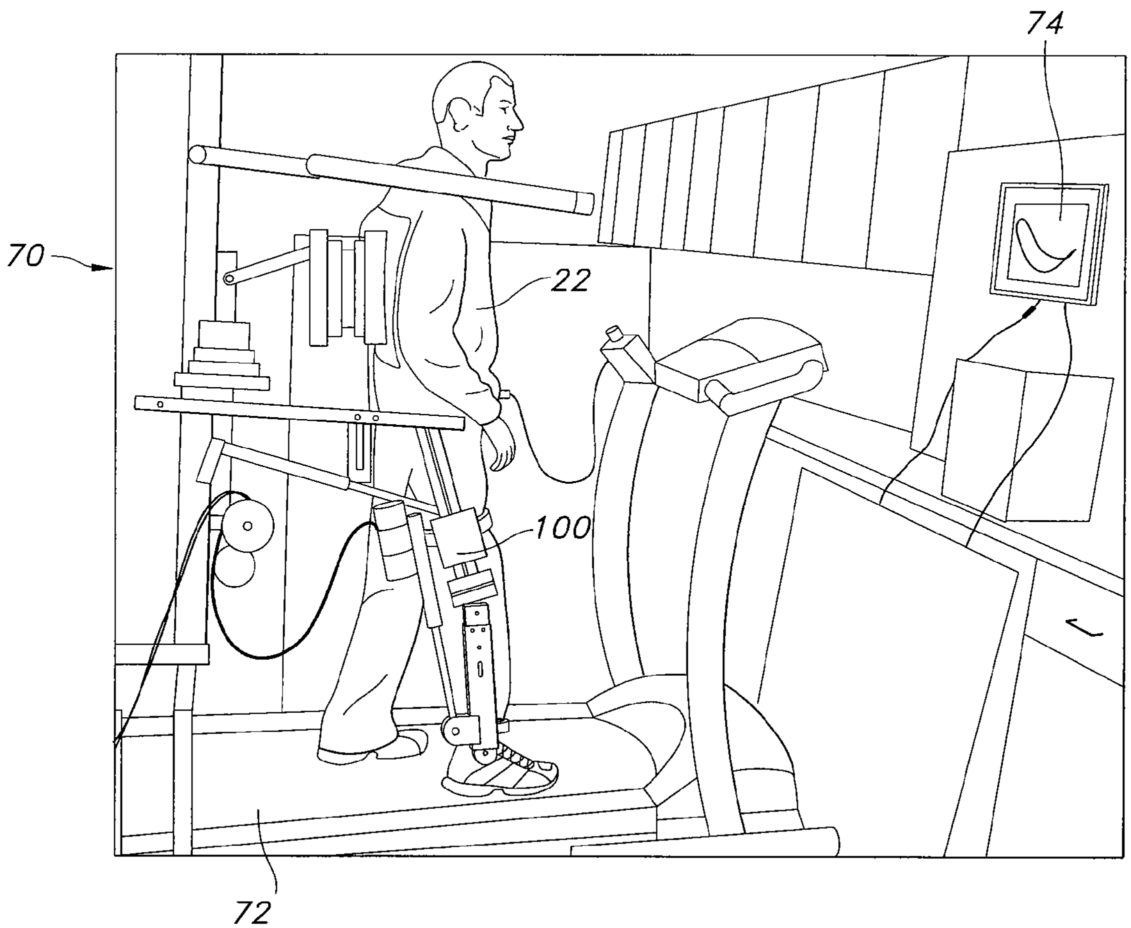

FIG. 2

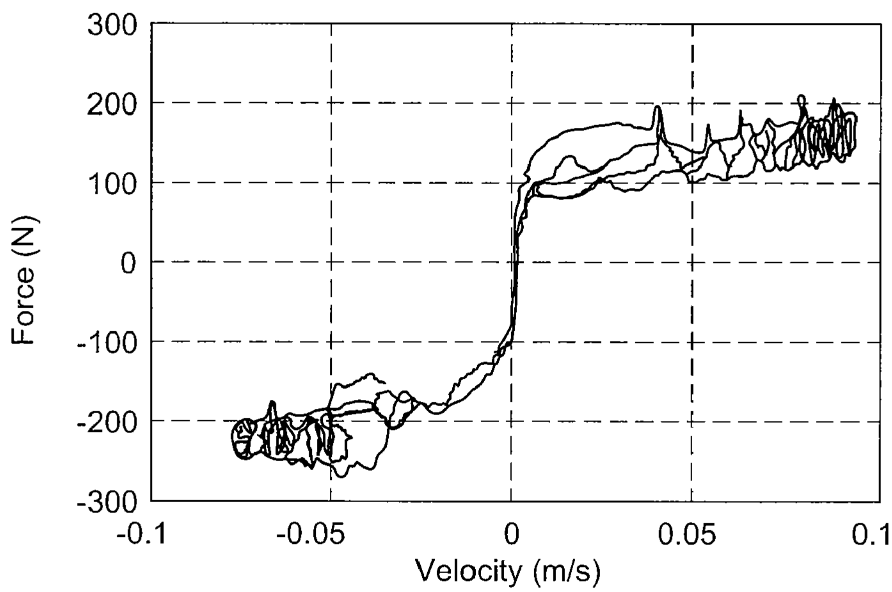
300
200
100
0
-100
-200
-300
Force (N)
-0.1
-0.05
0
0.05
0.1
Velocity (m/s)

FIG. 3

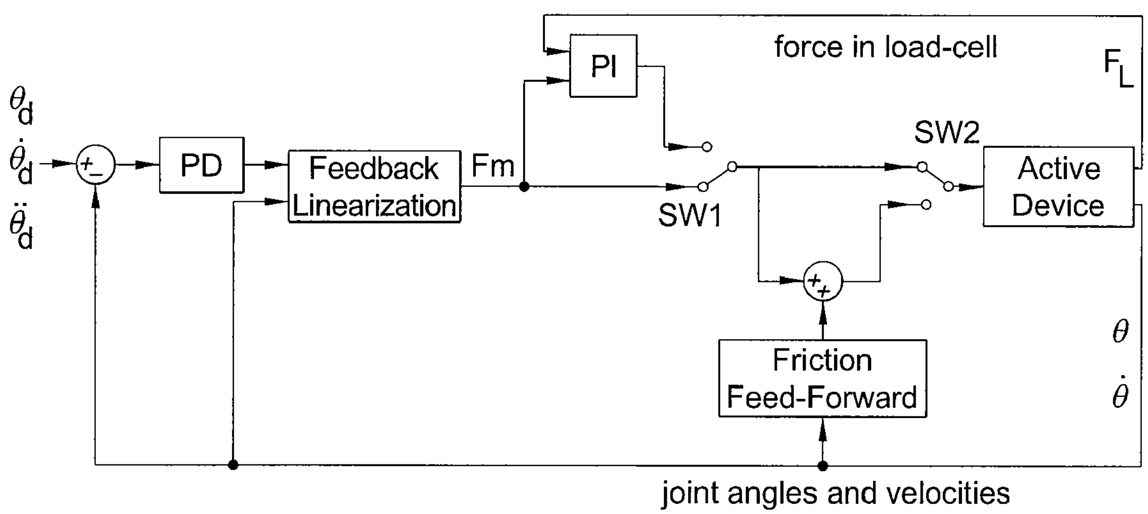
θ_d
$\dot{\theta}_d$
$\ddot{\theta}_d$
PD
Feedback Linearization
Fm
PI
force in load-cell
F_L
SW1
SW2
Active Device
Friction Feed-Forward
θ
$\dot{\theta}$
joint angles and velocities

FIG. 4

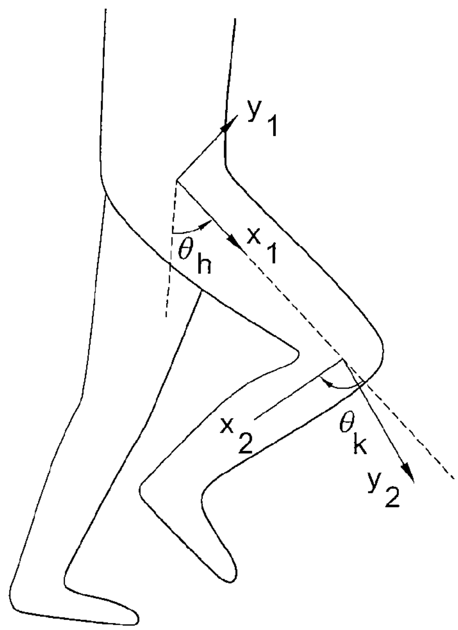
y1
x1
θh
x2
θk
y2

FIG. 5

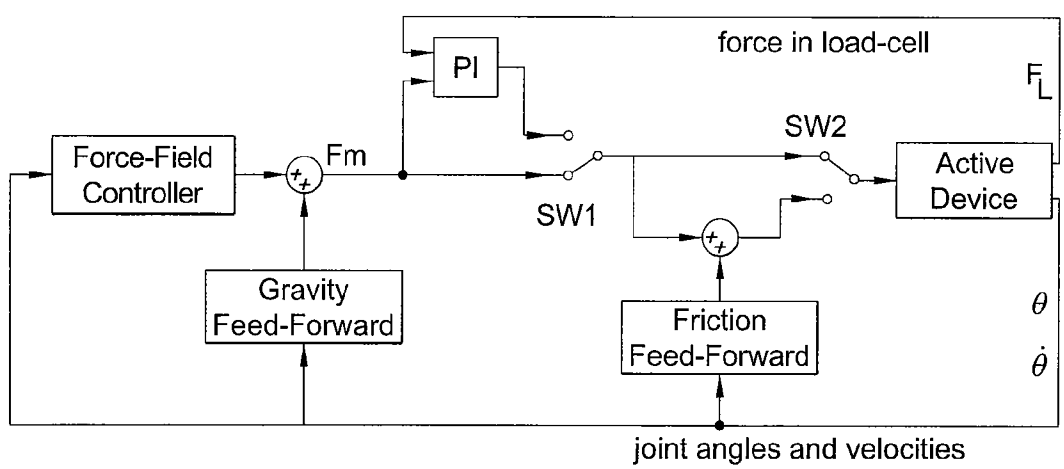
force in load-cell
PI
FL
Force-Field Controller
Fm
SW2
Active Device
SW1
Gravity Feed-Forward
Friction Feed-Forward
θ
θ̇
joint angles and velocities

FIG. 6

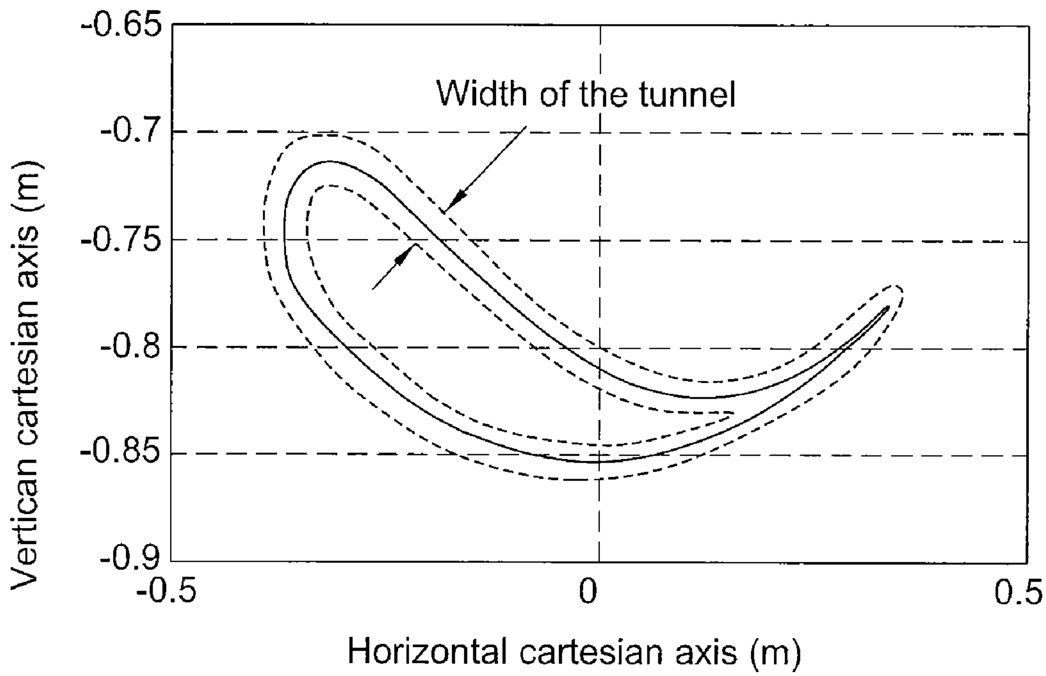
Width of the tunnel
Vertican cartesian axis (m)
-0.65
-0.7
-0.75
-0.8
-0.85
-0.9
-0.5
0
0.5
Horizontal cartesian axis (m)

FIG. 7

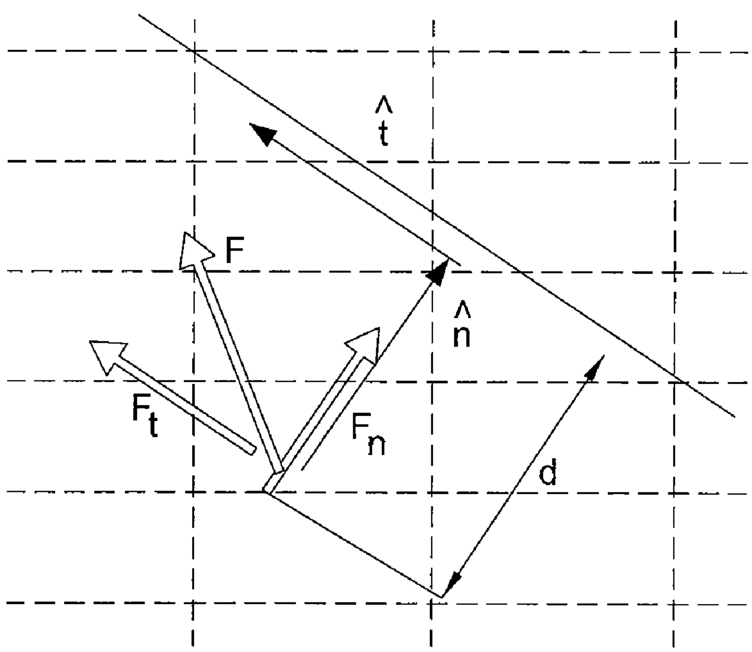
$\hat{t}$
F
$\hat{n}$
F_t
F_n
d

FIG. 8

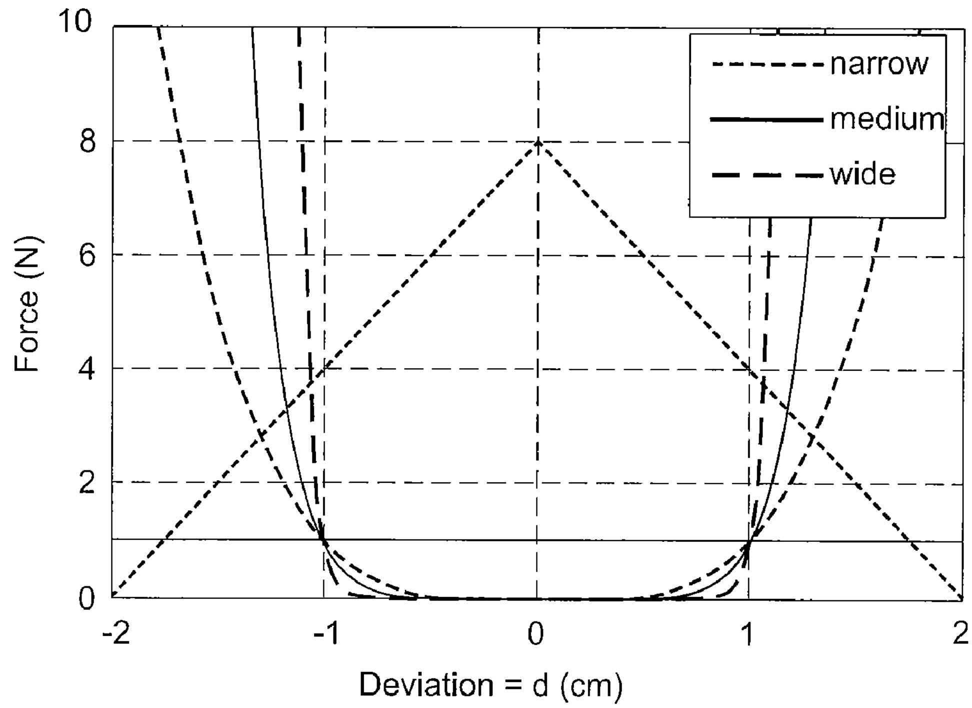
10
8
6
4
2
0
Force (N)
-2
-1
0
1
2
Deviation = d (cm)
narrow
medium
wide

FIG. 9A

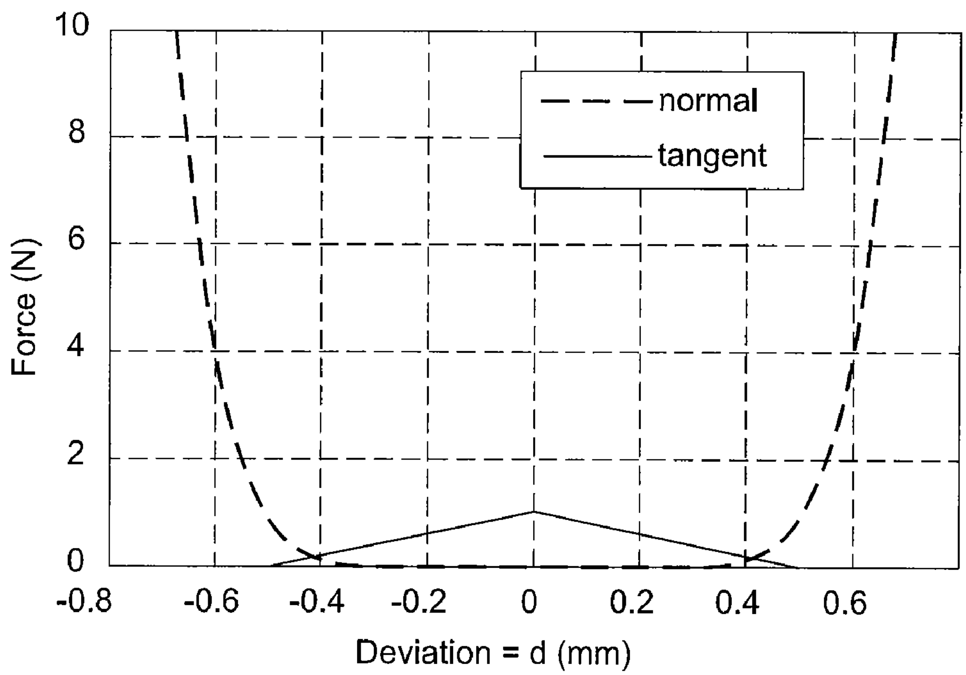
10
8
6
4
2
0
Force (N)
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Deviation = d (mm)
normal
tangent

FIG. 9B

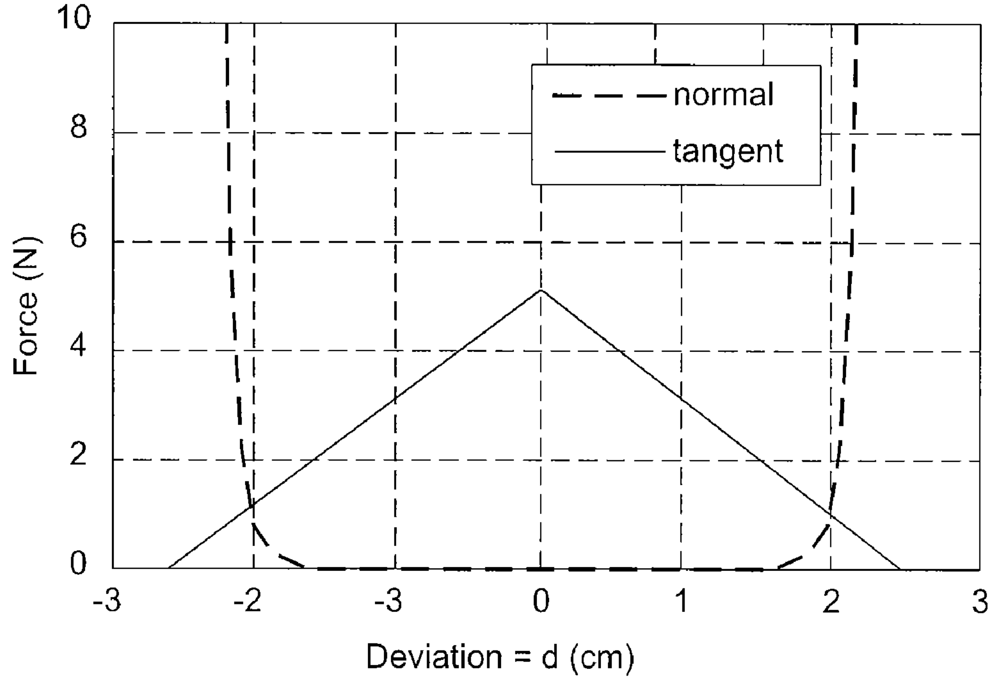
normal
tangent
Force (N)
10
8
6
4
2
0
-3
-2
-3
0
1
2
3
Deviation = d (cm)

FIG. 9C

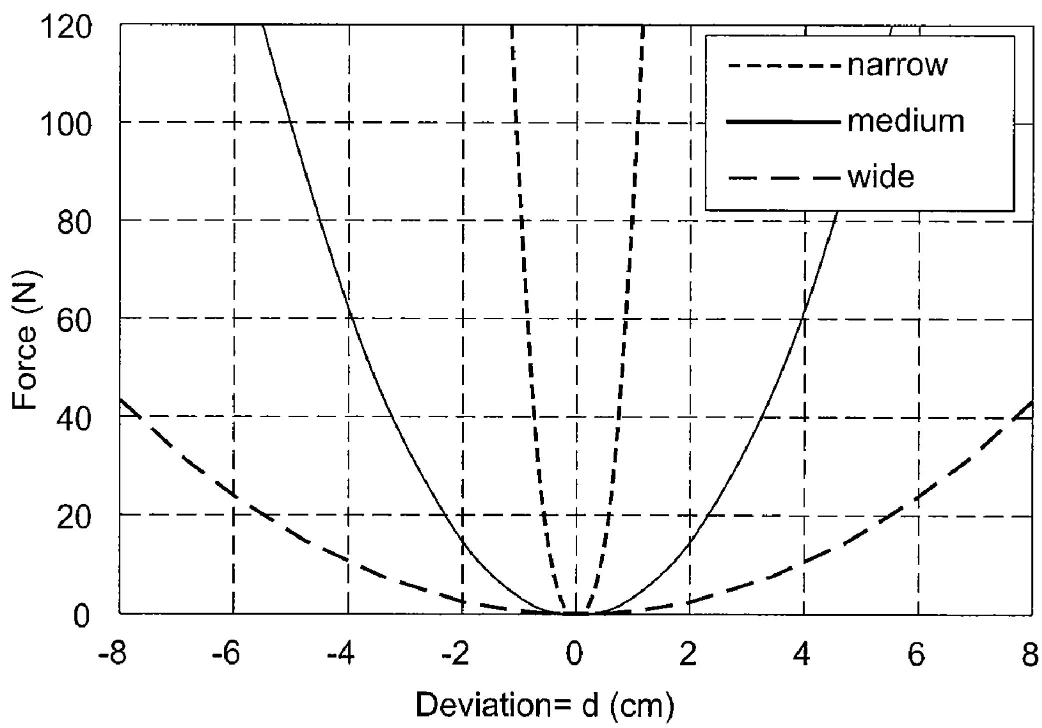
narrow
medium
wide
Force (N)
120
100
80
60
40
20
0
-8
-6
-4
-2
0
2
4
6
8
Deviation= d (cm)

FIG. 9D

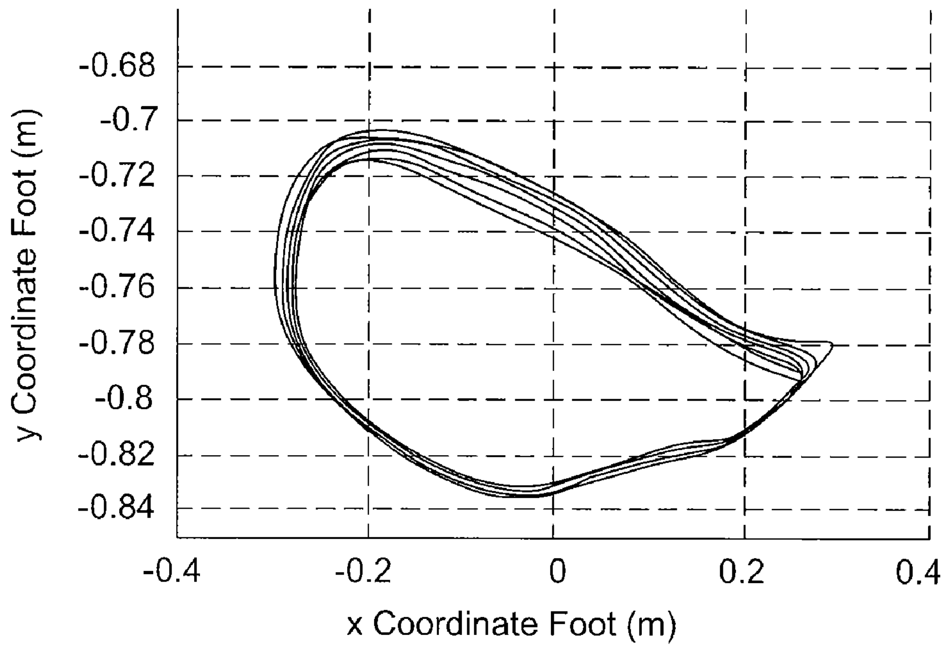

FIG. 10A

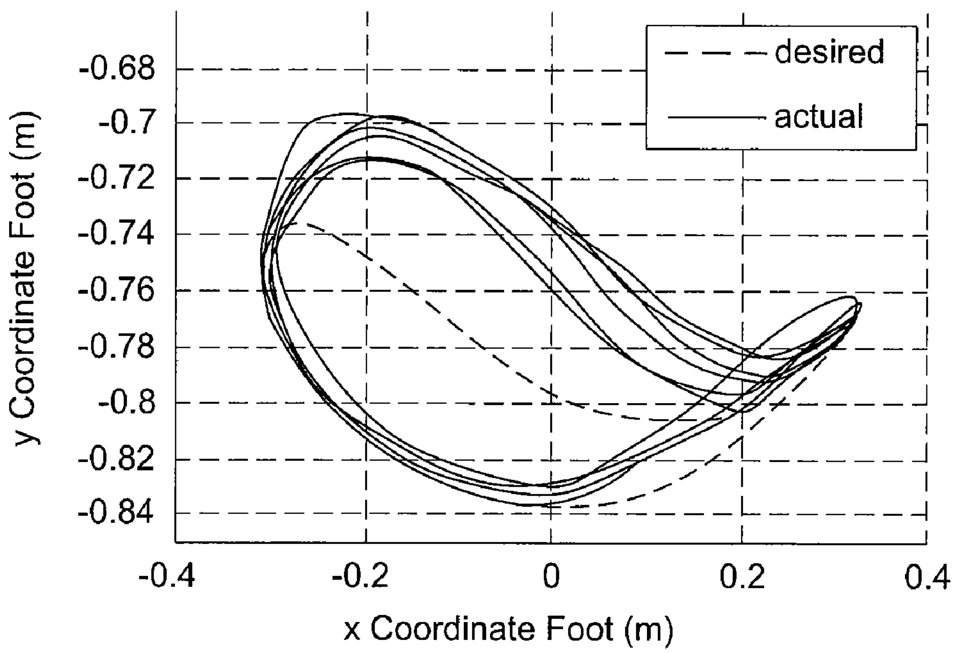

FIG. 10B

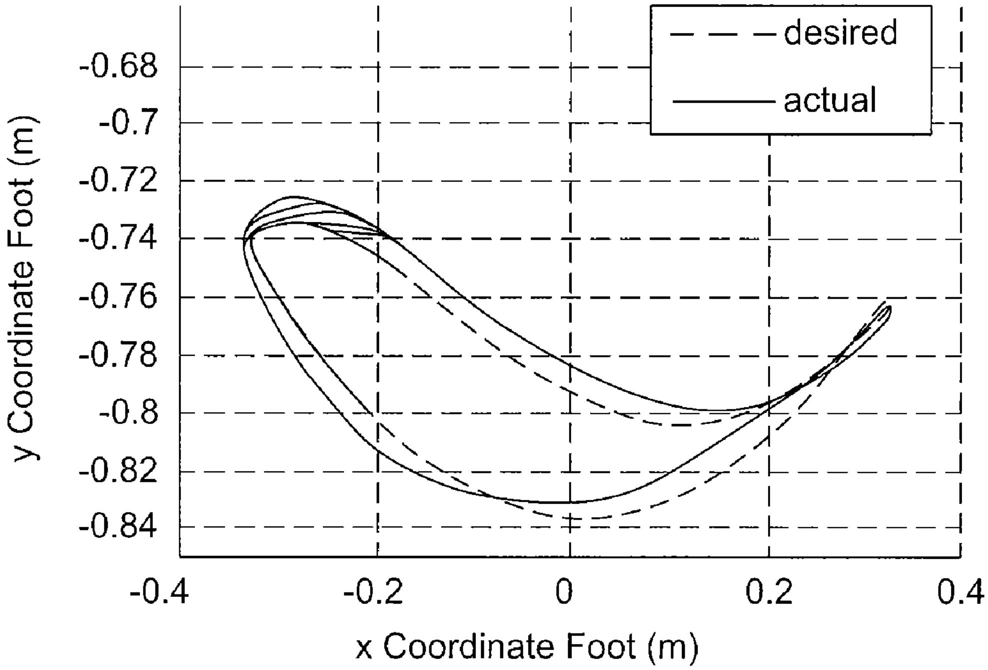

FIG. 10C

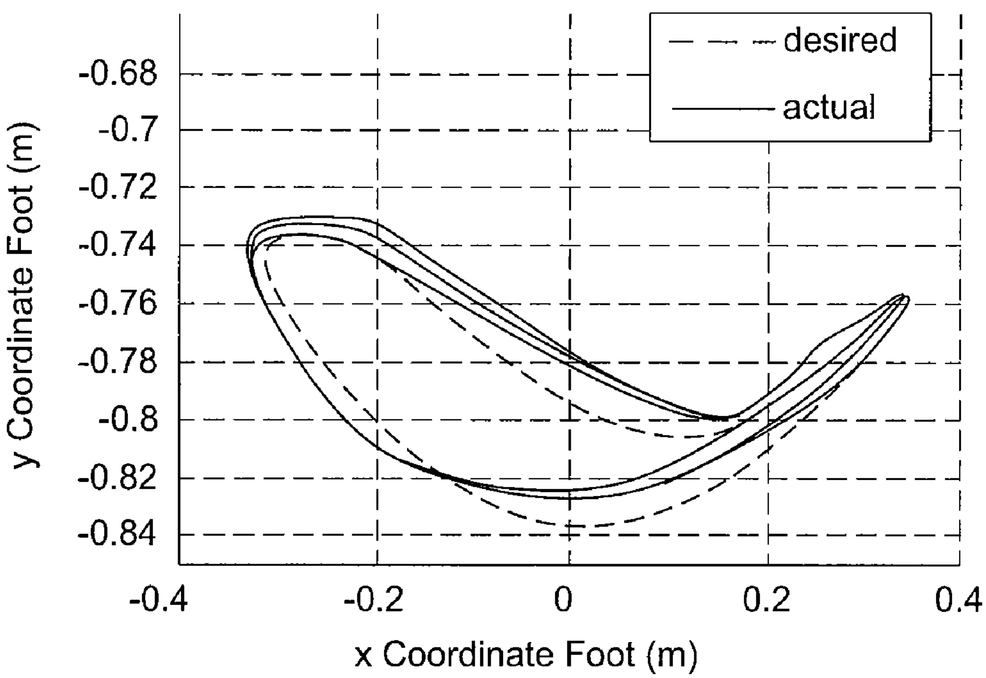

FIG. 10D

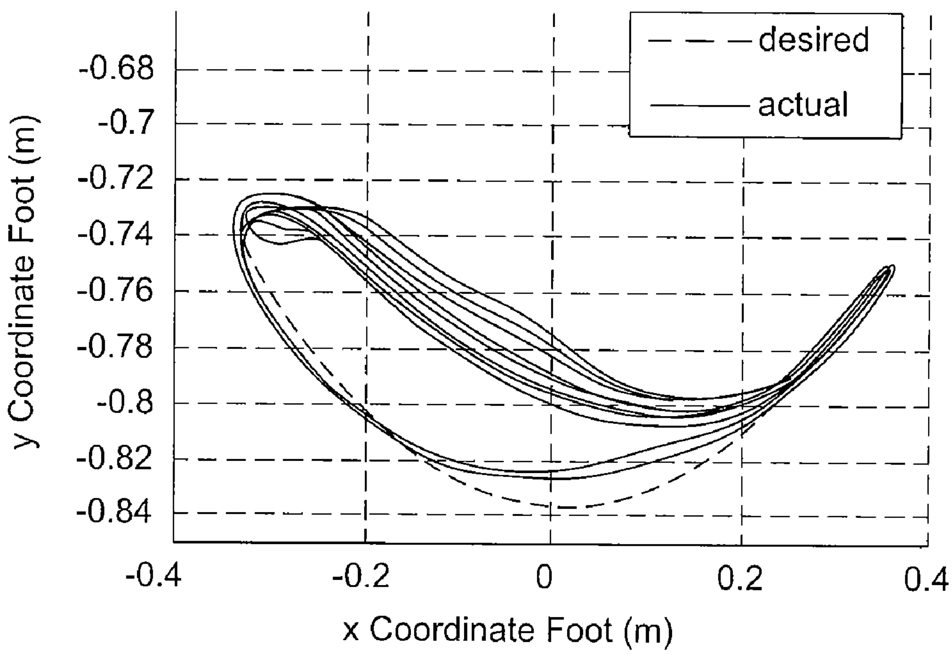

FIG. 10E

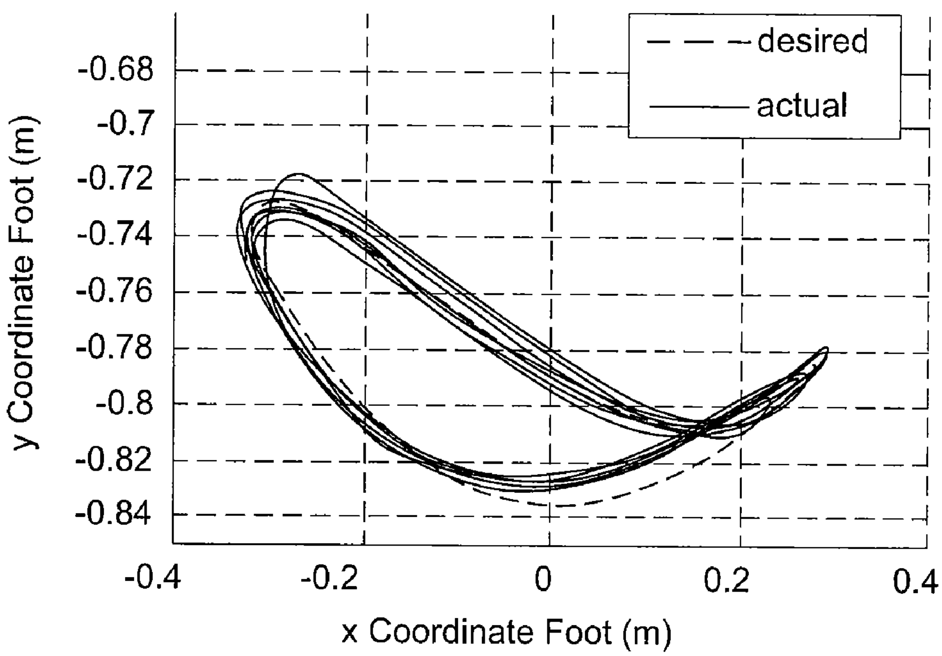

FIG. 10F

POWERED ORTHOSIS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application Ser. No. 60/922,216, filed Apr. 6, 2007, incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of NIH Grant #1 RO1 HD38582-01A2, awarded by the National Institutes of Health.

FIELD OF THE INVENTION

The present invention relates to an apparatus for assisting a user to move an extremity in a desired trajectory, such as an apparatus for applying forces to a user's leg to assist in gait rehabilitation of a patient with walking disabilities.

BACKGROUND OF THE INVENTION

Neurological injury, such as hemiparesis from stroke, results in significant muscle weakness or impairment in motor control. Patients experiencing such injury often have substantial limitations in movement. Physical therapy, involving rehabilitation, helps to improve the walking function. Such rehabilitation requires a patient to practice repetitive motion, specifically using the muscles affected by neurological injury. Robotic rehabilitation can deliver controlled repetitive training at a reasonable cost and has advantages over conventional manual rehabilitation, including a reduction in the burden on clinical staff and the ability to assess quantitatively the level of motor recovery by using sensors to measure interaction forces and torques in order.

Currently, available lower extremity orthotic devices can be classified as either passive, where a human subject applies forces to move the leg, or active, where actuators on the device apply forces on the human leg. One exemplary passive device is a gravity balancing leg orthosis, described in U.S. patent application Ser. No. 11/113,729 (hereinafter "the '729 application"), filed Apr. 25, 2005, and assigned to the assignee of the present invention, incorporated herein by reference. This orthosis can alter the level of gravity load acting at a joint by suitable choice of spring parameters on the device. This device was tested on healthy and stroke subjects to characterize its effect on gait.

Passive devices cannot supply energy to the leg, however, and are therefore limited in their ability compared to active devices. Exemplary active devices include T-WREX, an upper extremity passive gravity balancing device; the Lokomat® system, which is an actively powered exoskeleton designed for patients with spinal cord injury for use while walking on a treadmill; the Mechanized Gait Trainer (MGT), a single degree-of-freedom powered machine that drives the leg to move in a prescribed gait pattern consisting of a foot plate connected to a crank and rocker system that simulates the phases of gait, supports the subjects according to their ability, and controls the center of mass in the vertical and horizontal directions; the AutoAmbulator, a rehabilitation machine for the leg to assist individuals with stroke and spinal cord injuries and designed to replicate the pattern of normal gait; HAL, a powered suit for elderly and persons with gait deficiencies that takes EMG signals as input and produces appropriate torque to perform the task; BLEEX (Berkeley Lower Extremity Exoskeleton), intended to function as a human strength augmenter; and PAM (Pelvic Assist Manipulator), an active device for assisting the human pelvis motion. There are also a variety of active devices that target a specific disability or weakness in a particular joint of the leg.

A limiting feature of existing active devices, however, is that they move a subject through a predestined movement pattern rather than allowing the subject to move under his or her own control. The failure to allow patients to self-experience and to practice appropriate movement patterns may prevent changes in the nervous system that are favorable for relearning, thereby resulting in "learned helplessness," which is sub-optimal. Fixed repetitive training may cause habituation of the sensory inputs and may result in the patient not responding well to variations in these patterns. Hence, the interaction force between the human subject and the device plays a very important role in training. For effective training, the involvement and participation of a patient in voluntarily movement of the affected limbs is highly desirable. Therefore, there is a need in the art for devices that assist the patient as needed, instead of providing fixed assistance.

SUMMARY OF THE INVENTION

One aspect of the invention comprises a powered orthosis adapted to be secured to a corresponding body portion of a user for guiding motion of the user. The orthosis comprises a plurality of structural members and one or more joints adjoining adjacent structural members. Each joint has one or more degrees of freedom and a range of joint angles. One or more of the joints comprises at least one back-drivable actuator governed by at least one controller for controlling the joint angle. The one or more joint actuator controllers are synchronized to cause the corresponding joint actuators to generate forces for assisting the user to move the orthosis at least in part under the user's power along a desired trajectory within an allowed tolerance. The joint controllers may comprise set-point controllers or force-field controllers. In an embodiment in which the joint controllers comprise force-field controllers that define a virtual tunnel for movement of the orthosis, the forces applied to the orthosis for assisting the user are proportional to deviation from the desired trajectory, and may include tangential forces along the trajectory and normal forces perpendicular to the trajectory. Tangential forces are inversely proportional to the deviation from the desired trajectory, whereas the normal forces are directly proportional to the deviation from the desired trajectory.

Another aspect of the invention comprises a method for training a user to move a portion of the user's body in a desired trajectory. The method comprises securing the user to an orthosis as described above, and causing the synchronized joint controllers to operate the corresponding actuators to generate forces for assisting the user to move the orthosis at least in part under the user's power along a desired trajectory within an allowed tolerance. The method may further comprise providing visual feedback to the user that shows a relationship between the desired trajectory and an actual trajectory followed by the orthosis in response to movement by the user. In one embodiment, the method may comprise a method for rehabilitation of a patient with impaired motor control.

In one embodiment, the orthosis is a leg orthosis comprising a frame adapted to support at least a portion of the weight of the orthosis and the user, a trunk connected to the frame at one or more trunk joints, a thigh segment connected to the trunk at least a hip joint, a shank segment connected to the thigh segment at a knee joint, and optionally, a foot segment attached to the shank segment at an ankle joint. The hip joint may have at least one degree of freedom in the saggital plane governed by a first actuator and the knee joint may have at least one degree of freedom governed by a second actuator. A method of using such an embodiment may comprise training the user to adopt a desired gait.

Still another aspect of the invention comprises a method for training a healthy user to adopt a desired trajectory for a body motion, the method comprising securing the user to an orthosis as described herein and causing the synchronized joint controllers to operate the corresponding actuators to generate forces for assisting the user to move the orthosis at least in part under the user's power along the desired trajectory within an allowed tolerance.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description when read in connection with the accompanying drawings. It is emphasized that, according to common practice, various features/elements of the drawings may not be drawn to scale. On the contrary, the dimensions of the various features/elements may be arbitrarily expanded or reduced for clarity. Moreover, in the drawings, common numerical references are used to represent like features/elements. Included in the drawing are the following figures:

FIG. **1**A is a side perspective schematic drawing of an exemplary powered leg orthosis in accordance with the invention.

FIG. **1**B is a detailed view of selected joints from the schematic of FIG. **1**A.

FIG. **2** is an illustration of an overall gait training setup for use with the orthosis of FIG. **1**.

FIG. **3** is graph of exemplary frictional force data collected by experiment from a motor as a function of its linear velocity, which is illustrative of the type of data that can be incorporated into a friction model for calculation of friction compensation.

FIG. **4** is a schematic diagram of an exemplary PD controller.

FIG. **5** is a schematic illustration of the anatomical joint angle convention used in the equations discussed herein.

FIG. **6** is a schematic diagram of an exemplary force field controller.

FIG. **7** is an exemplary Cartesian plot of foot trajectory and the corresponding virtual tunnel associated with an exemplary force field controller.

FIG. **8** is a schematic diagram of forces normal and tangential to the foot trajectory.

FIG. **9**A is a plot of normal (U-shaped) and tangential (inverted V-shaped) force profiles as a function of distance from the center of the tunnel for different force field parameters (n).

FIG. **9**B is a plot of normal and tangential force profiles as a function of distance from the center of the tunnel for a relatively narrow tunnel.

FIG. **9**C is a plot of normal and tangential force profiles as a function of distance from the center of the tunnel for a relatively wide tunnel.

FIG. **9**D is a plot of normal and tangential force profiles as a function of distance from the center of the tunnel for exemplary narrow, medium, and wide tunnels.

FIG. **10**A is a plot of baseline actual normal gait trajectory for a human subject wearing the orthosis of FIG. **1**.

FIG. **10**B is a plot of a desired trajectory of FIG. **10**A rendered by distorting the baseline trajectory of FIG. **10**A, along with the actual trajectory of a human subject wearing the orthosis of FIG. **1** and attempting to match the desired trajectory using only visual feedback.

FIG. **10**C is a plot of training data for a user trying to match a desired foot trajectory while wearing the orthosis of FIG. **1** using a force-field controller with a relatively narrow virtual tunnel (D_n=−0.003, n=1, D_t−1, K_d=−30, K_t=50).

FIG. **10**D is a plot of training data for a user trying to match a desired foot trajectory while wearing the orthosis of FIG. **1** using a force-field controller with the same parameters as used while generating the plot in FIG. **10**C, but with a medium width virtual tunnel (D_n=0.006).

FIG. **10**E is a plot of training data for a user trying to match a desired foot trajectory while wearing the orthosis of FIG. **1** using a force-field controller with the same parameters as used while generating the plots in FIGS. **10**C and **10**D, but with a relatively wide virtual tunnel (D_n=0.008).

FIG. **10**F is a plot of training data for a user trying to match a desired foot trajectory while wearing the orthosis of FIG. **1** using no robotic assistance and no visual assistance, after completion of training with the force-field controller.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, an exemplary powered leg orthosis is schematically illustrated in FIGS. **1**A-**1**B. The exemplary orthosis is based upon the prototype passive Gravity Balancing Leg Orthosis described in the '729 application. The overall setup comprises frame **10**, trunk **20**, thigh segment **30**, shank segment **40**, and foot segment **50**. Frame **10** takes the weight of the entire device. Trunk **20** is connected to the frame through a plurality of trunk joints **21**_a_-**21**_d_ having four degrees-of-freedom. These degrees-of-freedom are vertical translation provided by parallelogram mechanism **21**_a_ having revolute joints **21**_d_, lateral translation via slider-block and slider-bar **21**_b_, rotation about vertical axis V at revolute joint **21**_c_, and rotation about horizontal axis H perpendicular to sagittal plane S at revolute joints **21**_d_. User **22** is secured to trunk **20** of the orthosis with a hip brace **24**.

Thigh segment **30** has two degrees-of-freedom with respect to trunk of the orthosis: translation in the sagittal plane along hip joint **26** and abduction-adduction about joint **27**, shown in FIG. **1**B. The thigh segment **30** may be telescopically adjustable to match the thigh length of a human subject. Shank segment **40** has one degree-of-freedom with respect to the thigh segment **30** about knee joint **42**, and may also be telescopically adjustable. Foot segment **50**, comprising a shoe insert, is attached to the shank of the leg with a one degree-of-freedom ankle joint **52**. Foot segment **50** comprises a structure that allows inversion-eversion motion of the ankle. The ankle segment described above is used when a human subject is in the device. At other times, such as during testing or setup, for example, a dummy leg may be used that does not have a foot segment.

Hip joint **26** in the sagittal plane and knee joint **42** are actuated using a first and second linear actuator **43** and **44**, respectively. These linear actuators **43**, **44** have encoders built into them for determining the joint angles. The physical interface between the orthosis and the subject leg is through two force-torque sensors: a first sensor **32** mounted between thigh segment **30** of the orthosis and the thigh user interface **34**, and a second sensor **33** mounted between shank segment **40** of the orthosis and the shank user interface **35**.

As shown in FIG. **1**A, frame **10** may comprise a base **12**, a pair of arm supports **14**, and an overhead weight support **16** from which some or all of the user's weight may be supported for users who need such assistance. A treadmill **72** is provided underneath the user between legs **11** of base **12**. Although shown with a treadmill **72** and static frame **10**, it should be noted that other configurations (not shown) may comprise a portable frame that allows the user to walk on solid ground rather than on a treadmill. Such portable configurations may comprise arm supports, such as in the form of a walker that rolls along with the user, or may not have such supports. Furthermore, while the design noted in FIG. **1**A shows two powered leg orthosis, other embodiments may have only a single powered orthosis, as is shown in FIG. **1**B, depending upon the needs of the user and purpose of the configuration.

An exemplary overall gait training setup **70** is shown in FIG. **2**. The user **22** walks on a treadmill **72** with orthosis **100** on the right leg only. The display **74** in front of the subject provides visual feedback of the executed gait trajectory. The visual display can be used to show the gait trajectory in real time during training. The subject's performance can be recorded from each training session. The trajectory can be recorded using either joint angles (in joint space) or the foot coordinates (in foot space). This motorized orthosis is architecturally similar to the passive leg described in the '729 application. A walker with a harness to the trunk may be used to keep the subject stable on the treadmill during exercise.

Referring now to FIG. **1**B, controllers connected to linear actuators **43** and **44** are used to create desired force fields on the moving leg as discussed in more detail below. The goal of these controllers is to assist or resist the motion of the leg at least in part under the user's power along a desired trajectory within an allowable tolerance, as needed, by applying force-fields around the leg. In this way, the user is not restricted to a fixed repetitive trajectory. Various types of controller methodologies may be used, including trajectory tracking controllers, set-point controllers, and force field controllers. Trajectory tracking controllers move the leg in a fixed trajectory, which is often not the most desirable way for gait training. Set-point control and force-field control use the concept of assistive force as needed, which is a functionality believed to be more desirable.

Trajectory Tracking Controller

In the trajectory tracking controller, desired trajectory $\Theta_d(t)$ is a prescribed function of time, whereas in set-point PD control, a finite number of desired set-points are used. The current set-point moves to the next point only when the current position is within a given tolerance region of the current set-point. Both the trajectory tracking controller and set-point PD controller use feedback linearized PD control in joint space. In a force-field controller, the forces are applied at the foot to create a tunnel or virtual wall-like force field around the foot. The patient using the orthosis for rehabilitation is then asked to move the leg along this tunnel. The set-points for the controller are chosen such that the density of points is higher in the regions of higher path curvature in the foot space.

To meet the challenging goal of using a light weight motor and at the same time requiring the motor to provide sufficient torque, a linear actuator driven by an electric motor may be used. Linear actuators typically cannot be back-driven, meaning that it is very hard to make the linear actuator move merely be applying force on it. This happens because the frictional and damping force in the lead screw of the motor gets magnified by its high transmission ratio. By using a suitable friction compensation technique, however, the motor can be made backdrivable.

Backdrivability of actuators is desirable for using force based control, because it makes it easier for the subject to move his or her leg without sizable resistance from the device. Exemplary friction compensation methods may comprise model based compensation, in which frictional forces are fed forward to the controller using a friction model obtained from experiments, or load-cell based compensation, in which load-cells are aligned with the lead screw of the linear actuator along with a fast PI controller.

For feed-forward friction compensation, a good friction model is required. Frictional force data may be collected by experiment from a motor as a function of its linear velocity, such as is shown in FIG. **3**. This behavior can be approximated with the equation:

$$F_{friction} = K_{fs}\,\mathrm{sign}(\dot{x}) + K_{fd}\dot{x}$$

where $\dot{x}$ is the linear velocity of the motor and K_{fs} and K_{fd} are constants.

The friction model is only an approximation and the actual friction has a complicated dependency on the load applied to the motor and on the configuration of the device. Some of the problems of model based friction compensation can be overcome by using a load cell in series and a fast PI controller with a suitable time constant.

Trajectory tracking controller tracks the desired trajectory using a feedback linearized PD controller. This controller is simple and is robust to friction with higher feedback gains. When used with friction compensation, small feedback gains can be used. FIG. **4** shows a schematic of an exemplary trajectory tracking PD control, in which Θ represents the joint angle, Θ_d the desired trajectory, and F_L the force measured by a load-cell. Switch SW**1** turns on the load-cell based friction compensation and switch SW**2** turns on the model-based friction compensation. Thus, the user may choose to use load-cell based friction compensation, which compensates whenever the load detects the user exerting a net force on the orthosis in the direction of travel indicating, or model-based compensation, which provides friction compensation along the trajectory based upon the direction and velocity of travel as derived from modeling. The model-based compensation tends to be more anticipatory, whereas the load-cell-based compensation is based more on feedback. A combination of compensation techniques may also be used, meaning that the model generally provides the compensation except when the load cell detects that additional compensation is needed. This same schematic applies to the set point controller, described herein later, except that for the set point controller $\dot{\theta}_d$ and $\ddot{\theta}_d$ are zero.

In this trajectory tracking controller, the desired trajectory in terms of joint angles is a function of time, $\Theta_d = \Theta_d(t)$. The desired trajectory may be obtained from healthy subject walking data, using experiments with a passive device. The equations of motion for the device are given below. Note that the frictional terms are not mentioned here, as they are assumed to be compensated using one of the two friction compensation methods outlined above.

Equations of Motion:

$$M\ddot{\theta} + C(\dot{\theta},\theta)\dot{\theta} + G(\theta) = \tau, \tag{1}$$

where $\theta = [\theta_h \theta_k]^T$ shown in FIG. **5**.

Control Law is given by:

$$\tau = M(\theta_d + K_d\dot{\theta}_e + K_p\theta_e) + C(\dot{\theta},\theta)\dot{\theta} + G(\theta),\ \text{where } \theta_e = \theta_d - \theta$$

This law linearizes the equations to an exponentially stable system:

$$\ddot{\theta}_e + K_d\dot{\theta}_e + K_p\theta_e = 0 \tag{2}$$

where

$$K_p = \begin{pmatrix} K_{p1} & 0 \\ 0 & K_{p2} \end{pmatrix} \text{ and } K_d = \begin{pmatrix} K_{d1} & 0 \\ 0 & K_{d2} \end{pmatrix}$$

are positive matrices.

Experimental Results

One way to use small feedback gains is to use friction compensation. If desired trajectory is a function of time, the error in any joint may keep increasing if that joint is prevented from moving. This may cause the force in the motor of that joint to increase with the error. One set of experimental results found that applying external forces caused forces in the hip motor to almost double. This increase in forces when the subject wishes not to move the leg may not be safe or suitable for training.

Set-Point PD Controller

A set-point PD controller is similar to trajectory tracking controller except that there are a finite number of desired trajectory points $((\theta_{d1}, \theta_{d2}, \ldots, \theta_{dn})$ and desired trajectory velocities and accelerations are set to zero ($\dot{\theta}_d = \ddot{\theta}_d = 0$). The controller takes the device to the current set-point. Once the current position of the device is close to the current set-point, the current set-point is switched to the next set-point. If the number of set-points is small, the device motion is jerky. By choosing a sufficient number of points, however, the leg trajectory can be made smooth.

One of the advantages of set-point PD controller over a trajectory tracking controller is that if the human subject wishes to stop the device, the forces on the leg stays within limit, and the set-point will not change.

The control law is same as the one used in the trajectory tracking PD controller with desired trajectory velocities and accelerations set to zero ($\dot{\theta}_d = \ddot{\theta}_d = 0$). The current setpoint $\theta_{cur} = \theta_1$ advances to the next set-point θ_{i+1} if $\|\theta - \theta_{cur}\| = \epsilon$, where ϵ is the allowed tolerance.

Simulated and Experimental Results with Set-Point Controller

Simulations and experiments were performed for three sets of feedback gains chosen such that the natural frequency of the system described in Eq. (2) was $\omega_n = 10.12$ and $\xi = \{3.2, 0.5\}$. The simulation essentially comprised coupling a model of a human leg and body dynamics to a model of the powered orthosis and controllers, and running the models together to predict how the system would work on a human subject. For greater values of damping, it was found that the joint trajectories lied inside the desired trajectory due to slowing effects of damping. At lesser values of damping, it was found that the trajectories fluctuated around the desired trajectory due to faster speeds and overshoots.

Force-Field Controller

The goal of a force-field controller is to create a force field around the foot in addition to providing damping to it. This force field is shaped like a "virtual tunnel" around the desired trajectory. FIG. **6** shows the basic structure of the controller, wherein FL is the force measured by the load-cell. Switch SW**1** turns on sensor-based friction compensation and switch SW**2** turns on model-based friction compensation, as described above with respect to the PD controller. The force-field controller also uses gravity compensation to help the human subject. This assistance can be reduced or completely removed if required. FIG. **7** shows a typical shape of the virtual tunnel walls (dashed lines) around the desired trajectory (solid line) for a cartesian plot of the foot in the trunk reference frame, with the origin set at the hip joint.

Because the virtual tunnel is used to guide the foot of the subject, the forces are applied on the foot, as illustrated in part in FIG. **8**. These forces are a combination of tangential force (F_t) along the trajectory, normal force (F_n) perpendicular to the trajectory, which are proportional to a deviation from the desired trajectory, and damping force (F_d) (not shown). The controller may be designed such that this normal component keeps the foot within the virtual tunnel. The tangential force provides the force required to move the foot along the tunnel in forward direction and is inversely proportional to the deviation from the desired trajectory. The normal force is directly proportional to the deviation from the desired trajectory. The damping force minimizes oscillations, as discussed previously.

Where P is the current position of the foot in the Cartesian space in the reference frame attached to trunk of the subject, N is the nearest point to P on the desired trajectory, $\hat{n}$ is the normal vector from P to N, and $\hat{t}$ is the tangential vector at N along the desired trajectory in forward direction, the force F on the foot is defined as:

$$F = F_t + F_n + F_d \tag{3}$$

$$F_t = K_{Ft}(1 - d/D_t)\hat{t}, \text{ if } d/D_t < 1$$

$$F_t = 0, \text{ otherwise} \tag{4}$$

where F_t is the tangential force, F_n is the normal force and F_d is the damping force. The tangential force F_t is defined as:

$$F_n = \left(\frac{d}{D_n}\right)^{2(n+1)} \hat{n} \tag{5}$$

The damping force F_d on the foot to reduce oscillations is given by:

$$F_d = -K_d \dot{x} \tag{6}$$

where K_{Ft}, D_t, D_n and K_d are constants, d is the distance between the points P and N, and $\dot{x}$ is the linear velocity of the foot.

The shape of the tunnel is given by Eq. (5). The higher the value of n, the steeper the walls, as shown in FIG. **9**A. Also, at higher values of n, the width of the tunnel gets closer to D_n. FIGS. **9**B and **9**C show exemplary plots of tangential and normal forces for relatively narrow (**9**B) and relatively wide (**9**C) virtual tunnels, as a function of distance d from the desired trajectory, where a positive force points towards the trajectory. The tangential force ramps down as the distance d increases, bringing the leg closer to the trajectory before applying tangential force.

The required actuator inputs at the leg joints that apply the above force field F is given by:

$$\tau_m = \begin{bmatrix} \tau_{m1} \\ \tau_{m2} \end{bmatrix} = J^T F + G(\theta) \tag{7}$$

where $G(\theta)$ is for gravity compensation, τ_m=motor torque, and J^T is a Jacobian matrix relating the joint speed to the end point speed. Finally, the forces in the linear actuators $F_m = [F_{m1}, F_{m2}]$ are computed using the principle of virtual work, given by:

$$F_{mi} = \frac{\dot{\theta}_i}{\dot{l}_i} \tau_{mi} \quad i = 1, 2,$$

where I_i is the length if the i^{th} actuator.

Simulated and Experimental results with Force Field Controller

Simulations performed using the parameters shown in FIGS. **9**B and **9**C showed that the error between the desired trajectory and the actual trajectory achieved was less for the relatively smaller virtual tunnel as compared to the relatively wider virtual tunnel, demonstrating that the maximum deviation of the foot from the desired trajectory can be controlled using the width of the tunnel D_n as the parameter. When K_{Ft} was increased and all other parameters were kept the same, the tangential forces also increased, reducing the gait cycle period, demonstrating that K_{Ft} can be used as a parameter to change the gait time period.

Experiments with the force field controller were conducted with healthy subjects in the device at three tunnel widths shown in the FIG. **9**D. These results showed that as the tunnel is made narrower, the actual human gait trajectory gets closer to the desired trajectory.

The experiments involved six healthy subjects, divided into two groups, each consisting of three experimental and three control. The subjects donned the device and the joints of the machine and the human were aligned. The subjects walked on a treadmill with a speed of 2 mph and their baseline foot trajectory was recorded, as shown in FIG. **10**A. A template was matched to this recorded foot trajectory and then was distorted by roughly 20% along the two Cartesian directions to generate a distorted template for the foot motion, as outlined by the dashed line in FIG. **10**B.

Each subject tried to match this distorted template voluntarily for ten minutes using visual feedback of the foot trajectory. As shown by the solid lines in FIG. **10**B, the subjects were not able to easily change the foot trajectory using only visual feedback. The experimental group was then given robotic training in three ten-minute sessions using narrow, wider, and widest tunnel widths, as illustrated in FIGS. **10**C, **10**D, and **10**E. At the end of these three sessions, the robotic assistance and the visual feedback were taken away. The gait data of the subject was recorded by joint sensors on the robot. The control group practiced matching the distorted gait template over three **10** minute sessions using only visual feedback. At the end of these three sessions, the visual feedback was taken away and the foot trajectory data was recorded, as shown in FIG. **10**F. This data shows that the experimental group was able to learn the distorted gait pattern using the robotic force field. Data from the control group did not show any marked learning between pre and post training data.

Various Embodiments

While the exemplary leg orthosis described herein comprises linear actuators at the hip joint and knee joint, with force-torque sensors and encoders, the invention is not limited to any particular type of actuator. Although the controllers were used with either model based or load-cell based friction compensation to make the linear actuators back-drivable, with load-cell based friction compensation being preferable, the invention is not limited to any particular type of friction compensation or method for making the actuators back-drivable. Back-drivability of the actuators is important for making the device responsive to human applied forces by not resisting the motion.

Three types of controllers are described herein for controlling the actuator: trajectory tracking PD controllers, set point PD controllers, or a force-field controllers. The set-point controller and force-field controller were found to be more desirable for training because the forces on the user do not increase if the user wishes to stop the motion of his leg. In a set-point controller, because the set-point always lies ahead of the human leg position along the trajectory by a specified amount, irrespective of the direction of motion of the leg, the interaction forces move the leg along the trajectory and do not increase in magnitude indefinitely. This feature is further augmented by the guiding nature of the tunnel walls in force-field controller. In both these controllers, the addition of damping forces in the controller makes sure that the velocities of the leg lie within safe limits. As shown in previous sections, various parameters can be chosen to apply suitable forces that can assist desirable motion and resist undesirable motion of the leg, and are suitable for rehabilitation of a lower extremity. Although three types of controllers have been described, with relative advantages of each, the invention is not limited to any particular type of controller, control methodology, or control logic.

Furthermore, while a particular leg orthosis design is described herein, the invention is not limited to any particular orthosis design, nor is it limited only to use in connection with leg orthoses. Finally, although the invention has great utility in physical therapy and rehabilitation applications, such as for assisting a patient with recovery from a stroke or other impairment, the experimental data showing the ability for healthy subjects to change their gait to mimic a programmed trajectory shows that this invention has other utility as well.

For example, the invention may be applied to athletic training, in which, for example, a runner wishes to change a small aspect of his or her stride to shave seconds off of his or her time. Using encoders in the actuators, the subject can record his or her preexisting foot trajectory while wearing the orthosis, modify stored foot trajectory data to reflect the desired trajectory, and then begin walking or running while wearing the orthosis with robotic feedback to guide the user's foot into the desired trajectory. Visual feedback can further help the user to hone his or her trajectory. The training can be continued for a sufficient amount of time and/or number of repetitions for the user to develop muscle memory for the new trajectory. Similarly, orthoses designed for other parts of the body may be used to improve the mechanics of a baseball pitch, a tennis serve, a golf swing, and the like, to name only a few of limitless examples. Furthermore, if the trajectory of a particular person is deemed to be ideal or desirable, the person with the ideal trajectory can record his or her trajectory, and that trajectory can then be used as the guide for users wishing to adopt the desired trajectory. The ideal or desirable trajectory may be proportionately or otherwise manipulated as required to account for differences in body size or structure between the user and the person with the desirable trajectory.

Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

What is claimed:

1. A powered orthosis adapted to be secured to a corresponding body portion of a user for guiding motion of the user, the orthosis comprising:

a plurality of structural members; and

one or more joints adjoining adjacent structural members, each joint having one or more degrees of freedom and a range of joint angles, one or more of the joints comprising:

at least one back-drivable actuator governed by at least one joint actuator controller for controlling the joint angle, the one or more joint actuator controllers comprising force-field controllers that define a virtual tunnel for movement of the orthosis, the force-field controllers synchronized to cause the corresponding joint actuators to generate forces for assisting the user to move the orthosis at least in part under the user's power along a desired trajectory within an allowed tolerance, the generated forces comprising tangential forces along the desired trajectory and normal forces perpendicular to the trajectory, the tangential forces being inversely proportional and the normal forces being directly proportional to deviation from the desired trajectory.

2. A system for training a user to move a portion of the user's body in a desired trajectory, the system comprising
the powered orthosis of claim 1, and
a visual display configured to provide real-time visual feedback to the user showing a relationship between a desired trajectory and an actual trajectory followed by the orthosis in response to movement by the user.

3. A system for training a user to move a portion of the user's body in a desired trajectory, the system comprising
a powered orthosis adapted to be secured to a corresponding body portion of a user for guiding motion of the user, the orthosis comprising:
a plurality of structural members; and
one or more joints adjoining adjacent structural members, each joint having one or more degrees of freedom and a range of joint angles, one or more of the joints comprising:
at least one back-drivable actuator governed by at least one joint actuator controller for controlling the joint angle, the one or more joint actuator controllers comprising force-field controllers that define a virtual tunnel for movement of the orthosis, the force-field controllers synchronized to cause the corresponding joint actuators to generate forces for assisting the user to move the orthosis at least in part under the user's power along a desired trajectory within an allowed tolerance; and
a visual display configured to provide real-time visual feedback to the user showing a relationship between the desired trajectory and an actual trajectory followed by the orthosis in response to movement by the user.

4. The system of claim 3, wherein the forces generated by the joint actuators and applied to the orthosis for assisting the user are proportional to deviation from the desired trajectory.

5. The system of claim 3, wherein the applied forces comprise tangential forces along the trajectory and normal forces perpendicular to the trajectory, in which the tangential forces are inversely proportional and the normal forces are directly proportional to the deviation from the desired trajectory.

6. The system of claim 3, wherein the forces comprise damping forces.

7. The system of claim 3, wherein the orthosis is a leg orthosis comprising a frame, a trunk connected to the frame at one or more trunk joints, a thigh segment connected to the trunk at least a hip joint, and a shank segment connected to the thigh segment at a knee joint.

8. The powered orthosis of claim 7, wherein the frame is adapted to support at least a portion of the weight of the orthosis and the user.

9. The powered orthosis of claim 7, further comprising a foot segment attached to the shank segment at an ankle joint.

10. The powered orthosis of claim 7, wherein the hip joint has at least one degree of freedom in the sagittal plane governed by a first actuator and the knee joint has at least one degree of freedom governed by a second actuator.

11. The powered orthosis of claim 10, wherein the first actuator and the second actuator each comprise linear actuators having friction compensation sufficient to make the actuators back-drivable.

12. The powered orthosis of claim 7, further comprising a first connector for connecting the orthosis thigh segment to a corresponding thigh of a user and a shank connector for connecting the orthosis shank segment to a corresponding shank of a user, the first connector having a first force-torque sensor to measure net forces between the user and the orthosis, and the second connector having a second force-torque sensor to measure net forces between the user and the orthosis.

13. A method for training a user to move a portion of the user's body in a desired trajectory, the method comprising:
(a) securing the user to an orthosis comprising a plurality of exoskeletal members and a plurality of joints each having one or more degrees of freedom and a spectrum of joint angles between adjacent members connected at the joint, a plurality of the joints each comprising at least one backdrivable actuator governed by a controller for controlling the joint angle, the plurality of joint controllers synchronized with one another;
(b) causing the synchronized joint controllers to operate the corresponding actuators to generate forces for assisting the user to move the orthosis at least in part under the user's power along a desired trajectory within an allowed tolerance; and
(c) providing visual feedback to the user that shows a relationship between the desired trajectory and an actual trajectory followed by the orthosis in response to movement by the user.

14. The method of claim 13, wherein the joint controllers comprise force-field controllers that define a virtual tunnel for movement of the orthosis, the method comprising in step (b) generating forces for assisting the user that are proportional to deviation of the actual trajectory from the desired trajectory.

15. The method of claim 14, comprising generating tangential forces along the trajectory inversely proportional to the deviation from the desired trajectory and normal forces perpendicular to the desired trajectory directly proportional to the deviation from the desired trajectory.

16. The method of claim 13, wherein the orthosis comprises a leg orthosis comprising a frame adapted to support at least a portion of the weight of the orthosis and the user, a trunk connected to the frame at one or more trunk joints, a thigh segment connected to the trunk at least a hip joint, and a shank segment connected to the thigh segment at a knee joint, and a foot segment attached to the shank segment at an ankle joint, the hip joint having at least one degree of freedom in the sagittal plane governed by a first actuator and the knee joint having at least one degree of freedom governed by a second actuator, the method comprising training the user to move the user's leg in a desired gait.

17. A method for rehabilitation of a patient with impaired motor control, comprising training the user to move a portion of the user's body in a desired trajectory in accordance with the method of claim 13.

18. A method for training a healthy user to adopt a desired trajectory for a body motion, the method comprising:
(a) securing the user to an orthosis comprising a plurality of exoskeletal members and a plurality of joints each having one or more degrees of freedom and a spectrum of joint angles between adjacent members connected at the joint, a plurality of the joints each comprising at least one back-drivable actuator governed by a controller for controlling the joint angle, the plurality of joint controllers synchronized with one another;
(b) causing the synchronized joint controllers to operate the corresponding actuators to generate forces for assisting the user to move the orthosis at least in part under the user's power along the desired trajectory within an allowed tolerance; and
(c) providing visual feedback to the user that shows a relationship between the desired trajectory and an actual trajectory followed by the orthosis in response to movement by the user.

* * * * *

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Bayerlein et al.

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(45) Date of Patent: Nov. 13, 2012

(54) **TREADMILL WITH INTEGRATED WALKING REHABILITATION DEVICE**

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(51) **Int. Cl.**

A63B 22/02	(2006.01)
A61H 1/00	(2006.01)
A61H 1/02	(2006.01)
A61H 5/00	(2006.01)

(52) **U.S. Cl.** **482/54**; 601/34; 601/35

(58) **Field of Classification Search** 482/1–9, 482/51–52, 54, 66, 69–70, 79–80, 111, 133–139, 482/142, 145, 901; 119/700; 434/247, 255; 601/5, 23, 33–36; *A63B 22/02; A61H 1/00, A61H 1/02, 5/00*

See application file for complete search history.

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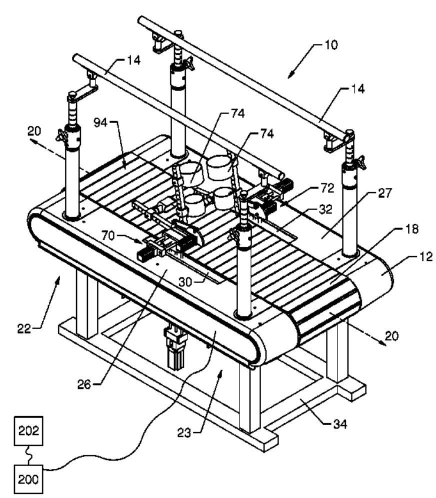
Primary Examiner — Oren Ginsberg
(74) *Attorney, Agent, or Firm* — Foley & Lardner LLP

(57) **ABSTRACT**

A treadmill for providing walking rehabilitation to a rehabilitee is provided including a base including a belt and a walking rehabilitation device interconnected with the base. The walking rehabilitation device includes a user engagement structure extending at least partially above the belt and being configured to be removably secured relative to one or more locations of a rehabilitee's lower extremities. The walking rehabilitation device further includes a plurality of drive systems coupled to the user engagement structure. The drive systems include at least a first drive system controlling the rehabilitee's motion in a first direction and a second drive system controlling the rehabilitee's motion in a second direction. The treadmill further includes one or more motors coupled to and driving the plurality of drive systems. The motion from the drive systems is transferred to the rehabilitee by the user engagement structure, allowing the rehabilitee to walk along the belt.

22 Claims, 11 Drawing Sheets



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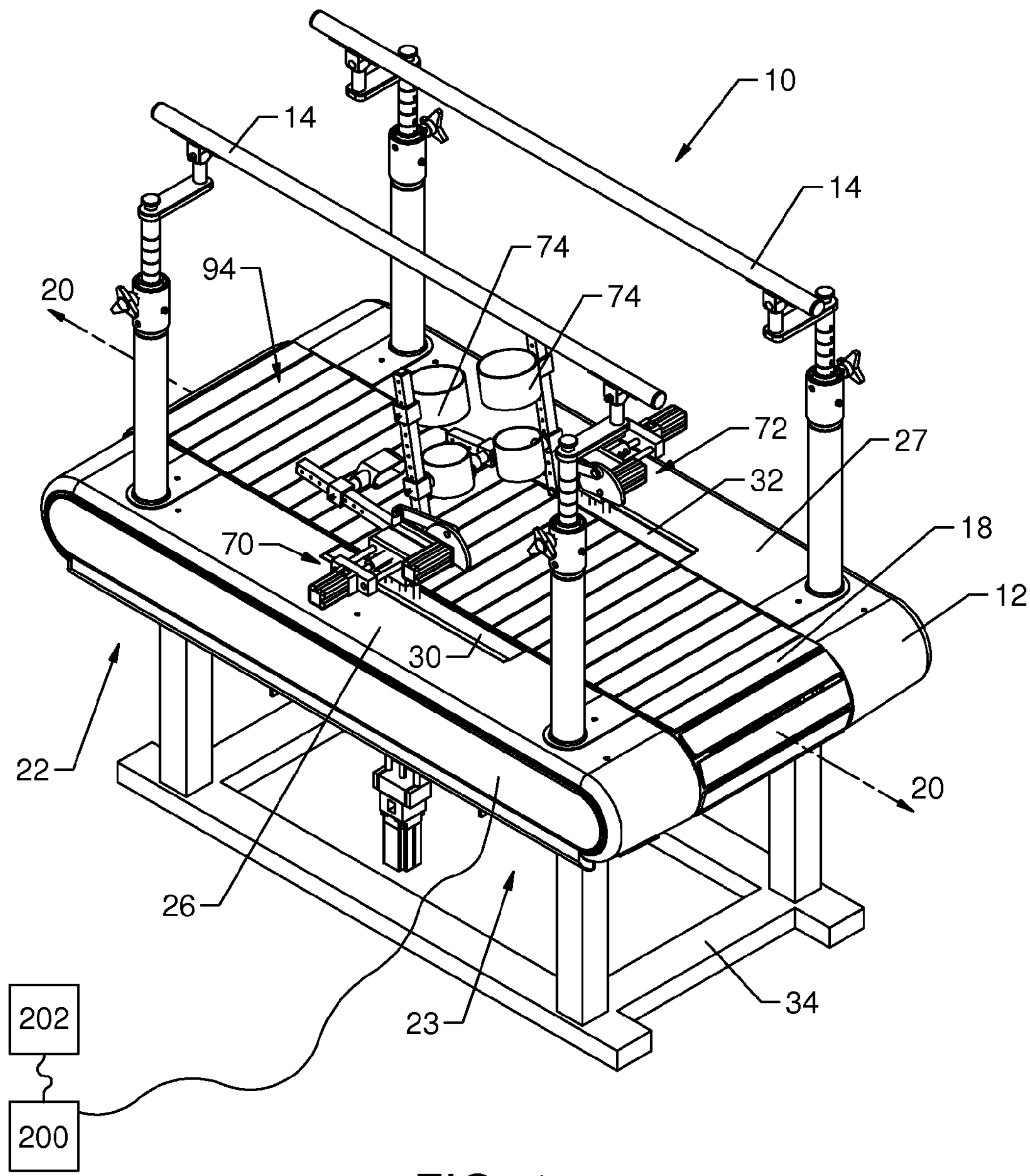

FIG. 1

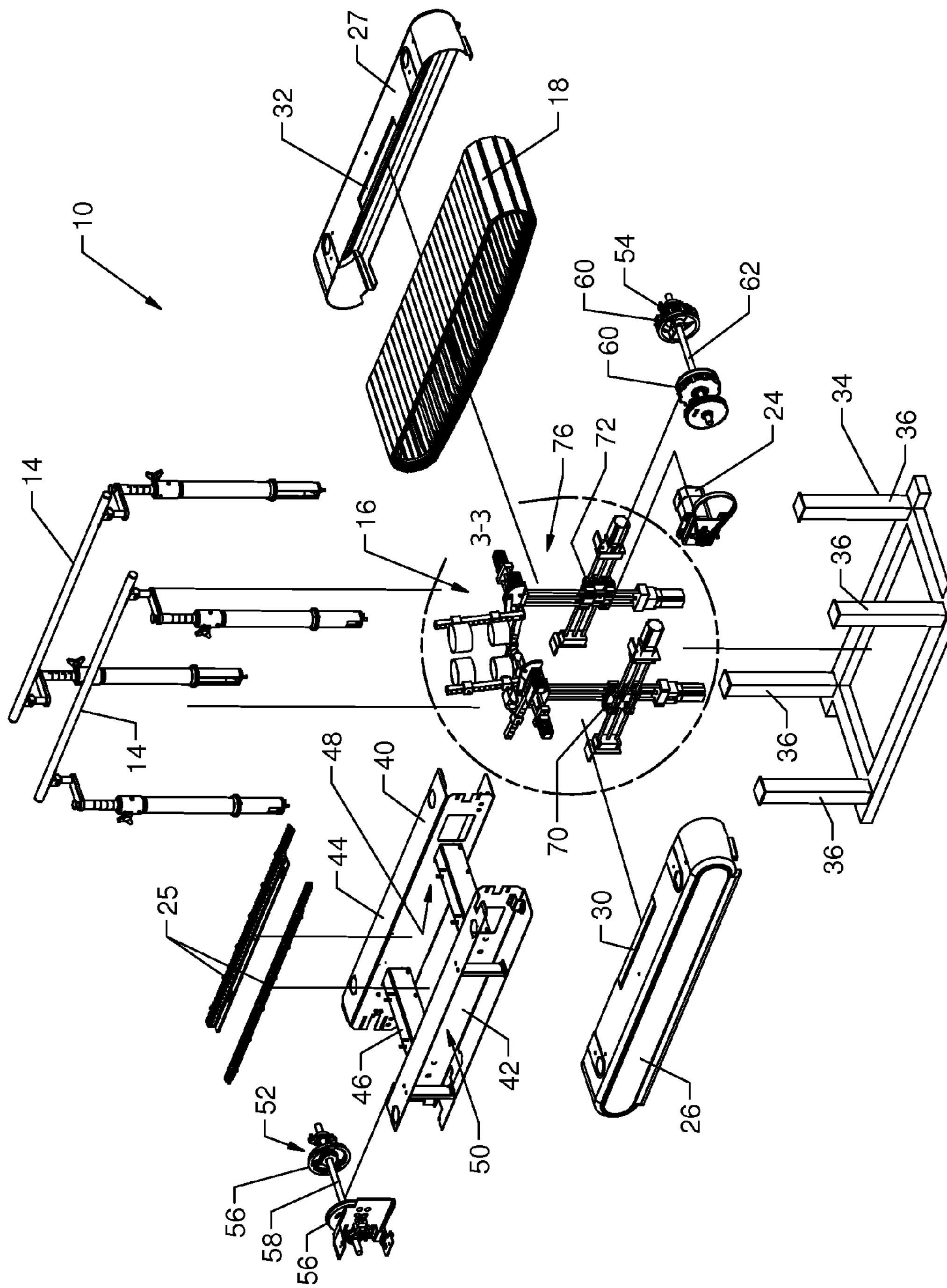
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FIG. 2

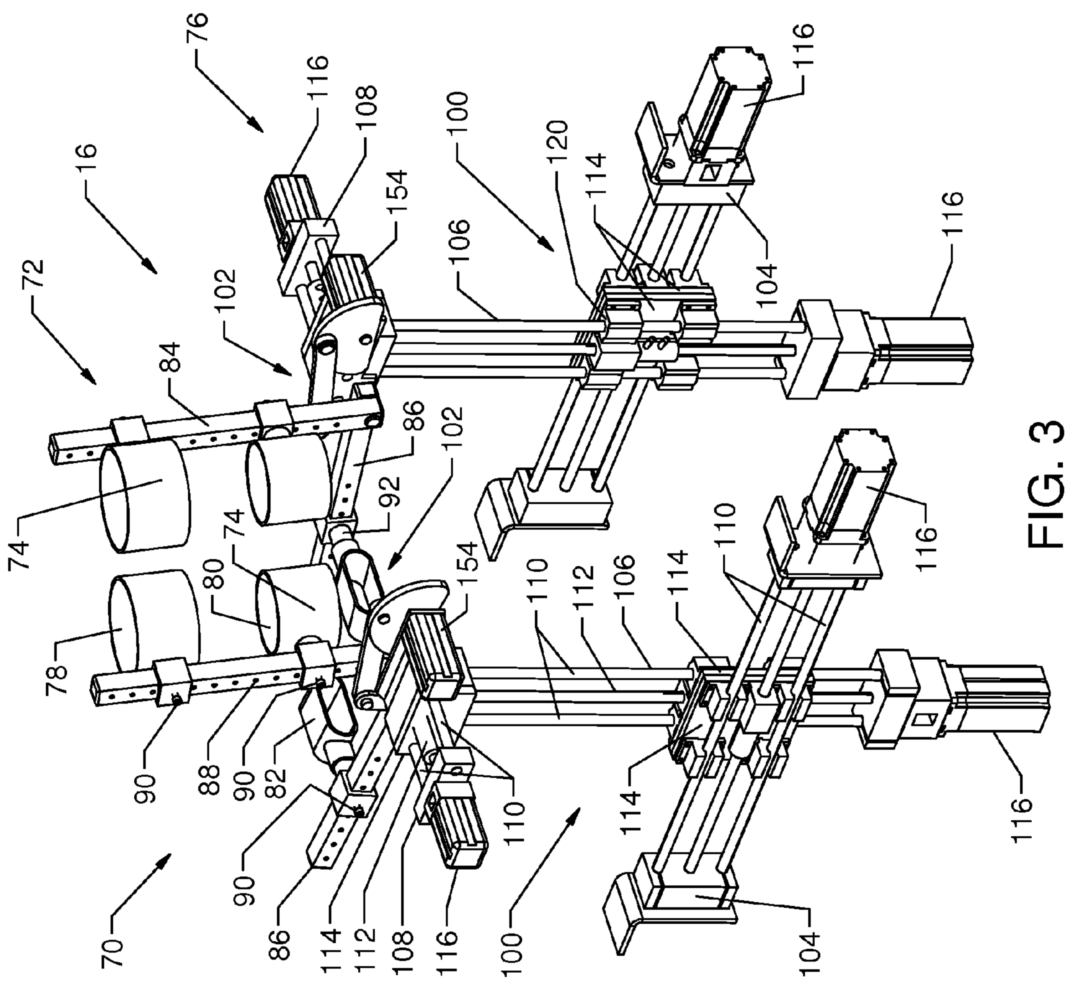
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FIG. 3

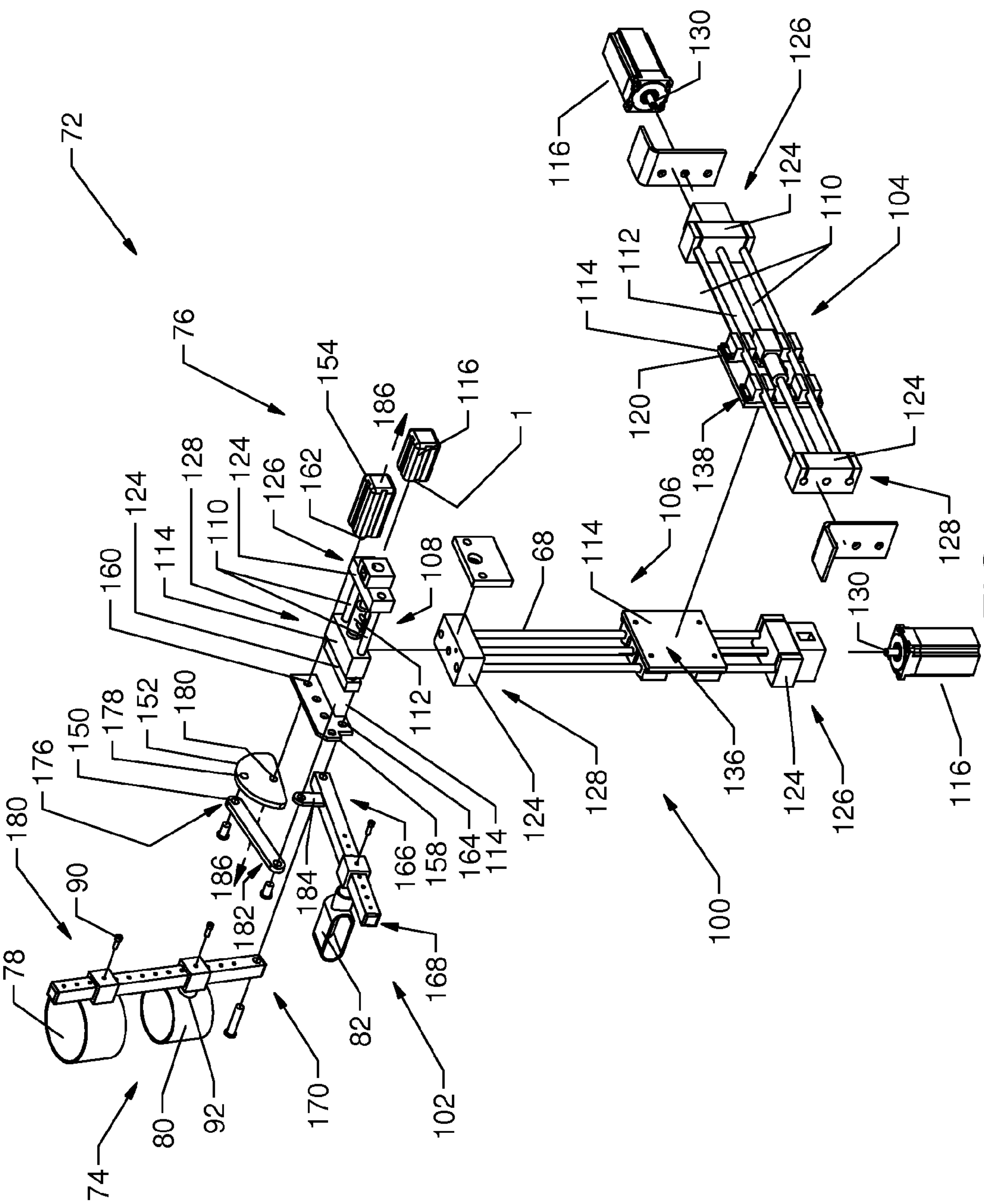
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FIG. 4

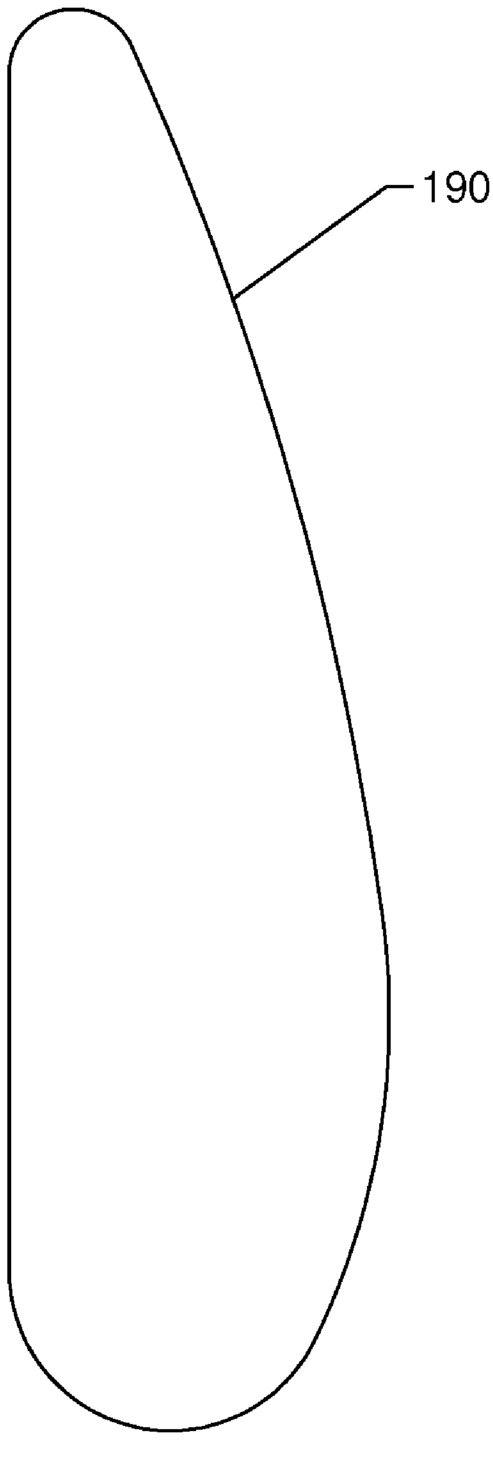

FIG. 5

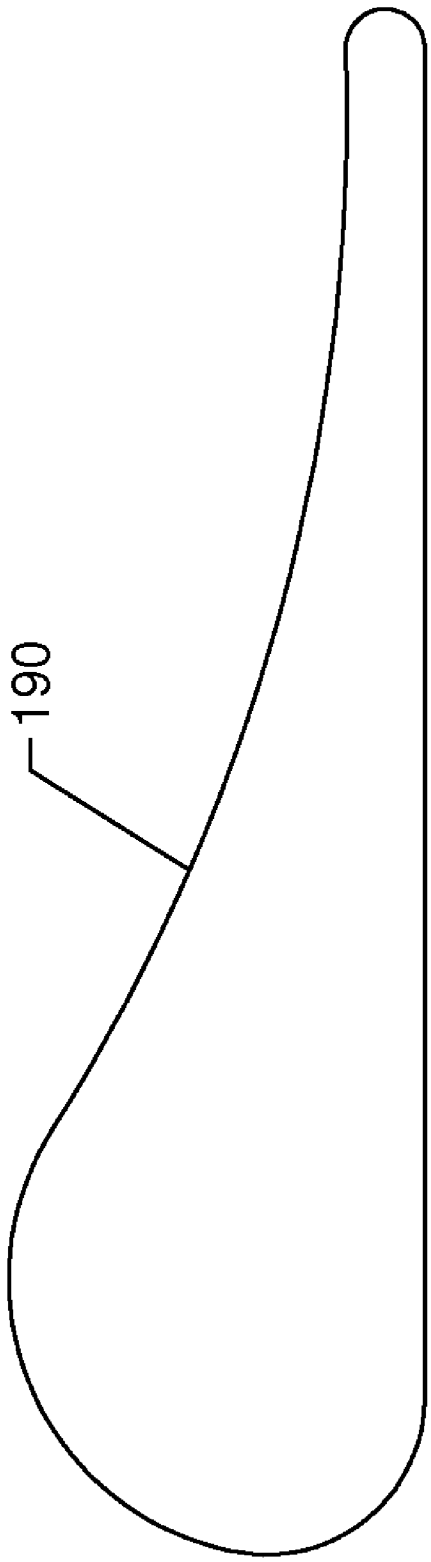

FIG. 6

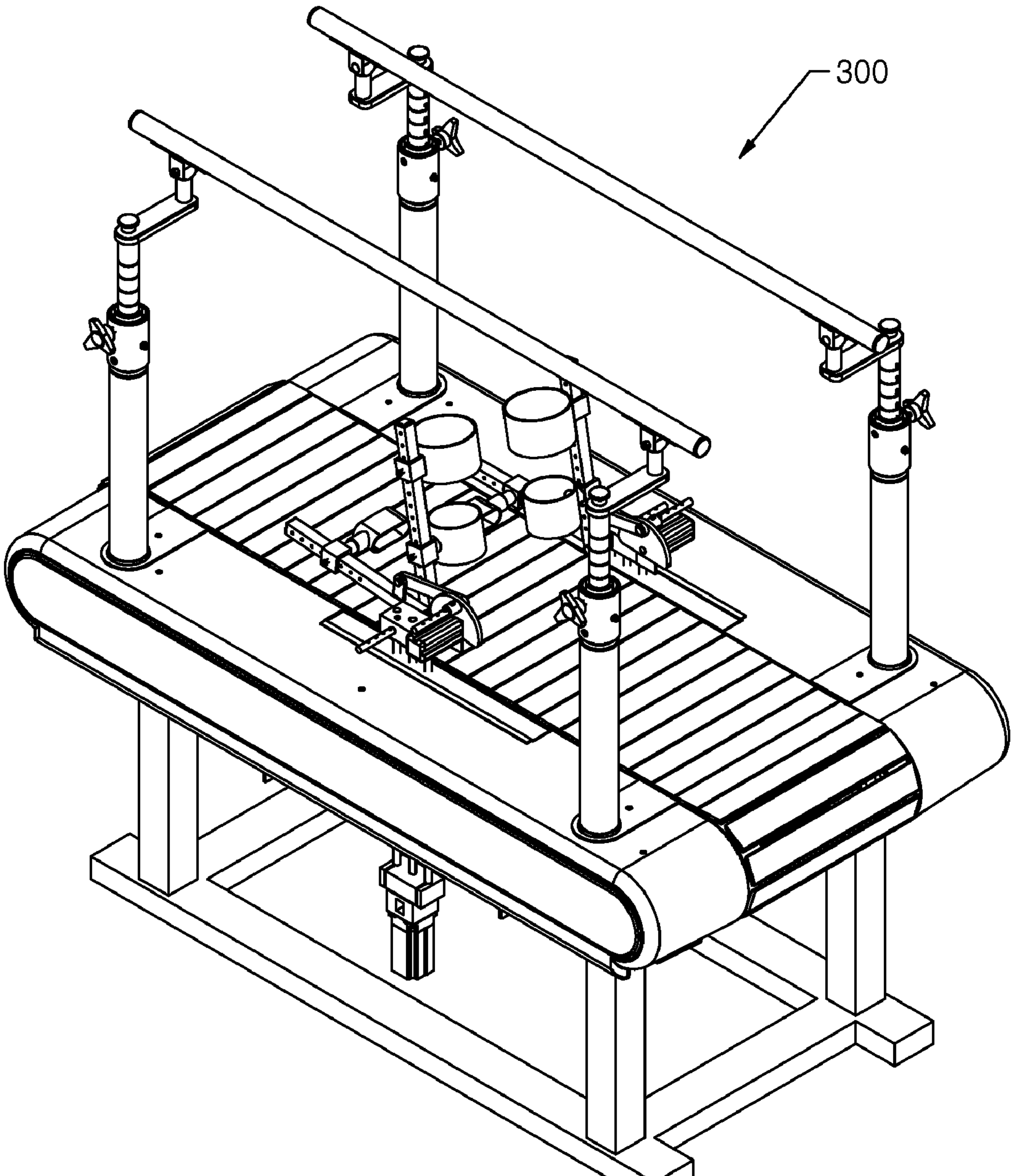

FIG. 7

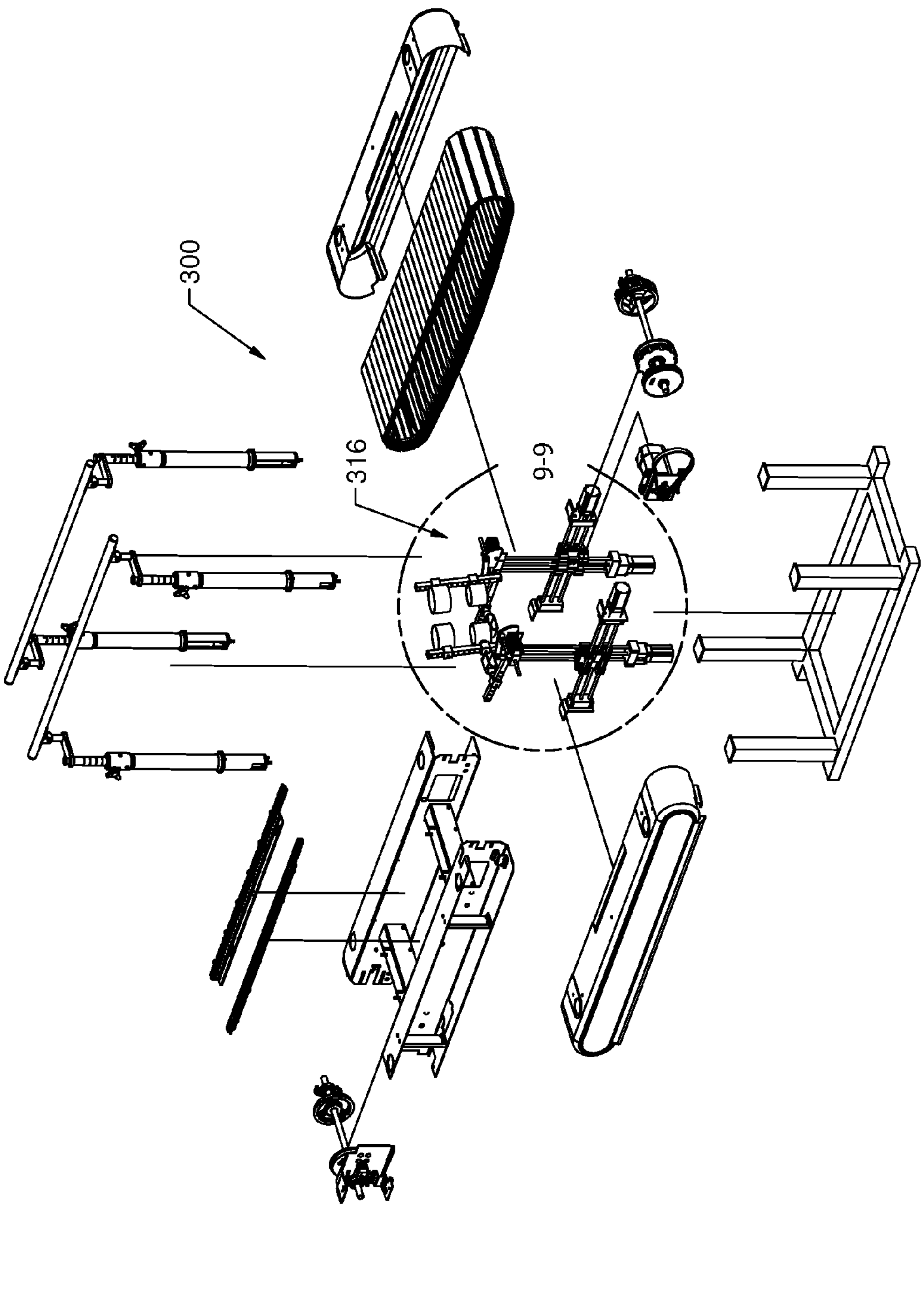

FIG. 8

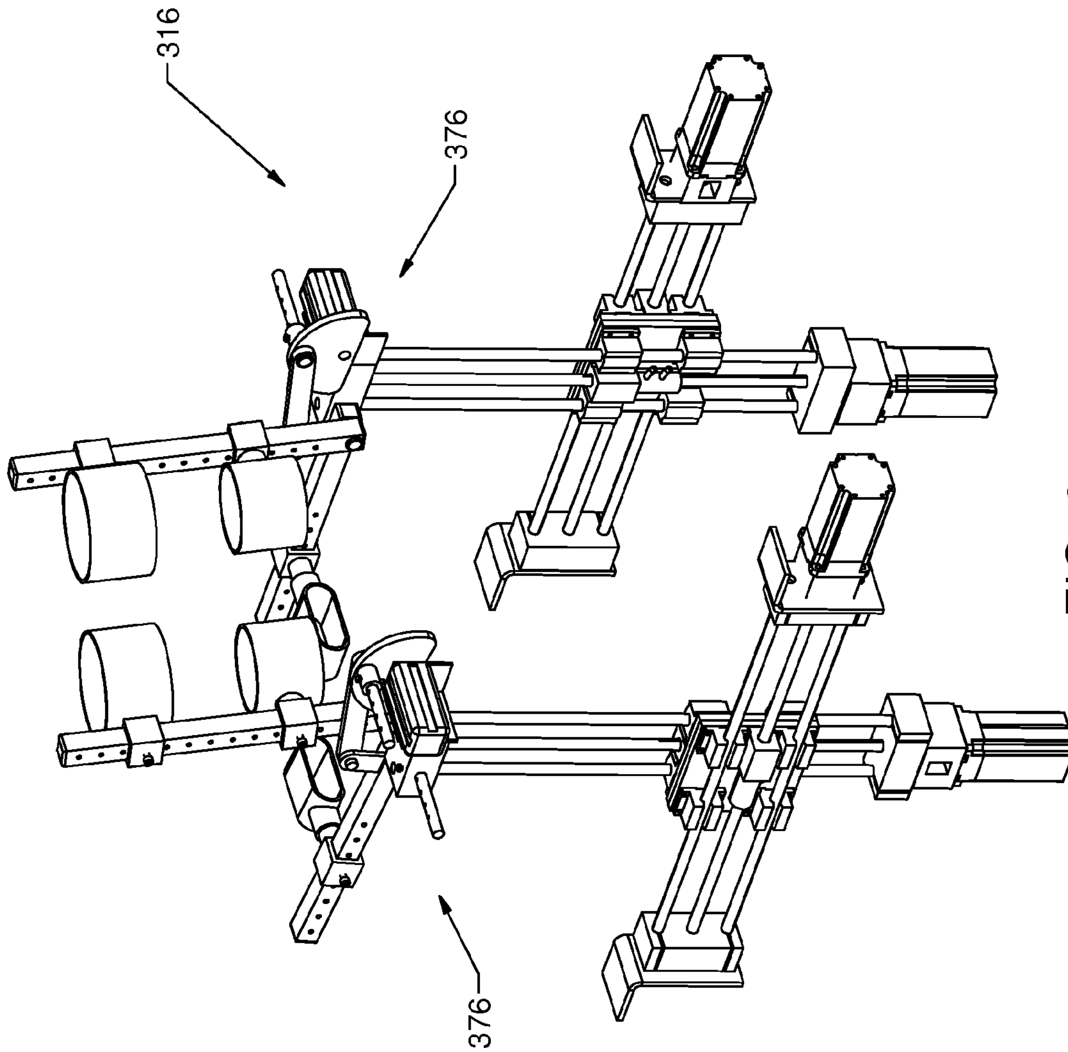

FIG. 9

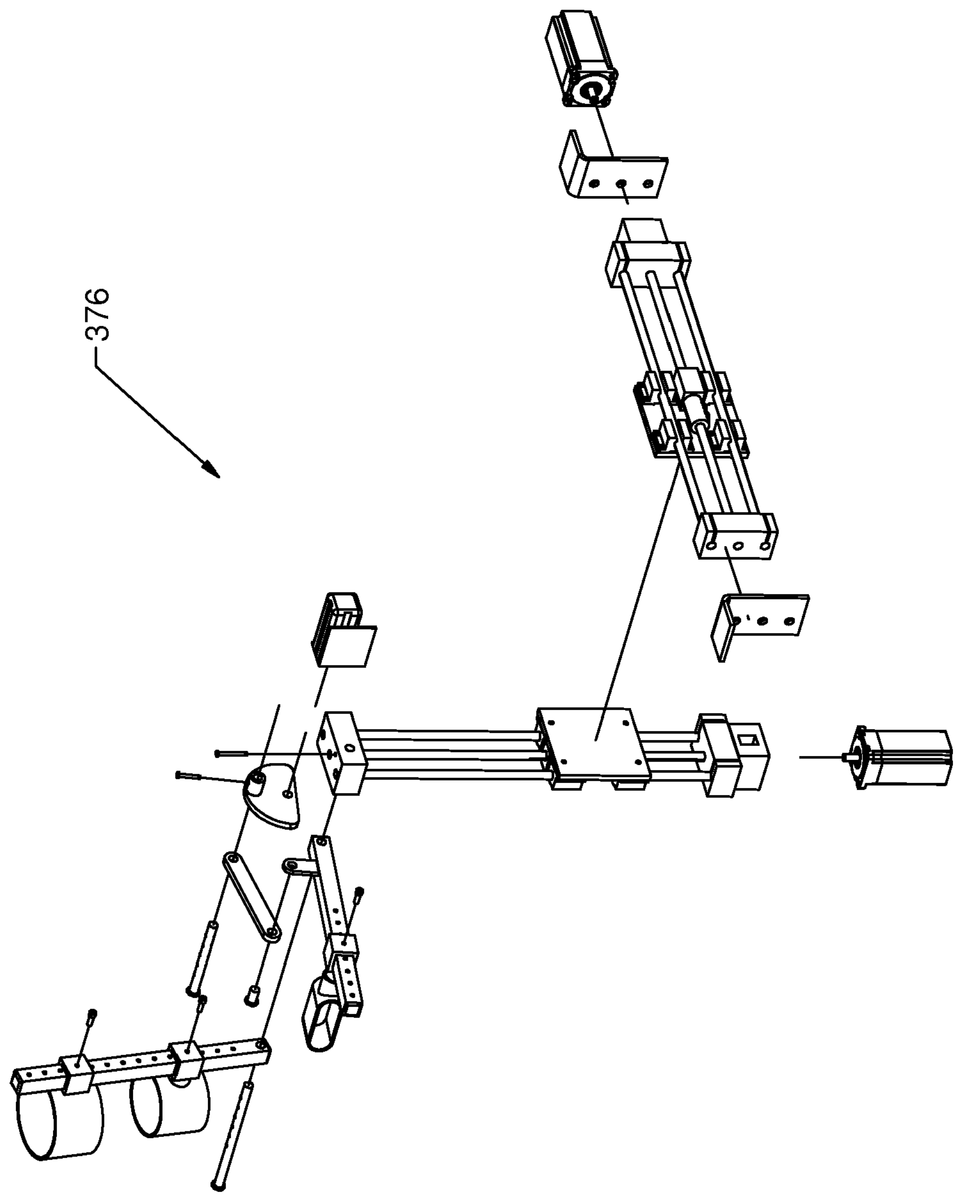

FIG. 10

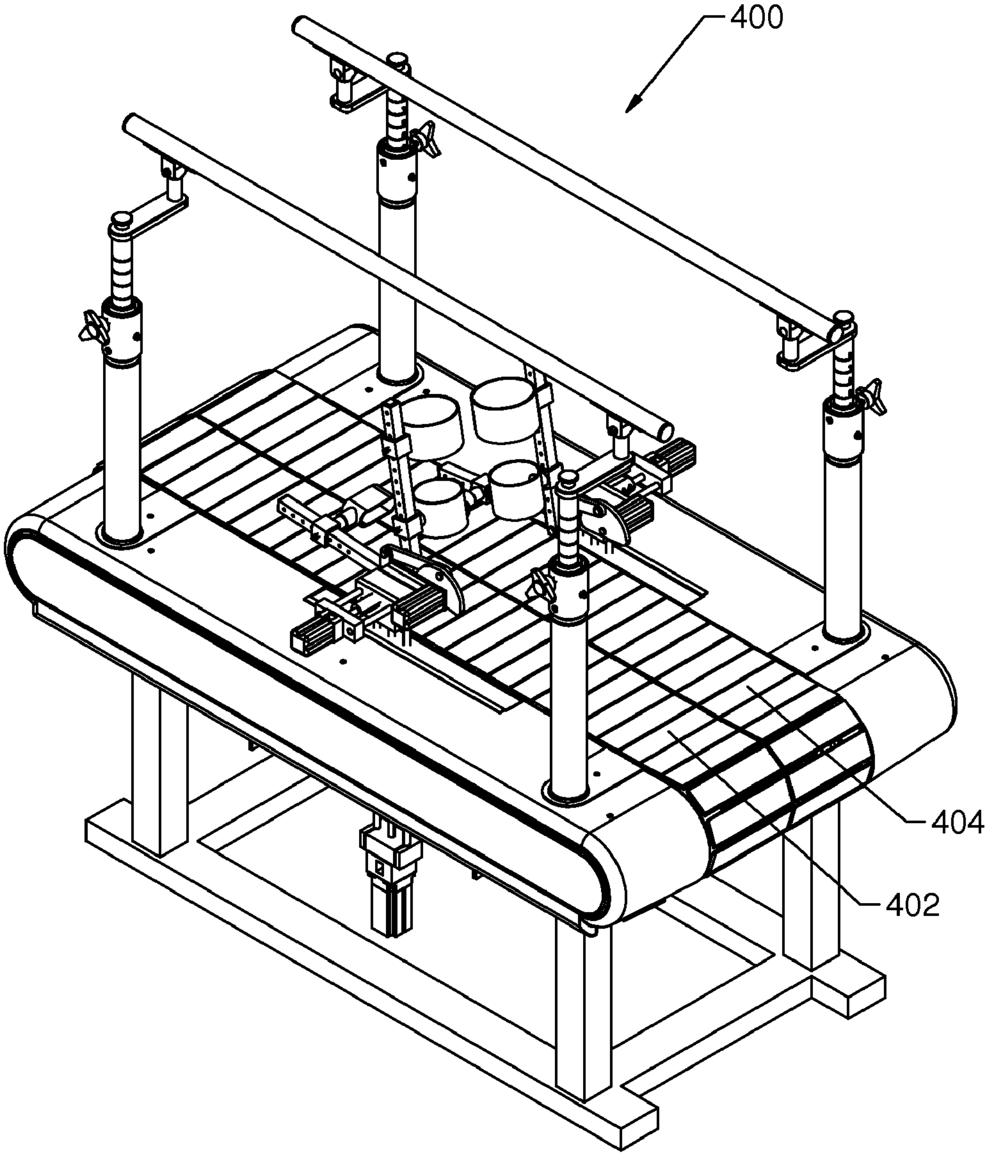

FIG. 11

TREADMILL WITH INTEGRATED WALKING REHABILITATION DEVICE

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This application claims priority from U.S. Provisional Application Ser. No. 61/168,512, filed Apr. 10, 2009, titled "Integrated Treadmill and Walking Aid," which is incorporated herein by reference in its entirety.

BACKGROUND

The present invention relates to the use of rehabilitation therapy that mimics walking (also referred to as, "walking therapy"). More specifically, the present invention relates to the use of a treadmill to provide walking therapy.

A number of disorders and injuries may cause an individual to experience complications when walking or render them unable to walk. For example, an individual may experience neurological damage due to stroke, spinal cord injury, etc. Walking therapy can help these individuals improve and/or regain their walk or gait. Such improvements may be the result of improving the training of muscle groups, improving kinesthetic awareness, and other related factors.

Walking therapy has traditionally been conducted with the help of two or more therapists that manually move a rehabilitee's legs to mimic walking motions. These traditional methods have a number of shortcomings. Among other things, these methods are very labor-intensive on the part of the physical therapists and can be subject to significant variability (e.g., due to different physical therapists working on different parts of a patient's legs, the inability to precisely control the gait of the patient's legs, etc.).

Generally, it is desirable to have more consistency when providing walking therapy. In some cases, consistency allows improvements to be more readily realized. In other cases, the results achieved are more accurate (e.g., because substantially the same muscle groups are repeatedly trained in substantially the same way, without undesirable variations, such as those occurring when a physical therapist's arms are tired, etc.). More recently, mechanically and/or robotically assisted devices that provide walking rehabilitation have been found to provide improved consistency.

SUMMARY

According to one embodiment a treadmill for providing walking rehabilitation to a rehabilitee comprises a base including a belt and a walking rehabilitation device interconnected with the base. The walking rehabilitation device comprises a user engagement structure extending at least partially above the belt and being configured to be removably secured relative to one or more locations of a rehabilitee's lower extremities; a plurality of drive systems coupled to the user engagement structure, the plurality of interconnected drive systems including at least a first drive system controlling the rehabilitee's motion in a first direction and a second drive system controlling the rehabilitee's motion in a second direction; and one or more motors coupled to and driving the plurality of drive systems, wherein motion from the plurality of drive systems is transferred to the rehabilitee by the user engagement structure, allowing the rehabilitee to walk along the belt.

According to another embodiment a method for providing walking rehabilitation to a rehabilitee, comprises providing a treadmill with a base, a belt, and a walking rehabilitation device, the walking rehabilitation device interconnected with the base and including plurality of drive systems operably interconnected with a user engagement structure; removably securing the user engagement structure relative to one or more locations of a rehabilitee's lower extremities; driving the plurality of drive systems with a plurality of servo motors; and imparting motion to the rehabilitee, causing them to walk along the belt with a desirable gait.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a treadmill including an integrated walking rehabilitation device according to a first exemplary embodiment.

FIG. **2** is an exploded view of the treadmill including an integrated walking rehabilitation device according to the exemplary embodiment shown in FIG. **1**.

FIG. **3** is a perspective view of the walking rehabilitation device according to the exemplary embodiment shown in FIG. **1**.

FIG. **4** is an exploded view of a right-hand structure of the walking rehabilitation device according to the exemplary embodiment shown in FIG. **3**.

FIG. **5** is a top view of an exemplary right leg gait pattern.

FIG. **6** is a side view of the exemplary right leg gait pattern of FIG. **5**.

FIG. **7** is a perspective view of another exemplary embodiment of a treadmill including an integrated walking rehabilitation device.

FIG. **8** is an exploded view of the treadmill including an integrated walking rehabilitation device according to the exemplary embodiment shown in FIG. **7**.

FIG. **9** is a perspective view of a walking rehabilitation device according to the exemplary embodiment shown in FIG. **7**.

FIG. **10** is an exploded view of a right-hand structure of the walking rehabilitation device according to the exemplary embodiment shown in FIG. **9**.

FIG. **11** is another exemplary embodiment of a treadmill including an integrated walking rehabilitation device.

DETAILED DESCRIPTION

FIG. **1** shows a treadmill **10** generally comprising a base **12**, one or more handrails **14** mounted to the base **12**, and an integrated walking rehabilitation device **16** according to an exemplary embodiment. The walking rehabilitation device **16** is configured to help a rehabilitee to restore or improve their gait by guiding the rehabilitee's lower extremities to move according to a desirable gait pattern. With repeated use, the walking rehabilitation device **16** may, among other things, help a rehabilitee relearn to walk in a physically correct matter, improve the their muscle function, improve their muscle memory, and improve their kinesthetic awareness, as will be discussed in more detail below.

The base **12** includes a belt **18** that extends substantially longitudinally along a longitudinal axis **20**. The longitudinal axis **20** extends generally between a front end **22** and a rear end **23** of the treadmill **10**; more specifically, the longitudinal axis **20** extends generally between the centerlines of a front and rear shaft, which will be discussed in more detail below. The belt **18** is driven longitudinally by a drive motor **24** and is guided by a pair of bearing rails **25** (see FIG. **2** illustrating the drive motor **24** and the bearing rails **25**). The speed at which the belt **18** is driven by the drive motor **24** may be adjusted (e.g., using buttons on a display, using a computer, etc.).

A pair of side panels **26** and **27** (e.g., covers, shrouds, etc.) are provided on the right and left sides of the base **12** to effectively shield the rehabilitee from the components or moving parts of the treadmill **10**. Openings **30** and **32** in the side panels **26**, **27** allow for a structure of the walking rehabilitation device **16** to extend above the belt **18** to be operatively coupled to the rehabilitee in the exemplary embodiment shown. It should be noted that brushes or other similar elements may be disposed in the openings to help prevent undesired objects from entering the openings.

The treadmill **10** is shown further including a support structure, shown as a stand **34**, disposed generally beneath the base **12** according to an exemplary embodiment. The stand **34** provides clearance for the moving components, in particular the vertically movable components, of the walking rehabilitation device **16**. In the exemplary embodiment shown, the stand **34** includes a plurality of support members, including four support legs **36** that raise the base a distance off the ground. The moving components of the walking rehabilitation device **16**, which are movably coupled to the base **12**, are correspondingly raised a distance off the ground. It should be noted that the support may have any configuration suitable to accommodate the moving parts of the walking rehabilitation device. According to some exemplary embodiments, a pit installation may be used, typically with the stand. In one exemplary embodiment, a pit installation involves forming a pit (e.g., opening, cavity, hole, etc.) in the ground of the space in which the treadmill will be located. The treadmill is disposed generally above the pit and the moving components of the walking rehabilitation system are accommodated within the pit. In some of these configurations, this allows the base of the treadmill to be positioned substantially flush with the ground, thereby allowing a physical therapist or other person to more readily assist the rehabilitee. In another exemplary embodiment, a raised platform may be built-up around the treadmill.

The handrails **14** are shown extending along the right-hand and left-hand sides of the treadmill **10** generally parallel to the longitudinal axis **20**. A rehabilitee may utilize the handrails **14** for support (e.g., keeping themselves upright, partially supporting the weight of their body, etc.). Further, the handrails **14** may be configured to be adjustable, to accommodate users of different heights, builds, etc. According to other exemplary embodiments, other devices configured to support or allow one to support at least part of the weight of the rehabilitee may be utilized with the treadmill **10** (e.g., a mechanical counterweight, a pneumatic device, a servo-controlled device, etc.) alone or in combination with the handrails **14** and/or handrails having other suitable configurations. These devices may be removable or integrated with the treadmill **10**. It should be noted that the left and right-hand sides of the treadmill and various components thereof are defined from the perspective of a forward-facing user standing on the running surface of the treadmill **10**.

Referring to FIG. **2**, the base **12** is shown including a frame **40** that comprises longitudinally-extending, opposing side members, shown as a left-hand side member **42** and a right-hand side member **44**, and one or more lateral or cross-members **46** extending between and structurally connecting the side members **42** and **44** according to an exemplary embodiment. Each side member **42**, **44** includes an inner surface **48** and an outer surface **50**. The inner surface **48** of the left-hand side member **42** is opposite to and faces the inner surface **48** of the right-hand side member **44**. According to other exemplary embodiments, the frame may have substantially any configuration suitable for providing structure and support for the treadmill.

A front shaft assembly **52** and a rear shaft assembly **54** are coupled to the frame **40** according to an exemplary embodiment. The front shaft assembly **52** includes a pair of front belt pulleys **56** interconnected with, and preferably directly mounted to, a front shaft **58**, and the rear shaft assembly **54** includes a pair of rear belt pulleys **60** interconnected with, and preferably directly mounted to, a rear shaft **62**. The front and rear belt pulleys **56**, **60** are configured to support and facilitate movement of the belt **18**. The belt **18** is disposed about the front and rear belt pulleys **56**, **60**, which are preferably fixed to the front and rear shafts **58**, **62**. As the drive motor **24** drives the rear shaft **62**, the rear belt pulleys **60** rotate, causing the belt **18** and the front belt pulleys **56** to rotate in the same direction. According to other exemplary embodiments, the motor may be operatively coupled to the front shaft and the drive belt.

Referring generally to FIGS. **1-4**, the walking rehabilitation device **16** includes a left-hand structure **70** and a right hand-structure **72**, each including a user engagement structure **74** coupled to, and more preferably operably interconnected with, a plurality of drive systems **76** according to an exemplary embodiment. In the exemplary embodiment shown, the right-hand structure **72** is coupled, and preferably directly mounted, to the right-hand side member **44** of the frame **40**, and the left-hand structure **70** is coupled, and preferably directly mounted, to the left hand side member **42** of the frame **40**. It should be noted that the user engagement structures at the left-hand side and the right-hand side may be referred to collectively as the user engagement structure.

The user engagement structure **74** is configured to be removably secured relative to desirable locations of the rehabilitee's lower extremities in order to transfer motion from the plurality of drive systems **76** to the rehabilitee, causing them to walk with a desirable gait. The user engagement structure **74** is coupled to, and preferably interconnected with, the plurality of drive systems **76**. At each of the right-hand structure **72** and the left-hand structure **70** of the walking rehabilitation device **16**, one or more support or coupling features, shown as straps **78**, **80**, **82**, releasably secure the user engagement structure **74** relative to the left leg or foot and the right leg or foot of the rehabilitee, respectively. In this way, driving force from the plurality of drive systems **76** can be transferred from the walking rehabilitation device **16** to the rehabilitee.

In the exemplary embodiment shown, the straps **78** and **80** are intended to be disposed about the rehabilitee's shins and the strap **82** is intended to be disposed about the rehabilitee's foot (e.g., at a location substantially corresponding to the arch of the wearer's foot, etc.). In some exemplary embodiments, the straps may be adjustable (e.g., using one or more fastening elements such as Velcro® or snaps), to adjust the fit of the straps relative to the rehabilitee's body. In some exemplary embodiments, the straps may be elastic or stretchable, facilitating a relatively tight fit about a desired portion of the rehabilitee's body. According to still other exemplary embodiments, any suitable support or coupling features may be used.

The relative positions of the straps **78**, **80**, **82** are also adjustable according to an exemplary embodiment. The straps **78** and **80** are shown coupled to a first support member **84**, and strap **82** is shown coupled to a second support member **86**. Each member **84**, **86** includes a plurality of holes **88** (e.g., openings, apertures, etc.). A fastener, shown as a pin **90**, is receivable in any of holes **88**, and may be positioned through a portion of the straps and into one of the holes **88** to couple a strap at a desired location relative to one of members **84**, **86**. The adjustability of the relative positions of the straps helps better accommodate rehabilitees having different builds, body types, proportions, etc. According to other exemplary embodiments, other suitable adjustment mechanisms may be used (e.g., slidable mechanisms, snapping mechanisms, etc.). According to still other exemplary embodiments, one or more support or coupling features of the user engagement structure are not adjustable.

Articulating features, shown as shafts **92**, may be included in the straps **78**, **80**, **82** or otherwise incorporated into the user engagement structure **74** to enable the portions of the rehabilitee's extremities coupled to the user engagement structure **74** to move relative to the first support member **84** and second support member **86**. Further, the shafts **92** may help facilitate movement of the user's shin relative to their foot. In this way, the shafts **92** allow a rehabilitee to move with more natural movement when using the walking rehabilitation device **16** and/or to be more comfortably accommodated therein. It should be noted that, in the exemplary embodiment shown, the shaft **92** corresponding to the strap **82**, also provides for lateral movement, allowing lateral articulation of the rehabilitee's ankle. According to some exemplary embodiments, other features may be incorporated to allow for this movement.

While the coupling features are shown configured to be coupled relative to a rehabilitee's shins and feet, the coupling features may be positioned relative to or about any desirable combination of locations of the rehabilitee's lower extremities (e.g., shins, arches of the feet, calves, heels, etc.). According to some exemplary embodiments, additional coupling features may be provided that are coupled to the user's upper extremities (e.g., waist, chest, arms, etc.), such as a harness. According to other exemplary embodiments, any device suitable for substantially securing the rehabilitee to the walking rehabilitation device and providing for motion to be imparted to the rehabilitee's lower extremities may be used. For example, the user engagement structure may include boots and clamping devices according to another exemplary embodiment.

Referring to FIGS. **2**-**3**, the plurality of drive systems **76** are configured to provide for movement of the lower extremities of the rehabilitee in a desired gait pattern. As the drive systems **76** provide movement to the rehabilitee, the rehabilitee walks along a surface **94** the belt **18**. The movement of the belt **18** allows the rehabilitee to remain at a substantially stationary location (i.e., along the surface **94** of the belt **18**) so that physical therapists can easily monitor and assist the rehabilitee.

The plurality of drive systems **76** are shown preferably including two or more linear drive systems **100** and an ankle articulation drive system **102** according to an exemplary embodiment. The linear drive systems **100** include a pair of longitudinal drive systems **104**, a pair of vertical drive systems **106**, and a pair of horizontal or lateral drive systems **108** according to an exemplary embodiment. The longitudinal drive systems **104** are configured to provide motion in a direction along or parallel to the longitudinal axis **20** and the surface **94** of the belt **18**. The vertical drive systems **106** are configured to provide motion in a direction perpendicular to the longitudinal axis **20** and the surface **94** of the belt **18**, generally aligned with the force of gravity. The lateral drive systems **108** are configured to provide for side-to-side motion relative to the surface **94** of the belt **18** between the right-hand side and the left-hand side of the treadmill **10**. Utilized in combination, a desirable and physically correct gait pattern can be achieved. Further, this gait pattern may be varied or adjusted depending on the rehabilitee and/or the desired rehabilitative treatment, as will be discussed in more detail later.

Each linear drive system **100** is shown including one or more substantially linear members, shown as rails **110** and drive screws **112**, one or more guides **114** movable along the rails **110**, and a servo motor **116** according to an exemplary embodiment. The rails **110** (e.g., shafts, bars, tracks, beams, etc.) and drive screws **112** generally define the path traveled by the guides **114**, and the guides are movable therealong. More specifically, the servo motor **116** is coupled to and rotatably drives the drive screw **112** of each linear drive system **100**, which, in turn, causes the guide **114** to advance or retreat along the rails **110**. It should be noted that variations of the linear drive system shown are contemplated. For example, two drive screw may be used with one rail, a single drive screw may be used, etc. Further, while in the embodiment shown each linear drive system is shown including three linear members, other numbers of linear members may be utilized (e.g., one, two, four, etc.). According to the exemplary embodiment shown, the linear drive systems are PowerTrax™ Series 200 slide systems by Nook Industries. According to other exemplary embodiments other suitable linear drive systems may be utilized. According to still other exemplary embodiments, guides including one or more curved portions may be utilized.

The guides **114** are shown including one or more receiving features, shown as apertures **120**, corresponding to the relative locations of the rails **110** and configured to receive the rails **110** and drive screws **112** therein, facilitating the slidable movement of the guides **114** relative to the rails **110**. The aperture **120** corresponding to the drive screw **112** is threaded to correspond to a plurality of threads of the drive screw **112**. In this way, rotation of the drive screw **112** imparts linear motion to the guide **114**. According to other exemplary embodiments, the guides may receive the rails in any fashion suitable to allow for slidable movement of the guides along the rails. For example, in some exemplary embodiments, the guides may include wheels, bearings, or other rotatable elements that facilitate movement along the rails.

The linear drive systems **100** may further include stops, shown as a pair of opposing blocks **124**, defining the maximum range of movement of the guides **114** in the direction in which the rails **110** are oriented (e.g., longitudinally, vertically, etc.). The rails **110** and the drive screws **112** extend between and are at least partially supported by the blocks **124**. Preferably, the rails **110** are directly mounted to the blocks **124** and the drive screws **112** are removably received in a pair of apertures disposed in the blocks **124** that allow for rotational movement of the drive screws **112** relative thereto. According to other exemplary embodiments, stops other than blocks may be used and/or the motion of the guides may be restricted in other ways.

The servo motor **116** is coupled, or preferably directly mounted, to a block at one of a first end **126** or a second end **128** of each linear drive systems **100**. The servo motors **116** are configured to help control and change the mechanical position of the guides **114** in response to inputs. A shaft **130** of each servo motor is coupled to the drive screw **112** of each linear drive system **100**, rotation of the shaft **130** imparting rotation to the drive screw **112**. Typically, mimicking a walking motion involves the drive mechanisms at the right-hand side being at a different point in the gait pattern than the left-hand side at substantially all times. Accordingly, the ability to independently control the mechanical position of each linear drive system at both the right and left-hand sides of the treadmill **10** with the servo motors **116** is desirable and allows for desired gait patterns to be fairly accurately replicated, as discussed in more detail below. The servo motor is, for example, a BSMN Series motor by Baldor Electric Company, but other suitable servo motors may be used. It should be noted that in alternative exemplary embodiments, a single servo motor may help control and change the position of the guides of more than one linear drive system. It also should be noted that motors other than servo motors may be used with one or more linear drive systems according to some exemplary embodiments.

Each of the right-hand structure **72** and the left-hand structure **70** of the walking rehabilitation system **16** include one longitudinal drive system **104**, one vertical drive system **106**, and one lateral drive system **108** that are positioned to correspond to the left-hand side member **42** and the right-hand side member **44** of the frame **40** according to an exemplary embodiment. The drive systems disposed along the right-hand side generally impart motion to the right-hand side of the rehabilitee's body, and the drive systems disposed along the left-hand side generally impart motion to the left-hand side of the rehabilitee's body.

The linear drive systems **100** at the left-hand structure **70** and the right-hand structure **72** are interconnected, such that motion having components in any combination of directions may be fluidly imparted to the rehabilitee. Discussing the right-hand structure **72**, which is the mirror image of the left-hand structure **70**, by way of example and not be way of limitation, the arrangement and interconnection of the drive systems **104**, **106**, **108** will now be addressed. The longitudinal drive system **104** is disposed adjacent to the inner surface **48** of the right-hand side member **44** of the frame **40** and directly mounted thereto (e.g., at blocks **124**). The vertical drive system **106** is interconnected with the longitudinal drive system **104** such that a surface **136** of the guide **114** of the vertical drive system **106** is coupled, and preferably directly mounted, to a surface **138** of the guide **114** of the longitudinal drive system **104**. Accordingly, the vertical drive system **106** moves longitudinally in response to the movement of the longitudinal drive system **104**. The servo motor **116** of the vertical drive system **106** drives the drive screw **112** and the rails **110** of the vertical drive system **106** relative to the guide of the vertical drive system **106**, which, as mentioned above, is substantially fixed relative to the guide **114** of the are slidably moveable relative thereto. The lateral drive system **108** is coupled to the vertical drive system **106** at least partially above the belt **18**, the block **124** at the first end **126** of the lateral drive system **108** being mounted to the block **124** at the second end **128** of the vertical drive system **106**. At this position, the lateral drive system **108** substantially avoids interfering with the belt **18** during operation of the treadmill. According to other exemplary embodiments, the longitudinal, vertical, and lateral drive systems may be arranged and interconnected in any manner suitable for substantially fluidly imparting motion having components in any of a combination of directions to the rehabilitee.

Referring in particular to FIGS. **3** and **4**, the ankle articulation drive systems **102** include the pair of first support members **84** and the pair of second support members **86**, discussed above, as well as a pair of third support members **150**, a pair of fourth support members **152**, and a pair of servo motors **154** according to an exemplary embodiment. The ankle articulation drive system **102** is configured to allow the flexure of a person's ankle during a rehabilitation exercise. The ankle articulation drive system is further configured to help control and guide the flexure so that the rehabilitee mimics the natural ankle articulation that occurs during walking. To accomplish this articulation, the servo motor **154** drives the members (e.g., linkages, elements, bars, etc.) of the ankle articulation drive system **102**, which are essentially a linkage system according to the exemplary embodiment shown, in response to inputs, which are discussed in more detail below. Allowing and/or helping the rehabilitee's ankles to articulate provides a number of benefits, including, but not limited to, allowing the rehabilitee to perform a desired heel strike and toe off.

Discussing the right-hand structure **72** of the walking rehabilitation system **16** by way of example, the members of the ankle articulation drive systems **102** are coupled to the block **124** at the second end **128** of the lateral drive system **108** by a coupling element, shown as a plate **158** having a plurality of holes. A first hole **160** of the plate **158** receives a shaft **162** of the servo motor **154**. The shaft **162** of the servo motor **154** is coupled to and drives the fourth support member **152**. A second hole **164** of the plate **158**, spaced a distance from the first hole **160**, is coupled to the second support member **86** at a first end **166** generally opposite a second end **168** such that the first end **166** of the second support member **86** is able to pivotally move relative to the plate **158**. The first support member **84** is also coupled to the plate **158** at the second hole **164**, a first end **170** of the first support member **84** also being pivotally movable relative to the plate **158**. In addition to being coupled by the plate **158**, the fourth support member **152** and second support member **86** are also coupled by the third support member **150**. At a first end **176**, the third support member **150** is pivotally coupled relative to the fourth support member **152** at a second hole **178** of the fourth support member **152** spaced a distance from a first hole **180**, by which the shaft **162** is coupled to the fourth support member **152**. At a second end **182**, the third support member **150** is pivotally coupled to the second support member **86** at a projection **184**.

During operation of the walking rehabilitation device **16**, the servo motor **154** is driven in response to inputs. Rotation of the shaft **162** of the servo motor **154** pivotally moves the fourth member **152** about a pivot axis **186** corresponding to the first hole **180** of the fourth member **152**. The pivoting motion of the fourth member **152** drives the first end **176** of the third support member **150**. As a result, the second end **182** of the third support member **150** drives the first end **166** of the second support member **86** via the projection **184** in a generally arched or curved path. The movement of the first end **166** of the second support member **86** is exaggerated at the second end **168** of the second support member **86**. That is, the second end **168** of the second support member **86** moves in a similar, but larger, arched or curved path than the first end **166** of the second support member **86**. The second end **168** of the second support member **86** generally corresponds to the location of the ball of the rehabilitee's foot when the walking rehabilitation device **16** is in use. Thus, by causing the second end **168** of the second support member **86** to move generally upward and downward in a generally arched or curved path, rotation of the shaft **162** of the ankle articulation drive systems **102** causes the rehabilitee's foot to articulate generally upward and downward about their ankle.

Similarly, the first end **170** of the first support member **84**, which, as mentioned above, is also pivotally coupled to the second end **168** of the second support member **86**, causes a second end **180** of the first support member **84** to be driven in an arched or curved path generally larger than the substantially arched or curved path through which the first end **170** of the first member is driven. The substantially arched or curved path through which the second end **180** of the first support member **84** is driven, is generally convex and extends in a direction generally parallel to the longitudinal axis **20**. The second end **180** of the first support member **84** generally corresponds to the location of the rehabilitee's shin when the walking rehabilitation device **16** is in use. Accordingly, by causing the second end **180** of the first support member **84** to move in the substantially arched or curved path, the shaft **162** of the ankle articulation drive systems **102** causes the rehabilitee's shin articulate generally forwardly and rearwardly about their ankle. Thus, the ankle articulation drive systems **102** helps the rehabilitee mimic the ankle articulation associated with walking. According to other exemplary embodiments, other ankle articulation drive systems **102** suitable for mimicking the ankle articulation associated with walking may be used.

According to an exemplary embodiment, an ankle articulation drive system is included in the walking rehabilitation device that is mechanically driven, rather than driven by a motor. For example, another member or linkage may be provided that mechanically drives the members of the ankle articulation system in response to motion of one or more of the linear drive systems.

According to an exemplary embodiment, a non-driven ankle articulation system may be incorporated into the user engagement structure of the walking rehabilitation device. Generally, the non-driven ankle articulation systems are configured to avoid restricting the motion of the wearer's ankle, and, thereby, allowing for natural articulation of the user's ankle during a rehabilitation exercise. Such movement may be facilitated by a plurality of pivotally interconnected members.

According to an exemplary embodiment, the drive systems (e.g., linear drive systems and/or the ankle articulation drive systems) can be any system or assembly that drives or introduces motion in a given direction or along a given path. For example, other possible drive systems may include any number of linkages (e.g., 3, 5, 6, 7, etc.), belts, cams, and/or chains. Also, a combination of different types of drive systems may be utilized in the walking rehabilitation device.

Referring to FIGS. **5** and **6**, an exemplary gait pattern **190** is shown from the top and the side according to an exemplary embodiment. The gait pattern seen in FIG. **5** corresponds to a desired gait pattern for the right foot of a rehabilitee. From these views it can be seen that motion in each of the longitudinal, vertical, and lateral directions is utilized to form the desired pattern. It should be noted that, while the lateral control is not necessary for the most basic gait replication, it is desirable because this pattern is a physically correct gait which generally includes some level of motion of a persons foot toward the centerline of their body during the forward swing portion of their gait. Thus, this is one way the walking rehabilitation device **16** provides for a more accurate replication of a desirable gait patterns.

A computing device **200** and a user interface **202** are utilized to provide instructions to the drive systems **76** according to an exemplary embodiment. Among other things, the computing device **200** may be configured to control the gait pattern, sending instructions to each servo motor **116**, **154** that indicate the desired the mechanical positions of the guides **114** of the linear drive systems **100** and the desired articulation of the ankle articulation drive systems **102**. The gait pattern may be progressive (e.g., having a stride that increases or decreases in length over time), or may be changed to provide for different rehabilitation regimens. According to one exemplary embodiment, the computing device **200** calculates desirable gait patterns for the rehabilitee in response to various inputs. Stated otherwise, the walking rehabilitation device **16** allows for the gait pattern to be customized to the rehabilitee. Some of these inputs may correspond directly to the physical characteristics of the rehabilitee (e.g., their weight, their knee-to-ankle length, hip-to-ankle length, hip-to-knee length, inseam, stride length, height, etc.). Other inputs may correspond more directly to the desired rehabilitation regimen (e.g., the gait pattern, speed, etc). According to some exemplary embodiments, the computing device may be further configured to store data, and, thereby, monitor a given rehabilitee's progress over time. In fact, the computing device may analyze the data and initial inputs to develop and series of training regimens for a rehabilitee to execute over time. It should be noted, that different treadmill computing devices may operate based on different combinations of inputs.

According to any exemplary embodiment, the walking rehabilitation device may include only right-handed elements or left-handed elements. Such a configuration may be particularly useful, for example, for use with rehabilitee's who have experienced more significant neurological damage to one side of their body relative to the other (e.g., as a result of a stroke).

It should be noted that the walking rehabilitation device **16** of the treadmill **10** is not limited to mimicking or replicating walking motions. Numerous other motions beneficial for rehabilitation purposes may be mimicked. For example, kicking motions, knee lifts, etc.

Referring to FIGS. **7-10**, another exemplary embodiment of the treadmill is shown as a treadmill **300** including a walking rehabilitation device **316** having a plurality of drive systems **376**. The treadmill **300** is substantially similar to the treadmill **10** with the exception that a lateral drive system is not included in the treadmill **10** and the ankle articulation drive systems **102** is coupled to the vertical drive system **106**.

Referring to FIG. **11**, another exemplary embodiment of the treadmill is shown as treadmill **400** including a walking rehabilitation device **16**. The treadmill **400** includes two belts **402**, **404**, one corresponding to the left-hand side of a user and the other corresponding to the right-hand side of the user. Stated otherwise, the treadmill **400** is a split-belt treadmill.

According to an exemplary embodiments, one or more of the linear drive systems may be mechanically driven, rather than being driven by a servo motor.

As utilized herein, the terms "approximately," "about," "substantially," and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numerical ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and are considered to be within the scope of the disclosure.

It should be noted that the term "exemplary" as used herein to describe various embodiments is intended to indicate that such embodiments are possible examples, representations, and/or illustrations of possible embodiments (and such term is not intended to connote that such embodiments are necessarily extraordinary or superlative examples).

For the purpose of this disclosure, the term "coupled" means the joining of two members directly or indirectly to one another. Such joining may be stationary or moveable in nature. Such joining may be achieved with the two members or the two members and any additional intermediate members being integrally formed as a single unitary body with one another or with the two members or the two members and any additional intermediate members being attached to one another. Such joining may be permanent in nature or may be removable or releasable in nature.

It should be noted that the orientation of various elements may differ according to other exemplary embodiments, and that such variations are intended to be encompassed by the present disclosure.

It is important to note that the constructions and arrangements of the treadmill as shown in the various exemplary embodiments are illustrative only. Although only a few embodiments have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors, orientations, etc.) without materially departing from the novel teachings and advantages of the subject matter recited in the claims. For example, elements shown as integrally formed may be constructed of multiple parts or elements, the position of elements may be reversed or otherwise varied, and the nature or number of discrete elements or positions may be altered or varied. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. Other substitutions, modifications, changes and omissions may also be made in the design, operating conditions and arrangement of the various exemplary embodiments without departing from the scope of the present disclosure.

What is claimed is:

1. A treadmill for providing walking rehabilitation to a rehabilitee, comprising:
- a base including a belt; and
- a walking rehabilitation device interconnected with the base, the walking rehabilitation device comprising:
  - a user engagement structure extending at least partially above the belt and being configured to be removably secured to one or more locations of a rehabilitee's lower extremities;
  - a plurality of interconnected drive systems coupled to the user engagement structure, the plurality of drive systems including at least a first drive system and a second drive system, the first drive system controlling the rehabilitee's motion in a first direction and moving the second drive system along a first axis, the second drive system controlling the rehabilitee's motion in a second direction; and
  - one or more motors coupled to and driving the plurality of drive systems;
- wherein motion from the plurality of drive systems is transferred to the rehabilitee by the user engagement structure, allowing the rehabilitee to walk along the belt, and the second drive system moves the second drive system relative to the first drive system along a second axis, and wherein the first direction is parallel to the first axis, and the second direction is parallel to the second axis.

2. The treadmill of claim **1**, wherein the first drive system comprises a substantially longitudinal drive system and the second drive system comprises a substantially vertical drive system, both drive systems being disposed at one of a left-hand side or a right-hand side of the treadmill.

3. The treadmill of claim **2**, wherein the plurality of drive systems further comprises a third drive system on the same side of the treadmill as the first drive system and the second drive system.

4. The treadmill of claim **3**, wherein the belt comprises a walking surface, and wherein the third drive system is a lateral drive system controlling the rehabilitee's motion in substantially side-to-side directions relative to the walking surface of the belt.

5. The treadmill of claim **3**, wherein the third drive system is an ankle articulation drive system.

6. The treadmill of claim **3**, wherein the drive systems on the right-hand side of the treadmill are the mirror image of the drive systems on the left-hand side of the treadmill.

7. The treadmill of claim **1**, wherein each drive system includes a guide slidably movable along one or more rails, and wherein one or more of the motors cause the guide to move along the rails.

8. The treadmill of claim **1**, further comprising a computing device configured to receive input to control and customize a gait for the rehabilitee.

9. The treadmill of claim **8**, further comprising a user interface, the user interface allowing a user to enter one or more inputs that are utilized by the computing device to calculate a desirable gait for the rehabilitee.

10. The treadmill of claim **1**, wherein the belt comprises a walking surface, and wherein at least one of the motors driving at least one of the first and second drive systems is located below the walking surface of the belt.

11. The treadmill of claim **1**, wherein the first drive system further controls the rehabilitee's motion in a direction substantially opposite the first direction, and the second drive system further controls the rehabilitee's motion in a direction substantially opposite the second direction.

12. A method for providing walking rehabilitation to a rehabilitee, comprising:
- providing a treadmill with a base, a belt, and a walking rehabilitation device, the walking rehabilitation device interconnected with the base and including a plurality of drive systems operably interconnected with a user engagement structure;
- removably securing the user engagement structure relative to one or more locations of a rehabilitee's lower extremities;
- driving the plurality of drive systems with a plurality of servo motors; and
- imparting motion to the rehabilitee, causing the rehabilitee to walk along the belt with a desirable gait;
- wherein the plurality of drive systems includes a first drive system and a second drive system, and wherein during the step of driving the plurality of drive systems, the first drive system remains at a fixed angle relative to the second drive system.

13. The method of claim **12**, further comprising the step of providing one or more inputs into a computing device to control and customize the gait for the rehabilitee, the computing device being configured to send instructions to the motors to indicate desired mechanical positions of a plurality of guides of the drive systems.

14. The method of claim **12**, wherein the first drive system is a substantially longitudinal drive system and the second drive system is a substantially vertical drive system, and wherein the first and second drive systems are configured to provide motion of the user engagement structure in substantially linear directions.

15. The method of claim **14**, wherein the belt comprises a walking surface, and wherein the plurality of drive systems includes a third drive system configured to provide side-to-side motion of the user engagement structure relative to the walking surface of the belt.

16. A treadmill for providing walking rehabilitation to a rehabilitee, comprising:
- a base including a belt; and
- a walking rehabilitation device interconnected with the base, the walking rehabilitation device comprising:

a user engagement structure extending at least partially above the belt and being configured to be removably secured to one or more locations of a rehabilitee's lower extremities;

a plurality of interconnected drive systems coupled to the user engagement structure, the plurality of drive systems including at least a first drive system and a second drive system, the first drive system controlling the rehabilitee's motion in a first direction and moving the second drive system along a first axis, the second drive system controlling the rehabilitee's motion in a second direction; and

one or more motors coupled to and driving the plurality of drive systems;

wherein motion from the plurality of drive systems is transferred to the rehabilitee by the user engagement structure, allowing the rehabilitee to walk along the belt; and

wherein the belt comprises a walking surface, and wherein at least one of the motors driving at least one of the first and second drive systems is located below the walking surface of the belt.

17. The treadmill of claim **16**, wherein the first drive system comprises a substantially longitudinal drive system and the second drive system comprises a substantially vertical drive system, both drive systems being disposed at one of a left-hand side or a right-hand side of the treadmill.

18. The treadmill of claim **17**, wherein the plurality of drive systems further comprises a third drive system, the third drive system being a lateral drive system controlling the rehabilitee's motion in substantially side-to-side directions relative to the walking surface of the belt.

19. The treadmill of claim **18**, wherein the third drive system is on the same side of the treadmill as the first drive system and the second drive system.

20. The treadmill of claim **16**, wherein each drive system includes a guide slidably movable along one or more rails, and wherein one or more of the motors cause the guide to move along the rails.

21. The treadmill of claim **16**, further comprising a computing device configured to receive input to control and customize a gait for the rehabilitee.

22. The treadmill of claim **16**, wherein the first drive system further controls the rehabilitee's motion in a direction substantially opposite the first direction, and the second drive system further controls the rehabilitee's motion in a direction substantially opposite the second direction.

* * * * *

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(54) **ROBOT FOR GAIT TRAINING AND OPERATING METHOD THEREOF**

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(52) **U.S. Cl.** **601/35**

(57) **ABSTRACT**

A robot for gait training includes a walking-assist robot (100) configured to by put on legs of a walking trainee; a treadmill (200) with a conveyor belt floor which moves at a designated speed in order for the walking trainee to continuously perform gait training at a fixed position; a load-hoist (300) for upwardly supporting the body of the walking trainee; and a controller (400). The controller (400) includes an input unit (410) for receiving or inputting information or commands about size of the body of the walking trainee, and a speed, angle and rotational force of each joint required for training of the walking trainee, an information storage device for selectively storing the information and commands received through the input unit (410), a control unit for controlling a driving state of the walking-assist robot (100), the treadmill (200) and the load hoist (300) according to the information or commands input through the input unit (410) or transmitted from the information storage device, and a monitor (420) for numerically or graphically displaying the information transmitted from the walking-assist robot (100), the treadmill (200), the load hoist (300) and the information storage device. Therefore, it is possible to check the angle, speed and torque of each joint of the walking trainee in real time. As a result, by comparing the current walking of the walking trainee with a standard walking pattern appropriate for the training for the walking trainee, it is possible to analyze and determine whether the gait training is correctly performed and which walking pattern is more appropriate for the walking trainee.

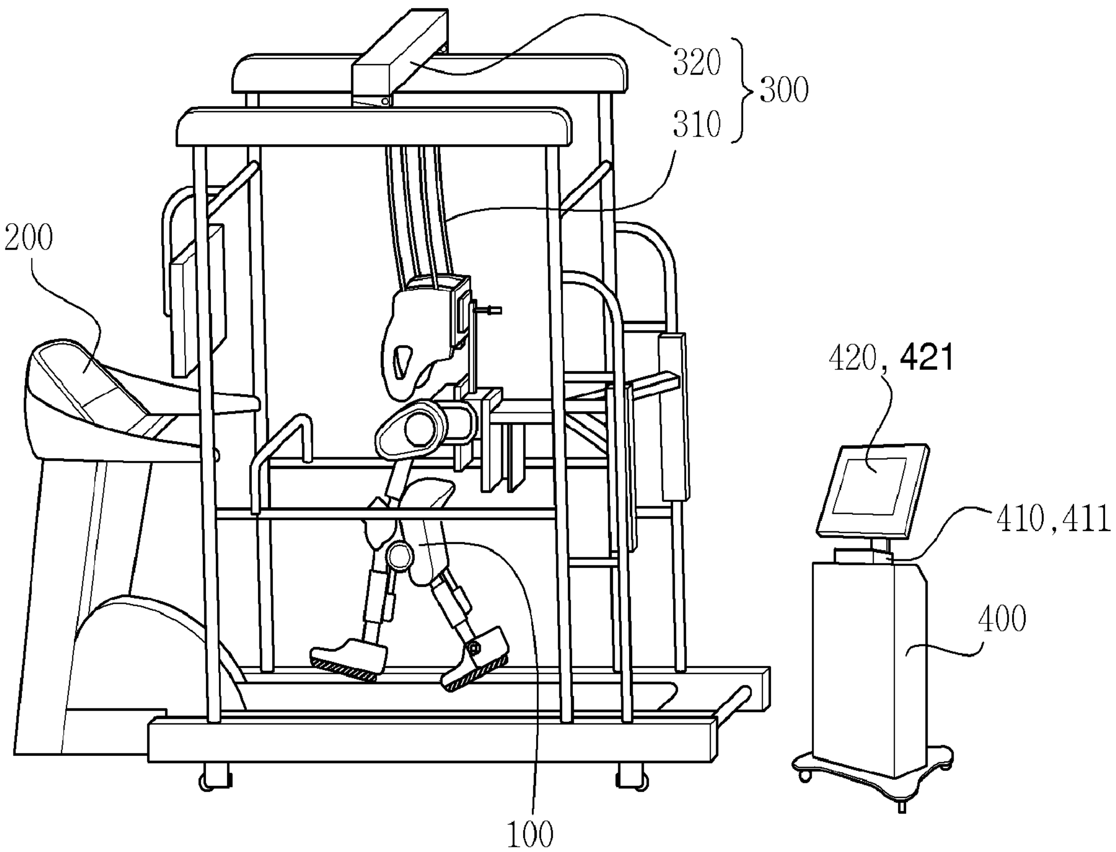


Fig. 1

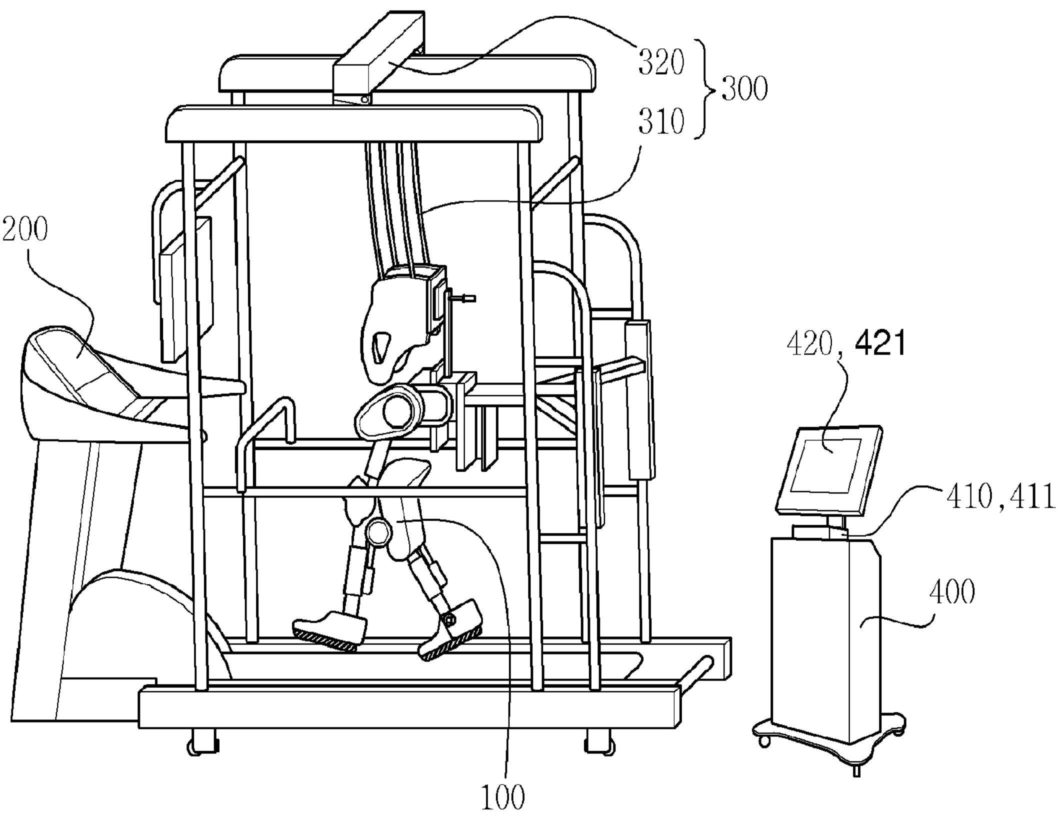


Fig. 2

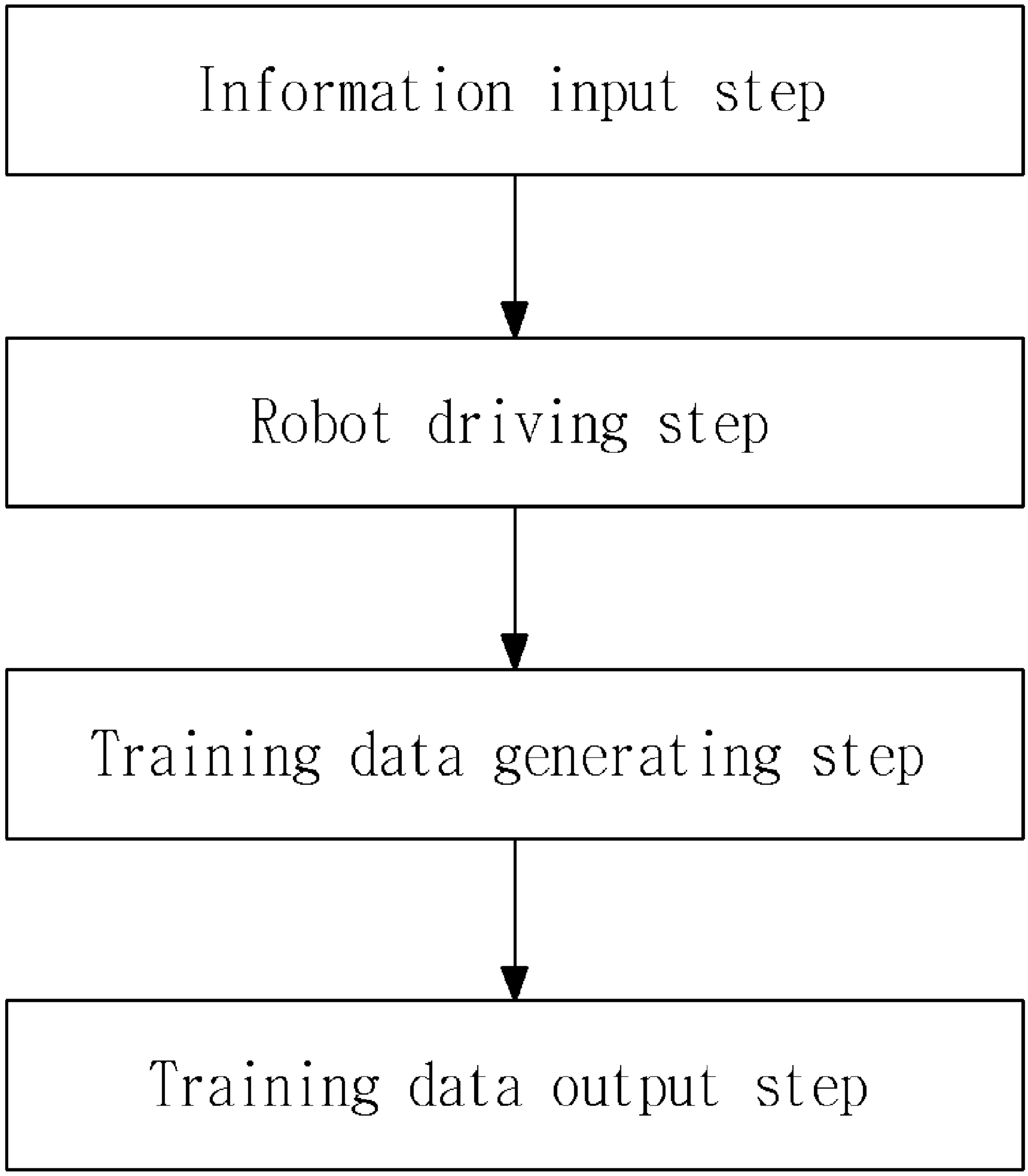
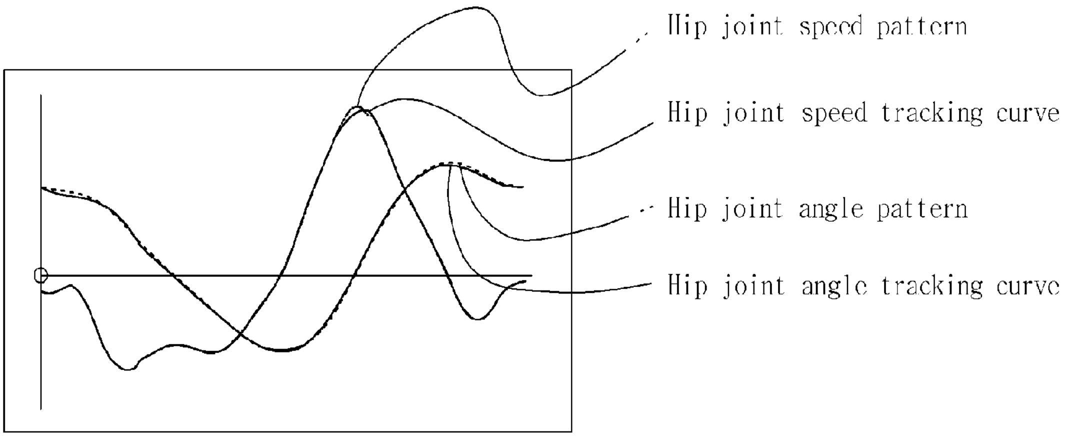
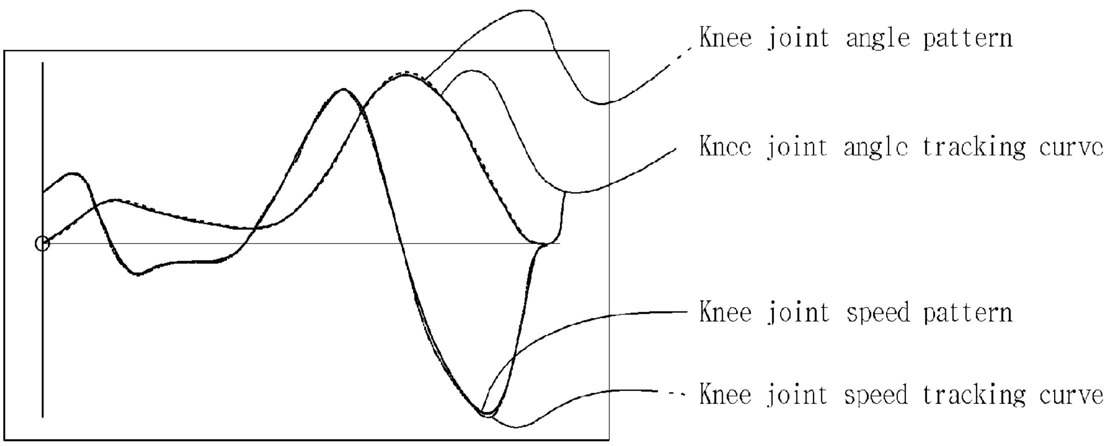

Information input step
Robot driving step
Training data generating step
Training data output step

Fig. 3

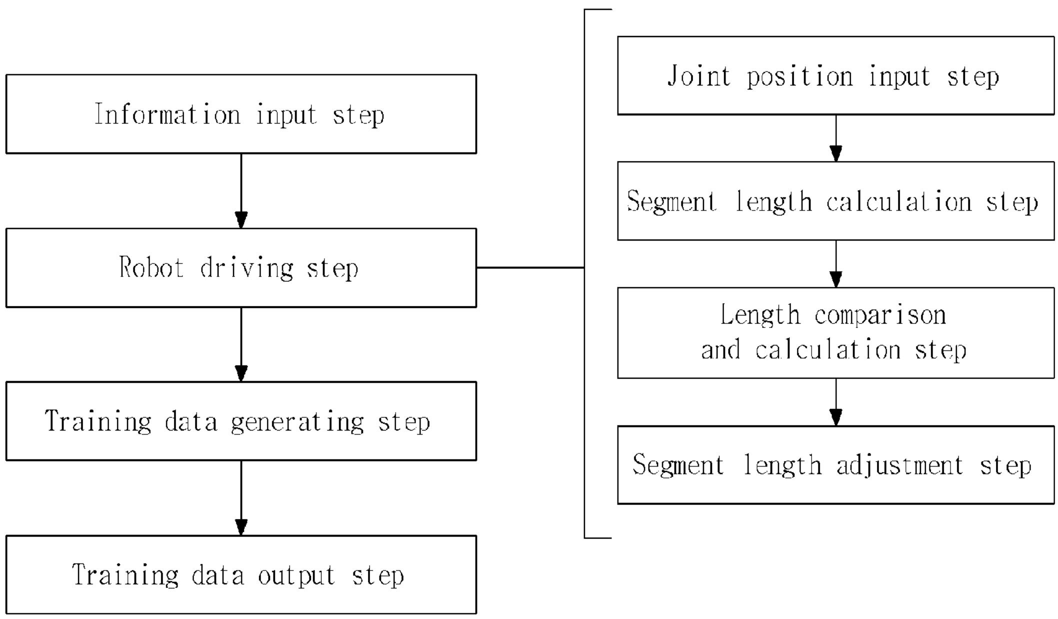


<Hip joint angle/speed tracking curve>



< Knee joint angle/speed tracking curve>

Fig. 4


Information input step
Robot driving step
Training data generating step
Training data output step
Joint position input step
Segment length calculation step
Length comparison and calculation step
Segment length adjustment step

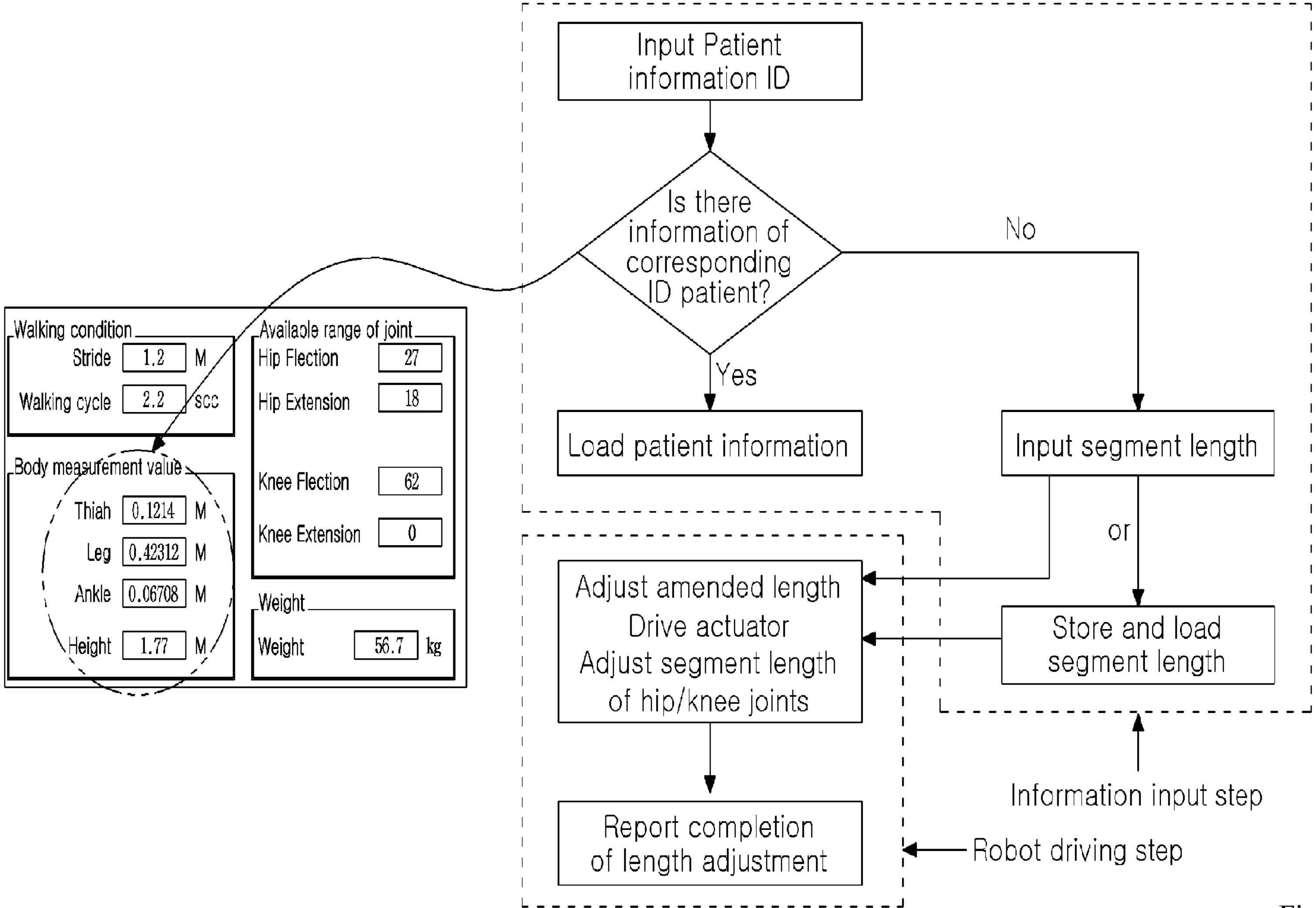

Input Patient information ID
Is there information of corresponding ID patient?
No
Yes
Load patient information
Input segment length
or
Store and load segment length
Adjust amended length
Drive actuator
Adjust segment length of hip/knee joints
Report completion of length adjustment
Information input step
Robot driving step
Walking condition
Stride 1.2 M
Walking cycle 2.2 scc
Body measurement value
Thigh 0.1214 M
Leg 0.42312 M
Ankle 0.06708 M
Height 1.77 M
Available range of joint
Hip Flection 27
Hip Extension 18
Knee Flection 62
Knee Extension 0
Weight
Weight 56.7 kg

Fig. 5

Fig. 6

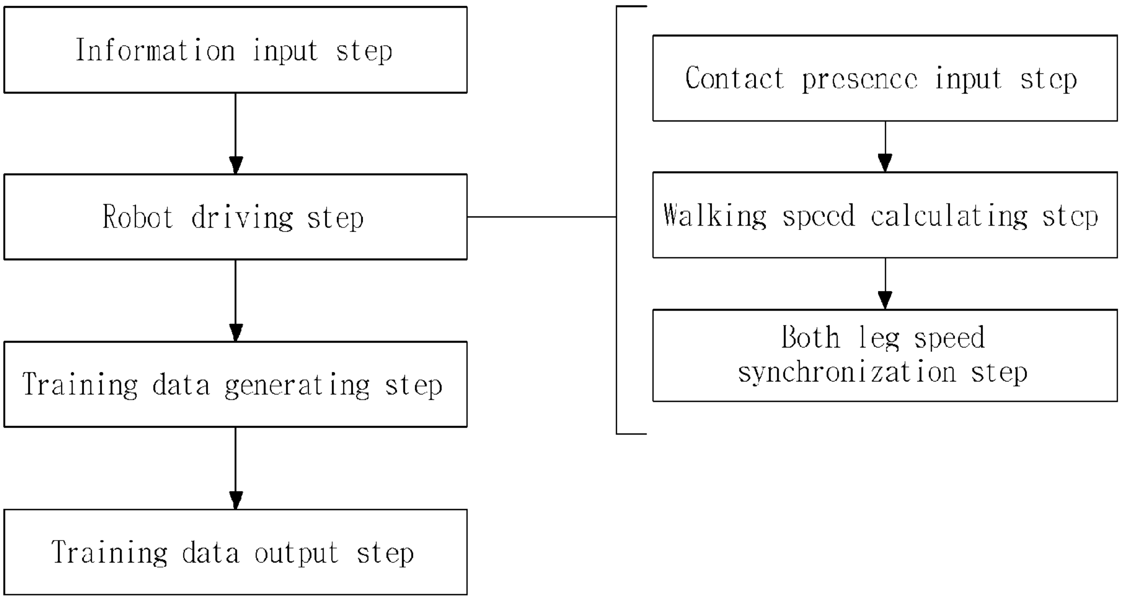
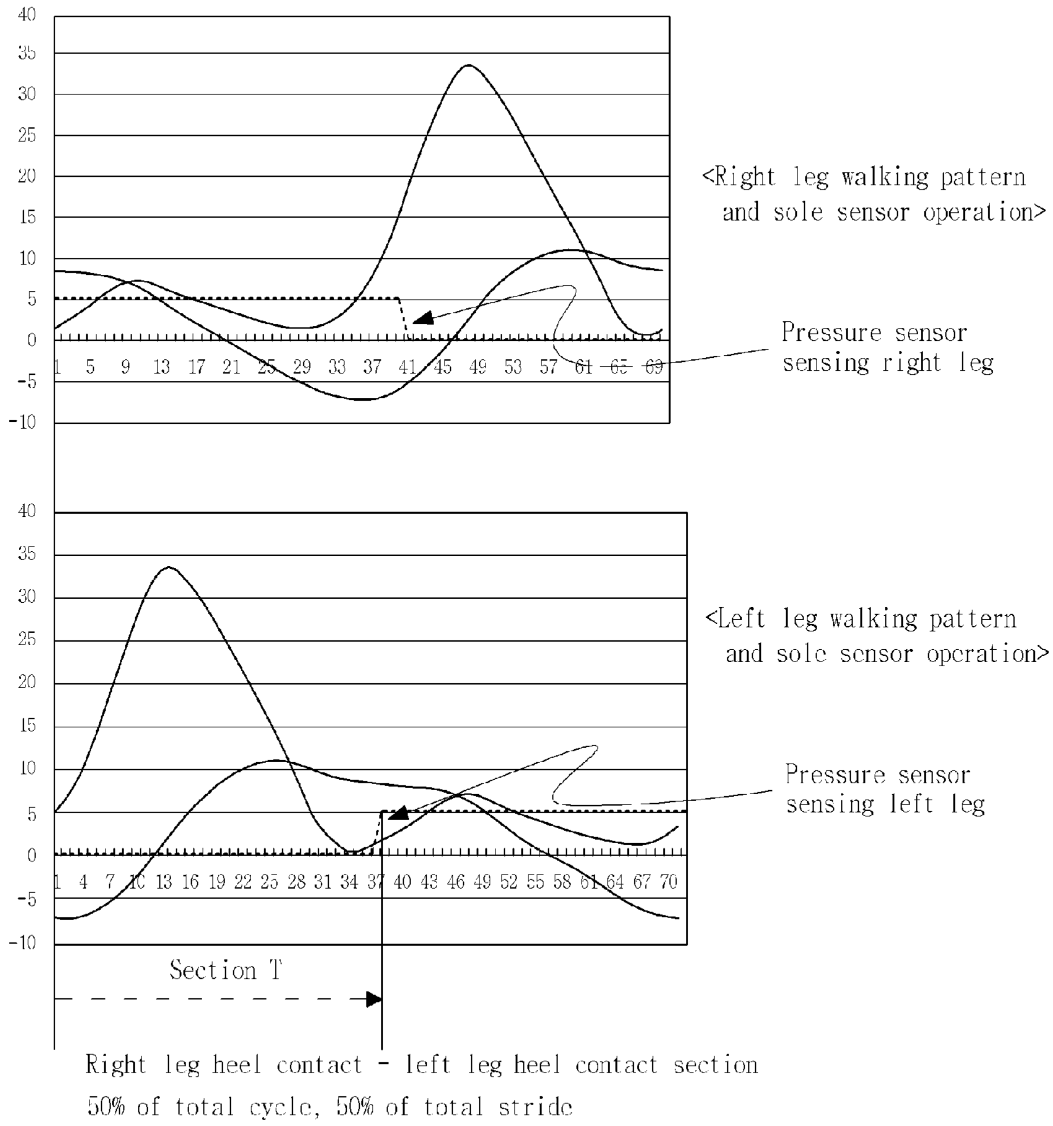

Information input step
Robot driving step
Training data generating step
Training data output step
Contact presence input step
Walking speed calculating step
Both leg speed synchronization step

Fig. 7



<Right leg walking pattern and sole sensor operation>
Pressure sensor sensing right leg
<Left leg walking pattern and sole sensor operation>
Pressure sensor sensing left leg
Section T
Right leg heel contact - left leg heel contact section
50% of total cycle, 50% of total stride

Fig. 8

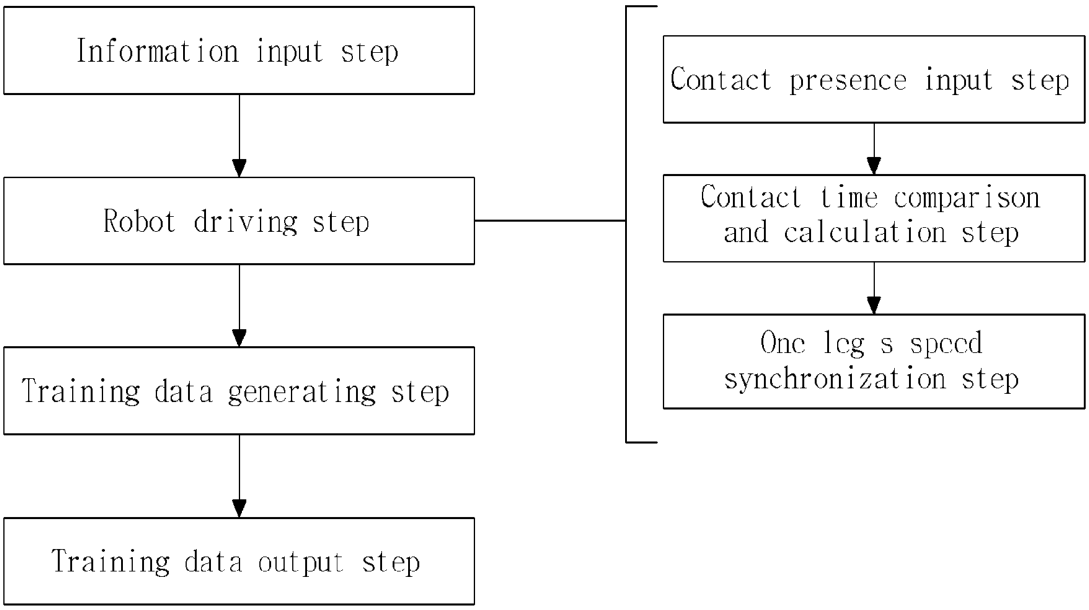
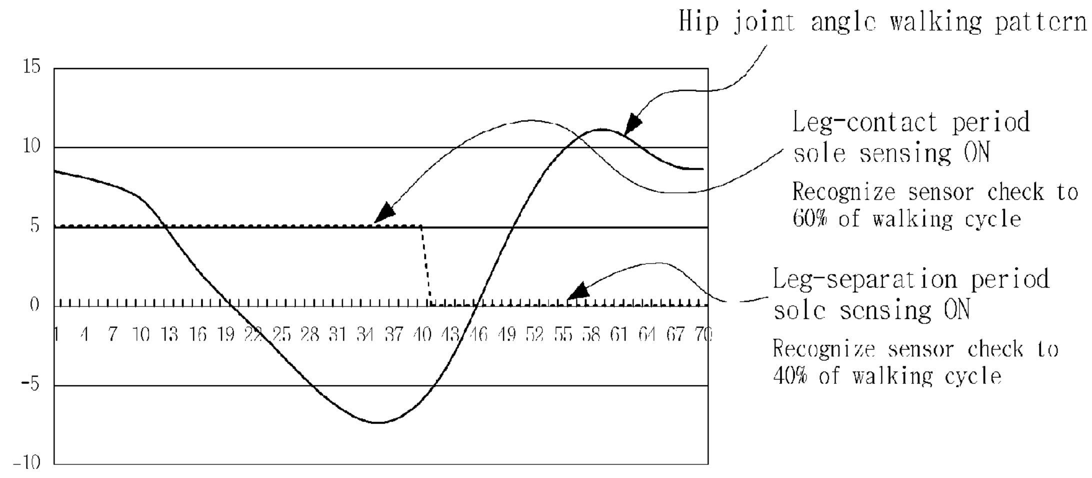
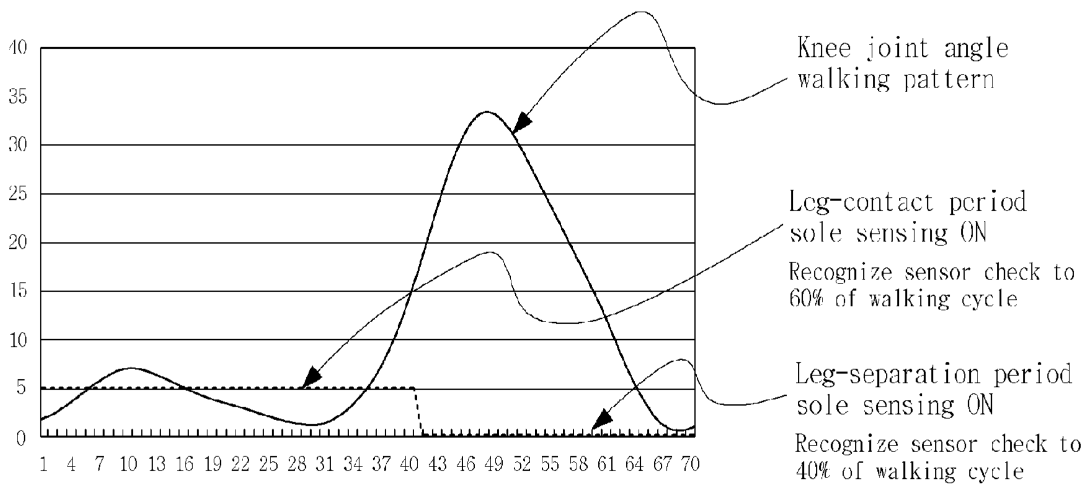

Information input step
Robot driving step
Training data generating step
Training data output step
Contact presence input step
Contact time comparison and calculation step
One leg s speed synchronization step

Fig. 9



<Knee joint angle pattern of right leg>



<Knee joint angle pattern of right leg>

Fig. 10

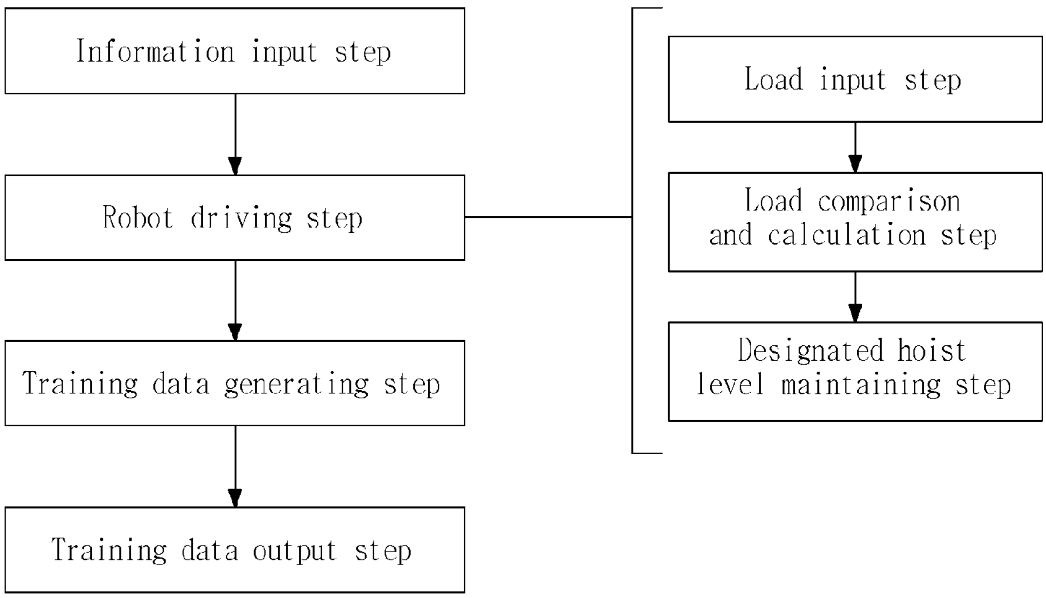

Information input step
Robot driving step
Training data generating step
Training data output step
Load input step
Load comparison and calculation step
Designated hoist level maintaining step

Fig. 11

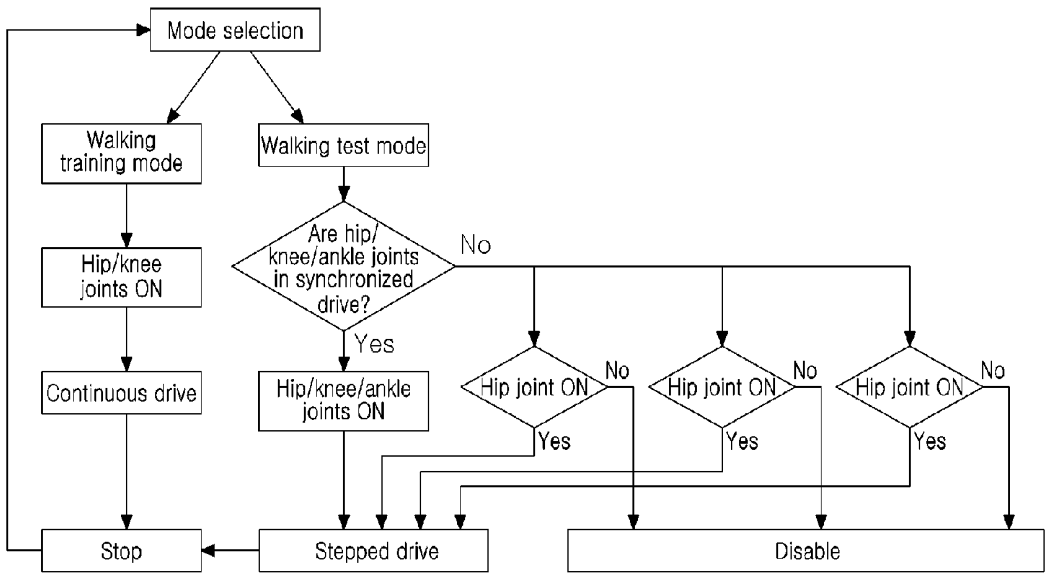

Mode selection
Walking training mode
Walking test mode
Hip/knee joints ON
Are hip/ knee/ankle joints in synchronized drive?
No
Yes
Continuous drive
Hip/knee/ankle joints ON
Hip joint ON
Hip joint ON
Hip joint ON
No
No
No
Yes
Yes
Yes
Stop
Stepped drive
Disable

Fig. 12

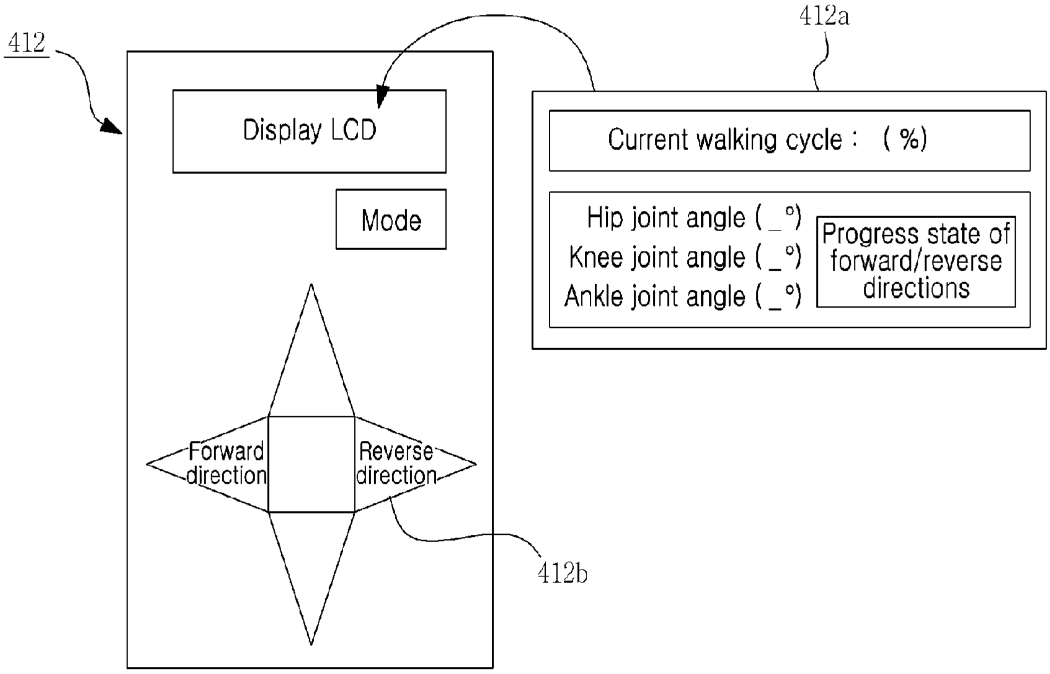

412
Display LCD
Mode
Forward direction
Reverse direction
412b
412a
Current walking cycle : (%)
Hip joint angle (_°)
Knee joint angle (_°)
Ankle joint angle (_°)
Progress state of forward/reverse directions

Fig. 13

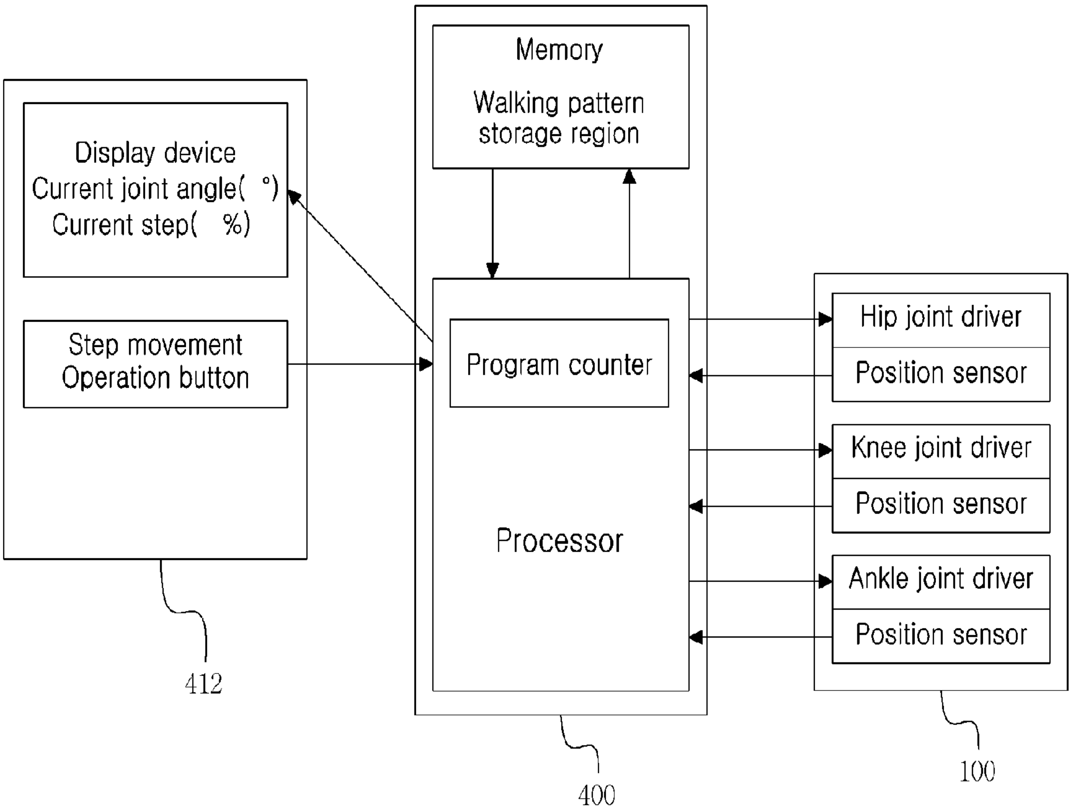

Memory
Walking pattern storage region
Display device
Current joint angle(°)
Current step(%)
Step movement
Operation button
Program counter
Processor
Hip joint driver
Position sensor
Knee joint driver
Position sensor
Ankle joint driver
Position sensor
412
400
100

Fig. 14

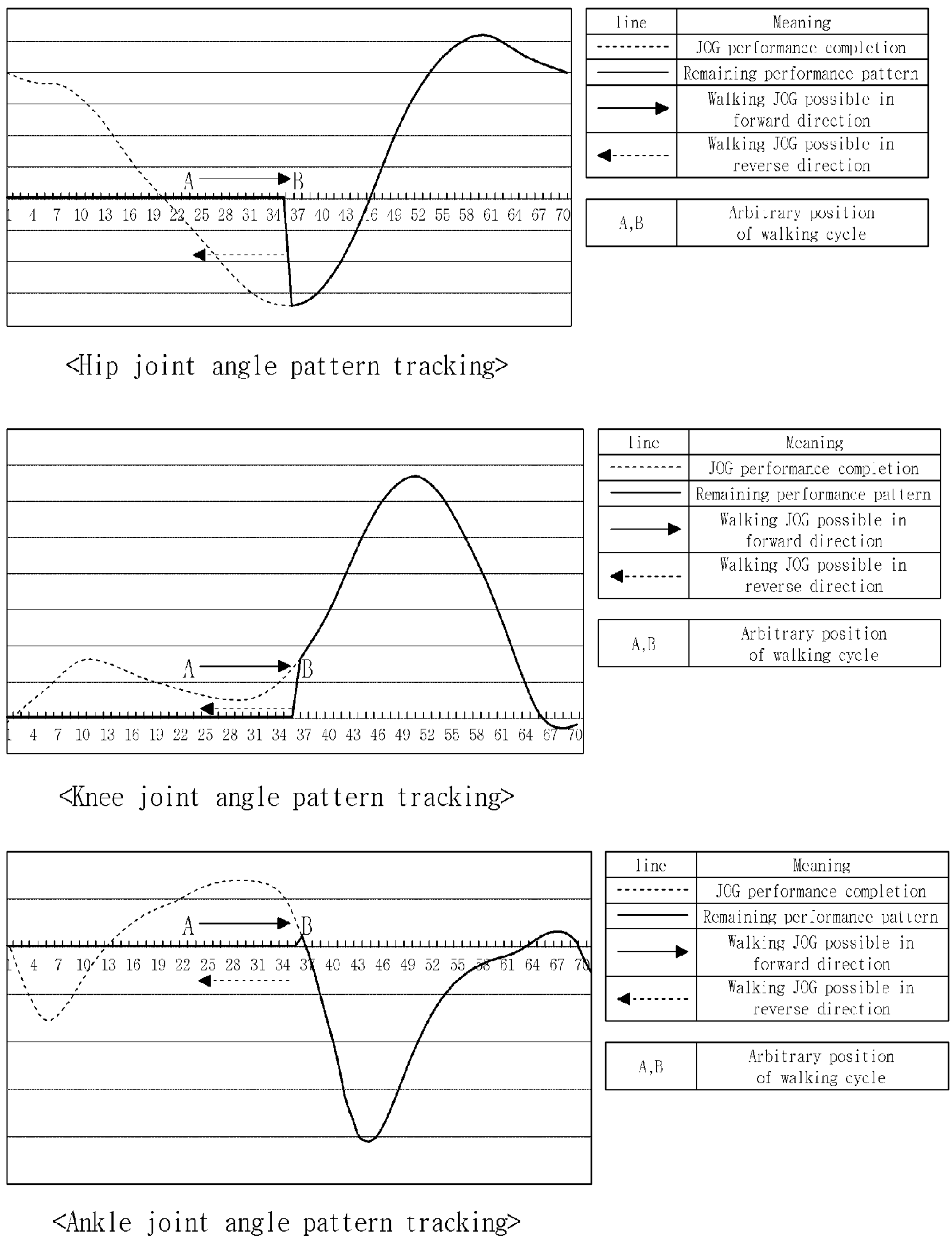
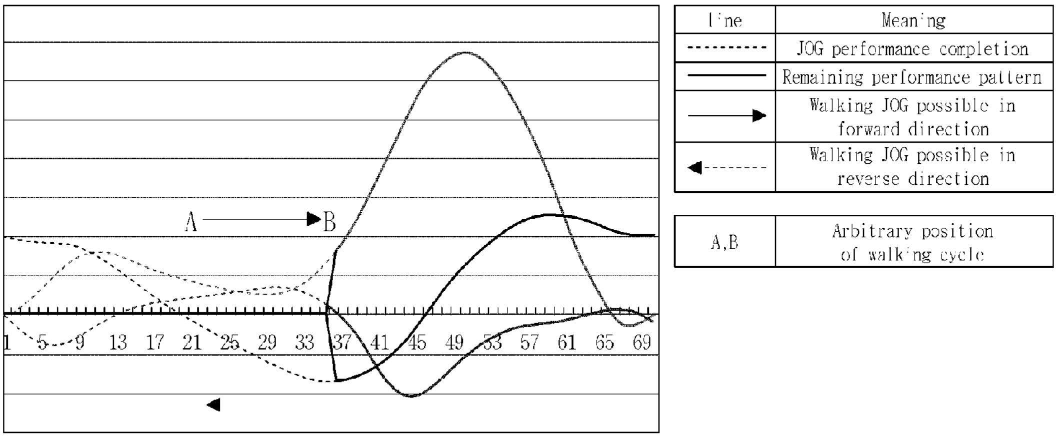
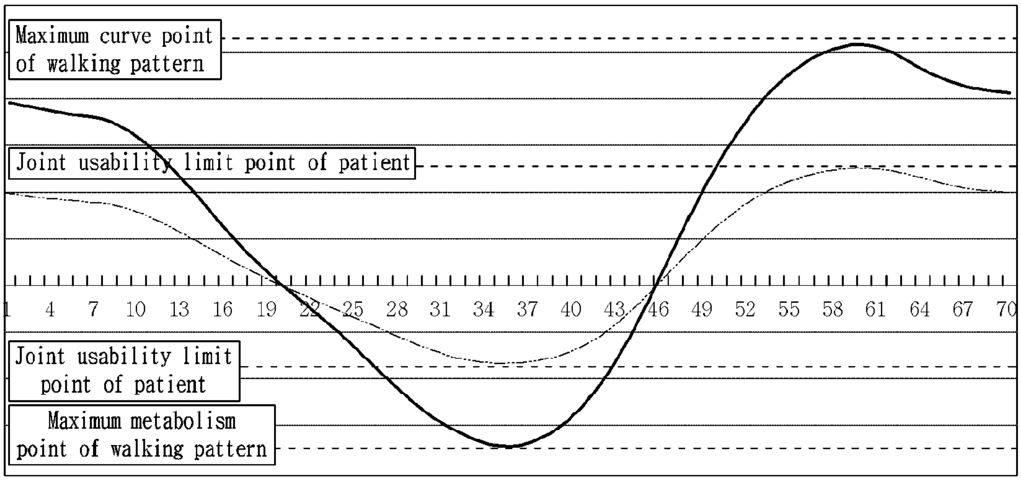

A
B
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70
line
Meaning
JOG performance completion
Remaining performance pattern
Walking JOG possible in forward direction
Walking JOG possible in reverse direction
A,B
Arbitrary position of walking cycle
<Hip joint angle pattern tracking>
A
B
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70
line
Meaning
JOG performance completion
Remaining performance pattern
Walking JOG possible in forward direction
Walking JOG possible in reverse direction
A,B
Arbitrary position of walking cycle
<Knee joint angle pattern tracking>
A
B
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70
line
Meaning
JOG performance completion
Remaining performance pattern
Walking JOG possible in forward direction
Walking JOG possible in reverse direction
A,B
Arbitrary position of walking cycle
<Ankle joint angle pattern tracking>

Fig. 15

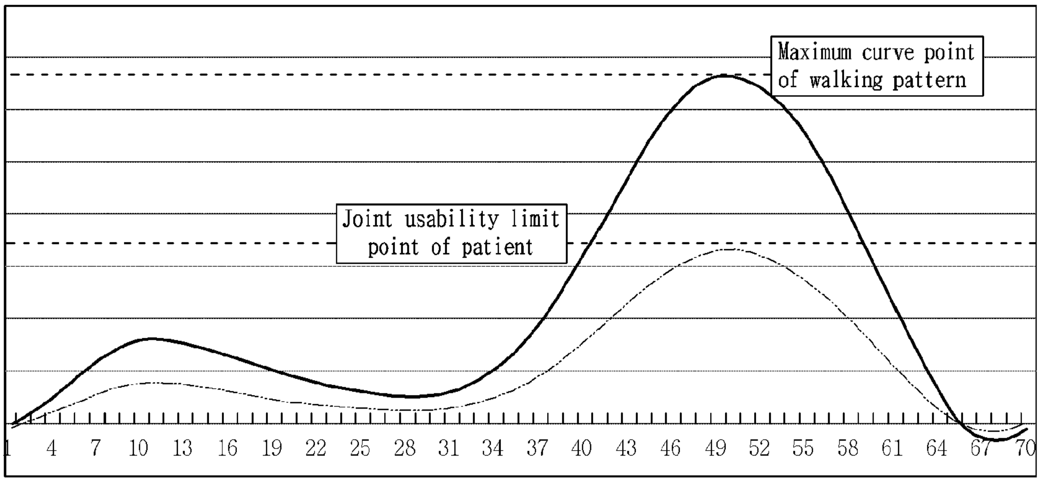


<Hip/knee/ankle joints synchronization angle pattern tracking>

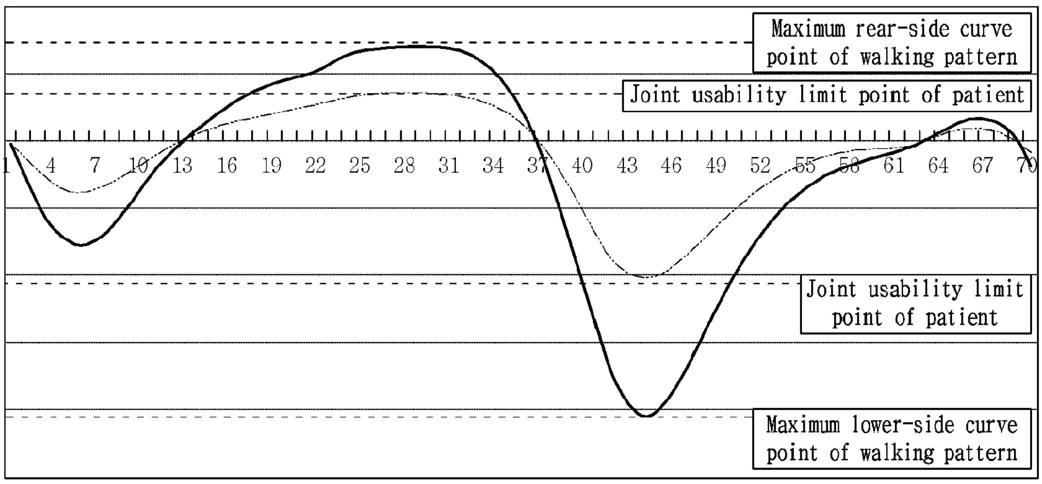
Fig. 16



<Pattern change of hip join>



<Pattern change of knee joint>



<Pattern change of ankle joint>

ROBOT FOR GAIT TRAINING AND OPERATING METHOD THEREOF

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is a Continuation-in-Part of international application Ser. No. PCT/KR2009/001533, filed Mar. 26, 2009, which published as WO 2009/145423A1 and claims priority to Korean Patent Application No. KR 10-2008-0029605, filed on Mar. 31, 2008. The contents of the aforementioned applications are incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a robot for gait training and an operating method thereof, and more particularly, to a robot for gait training and an operating method thereof for the purpose of rehabilitation of patients with walking disability.

[0004] 2. Description of the Related Art

[0005] Patients with walking disability perform gait training by bending their legs or moving according to walking patterns guided by walking-assist robots put on their bodies. During gait training using the walking-assist robot, if any one of an angle, speed and torque of each joint among hip joints, knee joints and ankle joints is out of a standardized walking pattern appropriate for training for walking trainees, this means that the walking trainee is not performing the gait training according to a walking pattern appropriate for the rehabilitation training

[0006] In a conventional art, walking trainees perform the gait training by driving walking-assist robots at a designated angle and speed while wearing the walking-assist robots on their legs. However, since it is difficult to determine whether the trainee performs the gait training in an appropriate walking pattern on the basis of movement of the legs at the designated angle and speed and to determine what training pattern is more appropriate for the walking trainee, effective gait training has been hard to achieve.

[0007] In addition, since the walking trainees wearing the walking-assist robots and performing the gait training have different body sizes, the conventional walking-assist robot is inconvenient in manually adjusting lengths of segments of the walking-assist robot to the body size of the walking trainees with assistance of a person who helps perform the gait training is necessary every time.

[0008] As the lengths of the segments are manually adjusted, it is difficult to adjust the walking-assist robot to an appropriate set of specific lengths of the walking trainee's body size, thus causing errors in adjustments. In addition, due to individual differences of the assistants who adjust the segment lengths, wearing the walking-assist robot tends to consume remarkably increased time and manpower.

SUMMARY OF THE INVENTION

[0009] In order to solve the afore-mentioned problems, an aspect of the present invention may be achieved by providing a robot for gait training and an operating method thereof that are capable of checking an angle, speed and torque of each joint of a walking trainee in real time, comparing the current walking of the walking trainee with the standardized walking pattern appropriate for the training for the walking trainee, and analyzing and determining whether the gait training is correctly performed and what walking pattern is more appropriate for the walking trainee.

[0010] In addition, another aspect of the present invention may be achieved by providing a robot for gait training and an operating method thereof that are capable of preventing occurrence of errors due to manual operations and remarkably improving effectiveness of time and manpower by driving a segment length adjustment device of a walking-assist robot and automatically setting the segment length of the walking-assist robot depending on the walking trainee's body size when information about the walking trainee's body size is input.

[0011] In order to accomplish the above aspects, the present invention provides a robot for gait training including: a walking-assist robot (**100**) put on legs of a walking trainee; a treadmill (**200**) with a conveyor belt floor which moves at a designated speed in order for the walking trainee to continuously perform gait training at a fixed position; a load-hoist (**300**) for upwardly supporting the body of the walking trainee; and a controller (**400**) including an input unit (**410**) for receiving or inputting information or commands about the size of the body of the walking trainee, and about a speed, angle and rotational force of each joint required for training of the walking trainee, an information storage device for selectively storing the information or commands received through the input unit (**410**) and information generated during a driving process of the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**), a control unit for controlling driving states of the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**) according to the information or commands input through the input unit (**410**) or transmitted from the information storage device, and a monitor (**420**) for numerically or graphically displaying the information transmitted from the walking-assist robot (**100**), the treadmill (**200**), the load hoist (**300**) and the information storage device.

[0012] Here, the walking-assist robot (**100**) may include: a position sensor for transmitting a position of each joint of the walking-assist robot (**100**) to the control unit of the controller (**400**); and a gear member for receiving a signal from the control unit of the controller (**400**) and adjusting the position of each joint and lengths of segments of the walking-assist robot (**100**).

[0013] In addition, the walking-assist robot (**100**) may further include a pressure sensor for transmitting the signal of a contact between a sole of the walking trainee and the treadmill (**200**) to the control unit of the controller (**400**).

[0014] Further, the load hoist (**300**) may include: a harness (**310**) put on the body of the walking trainee with a lower part thereof; a harness driving unit (**320**) for receiving a signal from the control unit of the controller (**400**) and having a drive means for adjusting a vertical length of the harness (**310**); and a load sensor for transmitting the value of a load applied to the harness (**310**) to the control unit of the controller (**400**).

[0015] Furthermore, the input unit (**410**) of the controller may include: a main body (**411**) cased with the information storage device, the monitor (**420**) and the control unit of the controller (**400**), and having an input terminal allowing a direct input of information or commands to the information storage device or the control unit of the controller (**400**); and a remote controller (**412**) having a wireless input terminal for transmitting the information or commands to the information storage device or the control unit of the controller (**400**).

[0016] In addition, the remote controller (**412**) may include: a wireless input unit (**412***a*) for transmitting an input command of progressing the walking-assist robot (**100**) in a forward direction or a reverse direction to the information storage device or the control unit of the controller (**400**) through a touch operation in real time; and a wireless monitor (**412***b*) for displaying in real time a progress state of the walking-assist robot (**100**) in a forward direction or a reverse direction, a hip joint angle, a knee joint angle, an ankle joint angle, and the current time in the designated walking cycle.

[0017] Further, the present invention provides an operating method of a robot for gait training including a walking-assist robot (**100**) put on legs of a walking trainee, a treadmill (**200**) for providing a conveyor belt floor moving at a designated speed in order for the walking trainee to continuously perform gait training at a fixed position on the treadmill, a load hoist (**300**) for upwardly supporting the body of the walking trainee, and a controller (**400**) for receiving and selectively storing information about the size of the body of the walking trainee, and speed, angle and rotational force of each joint required for training of the walking trainee, and numerically or graphically displaying the information and commands, and controlling driving states of the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**). The method includes: an information input step of acquiring the size of the body of the walking trainee, information about a walking pattern obtained through a gait training or a walking test, and information or commands required to drive and set the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**) by transferring them from a server of a network system or an information storage device of the controller (**400**) or by receiving them through an operation of an input terminal of an input unit (**410**) of the controller; a robot driving step of driving the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**) in a specific pattern according to the information or commands input in the information input step; a training data generating step of receiving information about speed, angle and torque of each joint of the walking trainee under the gait training in the specific pattern in the robot driving step in real time, and selectively classifying and storing the information inputted in real time in the information storage of the controller; and a training data output step of outputting the information input or stored in the training data generating step on a screen of the a monitor (**420**) of the controller in real time.

[0018] Here, the walking-assist robot (**100**) may include a position sensor for transmitting a position of each joint of the walking-assist robot (**100**) to the control unit of the controller (**400**), and a gear member for adjusting a position of each joint and lengths of segments of the walking-assist robot (**100**) depending on a gearing state therebetween, and the robot driving step may include: a joint position input step of receiving the position of each joint of the walking-assist robot (**100**) from the position sensor of the walking-assist robot (**100**); a segment length calculation step of calculating relative distances between positions of the respective joints input in the joint position input step and obtaining the lengths of the segments of the walking-assist robot (**100**); a length comparison and calculation step of comparing the lengths of the segments obtained in the segment length calculation step and the size data of the body of the walking trainee input in the information input step and calculating differences therebetween; and a segment length adjustment step of adjusting the driving direction and displacement of the gear member of the walking-assist robot (**100**) according to the differences obtained in the length comparison and calculation step and locating each joint of the walking-assist robot (**100**) at the position of each corresponding joint of the walking trainee.

[0019] Further, the walking-assist robot (**100**) may include a pressure sensor for transmitting a signal for contact between a sole of the walking trainee and the treadmill (**200**) to the control unit of the controller (**400**), and the robot driving step may include: a contact signal input step of receiving a signal for contact between the sole of the walking trainee and the treadmill (**200**) from the pressure sensor of the walking-assist robot (**100**) in real time; a walking speed calculation step of calculating a walking speed of the walking trainee by dividing a stride between two legs by a walking cycle defined by a time difference of the contacts of the two legs with the treadmill (**200**) during one stride of the walking trainee in real time or periodically; and a both leg speed synchronization step of driving the treadmill at the same speed as the walking speed obtained in the walking speed calculating step.

[0020] Furthermore, the walking-assist robot (**100**) may include a pressure sensor for transmitting a signal for contact between a sole of the walking trainee and the treadmill (**200**) to the control unit of the controller (**400**), and the robot driving step may include: a contact signal input step of receiving the contact presence between the sole of the walking trainee and the treadmill (**200**) from the pressure sensor of the walking-assist robot (**100**) in real time; a contact time comparison and calculation step of comparing times of one leg of the walking trainee contacting with and separating from the treadmill (**200**) with reference times predetermined through the information input step, and calculating difference therebetween; and a one leg speed synchronization step of adjusting a driving speed of the treadmill (**200**) according to the difference obtained in the contact presence comparison and calculation step and driving the treadmill (**200**) at the same speed as the walking speed of one of the two legs of the walking trainee.

[0021] In addition, the load hoist (**300**) may include a harness (**310**) put on the body of the walking trainee with a lower part thereof, a harness driving unit (**320**) having a drive means for adjusting a vertical length of the harness (**310**), and a load sensor for transmitting the value of a load applied to the harness (**310**) to the control unit of the controller (**400**), and the robot driving step may include: a load input step of receiving the value of a load applied to the harness (**310**) from the load sensor of the load hoist (**300**) in real time; a load comparison and calculation step of comparing the load inputted in the load input step and a designated hoist level inputted in the information input step and calculating difference therebetween; and a designated hoist level maintaining step of adjusting the driving direction and driving time of the harness driving unit (**320**) of the load hoist (**300**) according to the difference obtained in the load comparison and calculation step and adjusting the hoist level of the walking trainee to the designated hoist level by adjusting the length adjustment of the harness (**310**).

[0022] Further, the operating method of a robot for gait training may be separately operated either in a walking test mode or in a gait training mode. In the walking test mode, the robot driving step, the training data generating step and the training data output step are performed in real time during receipt of a progress command of a forward direction or a reverse direction for the walking-assist robot (**100**) in the information input step, whereas driving of the walking-assist robot (**100**) is stopped in a state in which the command of the progress direction for the walking-assist robot (**100**) is not inputted. In the gait training mode, when a command for driving the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**) in a specific pattern is primarily input in the information input step, the robot driving step, the training data generating step and the training data output step are continuously performed according to the command primarily input in the information input step until another command is re-inputted in the information input step.

[0023] Here, the walking test mode may be separately operated either in an individual drive mode of individually moving each joint corresponding to the hip joint, knee joint and ankle joint of the walking-assist robot (**100**); or in a combined drive mode of simultaneously moving the respective joints of the walking-assist robot (**100**) corresponding to the hip joint, knee joint and ankle joint.

[0024] In addition, in the walking test mode, the input unit (**410**) of the controller may be a remote controller (**412**) for wirelessly transmitting the information or commands to the information storage device or the control unit of the controller (**400**).

[0025] Further, the remote controller (**412**) may include: a wireless input unit (**412***a*) for transmitting an input command of progressing the walking-assist robot (**100**) in a forward direction or a reverse direction to the information storage device or the control unit of the controller (**400**) through a touch operation in real time; and a wireless monitor (**412***b*) for receiving information about a walking progress state of the walking-assist robot (**100**) in the forward direction or the reverse direction, the time in the walking cycle, and a hip joint angle, a knee joint angle and an ankle joint angle at the corresponding time, from the information storage device or the control unit of the controller (**400**) and displaying the information in real time.

[0026] Furthermore, in the training data output step, both the information about the angle, speed, rotational force and hoist level of each joint in a standard type appropriate for the walking trainee previously inputted in the information input step and the information about the angle, speed, rotational force, and hoist level of each joint inputted in real time in the training data generating step may be displayed together on one screen.

ADVANTAGEOUS EFFECTS

[0027] As can be seen from the foregoing, the angle, speed, torque of each joint and contact state with the conveyor belt floor of the walking trainee can be checked in real time through the monitor of the controller and the wireless monitor of the remote controller. In addition, it is possible to analyze and determine whether the walking trainee correctly performs the gait training and which walking pattern is more appropriate for the walking trainee, by clearly checking and comparing a difference between the standard walking pattern and the currently performed walking and displaying both the standardized walking patterns appropriate for the training for the walking trainee and the current walking on one screen.

[0028] Further, by storing and sharing records of patient's body size and training information through a communication network that enables transmission of information between the information storage device of the controller and a plurality of controllers, even when the patient performs the gait training at different times and places, the segment lengths of the walking-assist robot can be automatically adjusted depending on the walking trainee's body size, without re-inputting of the patient's body size or training conditions. Furthermore, it is possible to check information about the training performance and training method of the walking trainee and to maintain consistent treatment through the training with a walking pattern appropriate for the walking trainee on the basis of the information.

[0029] In addition, when information of patient ID of a walking trainee, or the walking trainee's body size such as a height, a thigh length, a shank length, and an ankle height is inputted, the segment length adjustment device of the walking-assist robot is automatically driven to adjust the segment lengths of the walking-assist robot depending on the segment lengths of the walking trainee, preventing error occurrences by a manual adjustment of the segment lengths of the walking-assist robot and thus remarkably improving effectiveness of time and manpower.

[0030] Further, by calculating a walking speed of a walking trainee from a sensing cycle and a stride of the pressure sensors installed on two legs to synchronize a driving speed of the treadmill to the walking speed of the walking trainee, or by comparing a sensing time and position of the pressure sensor installed at one leg with a preset time and position to synchronize the driving speed of the treadmill to the walking speed of the walking trainee, it is possible to prevent a leg-drag during the gait training and instability of a walking position and to perform stably the gait training in a designated space, regardless of whether the walking trainee wears the walking-assist robot on one leg or both legs.

[0031] Furthermore, when a training performance capability of the walking trainee is improved or lowered and requires change or modification of the walking pattern before continuous performance of the gait training according to a specific walking pattern in the gait training mode or during the gait training in the gait training mode, the walking test mode can be operated to independently or synchronously drive the respective joints of the walking-assist robot, in order to check available criteria of the respective joints of the walking trainee and to find a walking pattern most appropriate for the gait training of the walking trainee.

[0032] In addition, since a command needed to drive the walking-assist robot can be inputted using the remote controller in real time even at a position distant from the main body of the controller, a therapist can control the walking-assist robot to perform more efficiently the gait training while checking the walking state of the walking trainee from various positions. Further, while the gait training is performed according to a specific walking pattern using the wireless input unit of the remote controller in the walking test mode, a usability limit of each joint of the walking trainee can be clearly found by repeating progress of the robot in the reverse direction and the forward direction at times when the patient feels discomfort or does not wish to progress further and by checking an availability state of each joint through the wireless monitor in real time.

[0033] Furthermore, it is possible to receive information or commands required to drive the robot and automatically drive the robot according to the information or commands, display the driving state of the robot along with data of an ideal pattern, and independently or synchronously drive each joint of the robot using the remote controller in the walking test mode to apply various driving patterns on trial, thereby finding out causes of the problems. Thus, the operating method may be variously applied to walking analysis of other bipedal walking robots as well as the walking-assist robot put on a human body.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] FIG. **1** is a schematic view of a robot for gait training in accordance with a first embodiment of the present invention.

[0035] FIG. **2** is a flowchart showing an operating method of a robot for gait training in accordance with the first embodiment of the present invention.

[0036] FIG. **3** is a graph of an example of an output displayed on a screen, showing a speed and angle of a hip joint and a speed and angle of a knee joint, which are inputted during training in real time, and pre-input information about a standardized walking pattern appropriate for the training of the walking trainee.

[0037] FIG. **4** is a flowchart showing an operating method of a robot for gait training in accordance with a second embodiment of the present invention.

[0038] FIG. **5** is a flowchart showing an example of an operating method of automatically adjusting lengths of segments of a walking-assist robot.

[0039] FIG. **6** is a flowchart showing an operating method of a robot for gait training in accordance with a third embodiment of the present invention.

[0040] FIG. **7** is a graph showing a relationship between a sensing state of a pressure sensor and a walking cycle and stride.

[0041] FIG. **8** is a flowchart showing an operating method of a robot for gait training in accordance with a fourth embodiment of the present invention.

[0042] FIG. **9** is a graph showing a real-time sensing state of a pressure sensor according to a standard walking pattern.

[0043] FIG. **10** is a flowchart showing an operating method of a robot for gait training in accordance with a fifth embodiment of the present invention.

[0044] FIG. **11** is a flowchart showing a process of selectively operating a gait training mode and a walking test mode.

[0045] FIG. **12** is a schematic view showing an example of a remote controller.

[0046] FIG. **13** is a block diagram showing an information and signal transmission relationship between a remote controller, a controller, and a walking-assist robot in a walking test mode.

[0047] FIG. **14** is a graph showing a process of finding a critical point of usability of the walking trainee's joints by repeating an operation in which the respective joints of the walking-assist robot are individually driven in a forward direction and changed to be driven in a reverse direction at an arbitrary position according to a tracking walking pattern preset in a walking test mode.

[0048] FIG. **15** is a graph showing a process of finding a critical point of usability of the walking trainee's joints by repeating an operation in which all joints of the walking-assist robot are synchronously driven in a forward direction and changed to be driven in a reverse direction at an arbitrary position according to a tracking walking pattern preset in a walking test mode.

[0049] FIG. **16** is a graph showing a walking pattern reconstructed using a critical point of joint usability of the walking trainee.

DESCRIPTION ABOUT NUMERALS USED IN DRAWINGS

[0050]

100:	Walking-assist robot	200:	Treadmill
300:	Load hoist	310:	Harness
320:	Harness driving unit	400:	Controller
410:	Input unit of the Controller	411:	Main body of the Input unit
412:	Remote controller	412a:	Wireless input unit
412b:	Wireless monitor	420:	Monitor of the Controller
421:	Main Body of the Monitor		

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0051] A robot for gait training and an operating method thereof in accordance with the present invention will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown.

[0052] FIG. **1** is a schematic view of a robot for gait training in accordance with a first embodiment of the present invention, FIG. **2** is a flowchart showing an operating method of a robot for gait training in accordance with the first embodiment of the present invention, and FIG. **3** is a graph of an example of an output displayed on a screen, showing a speed and angle of a hip joint and a speed and angle of a knee joint, which are inputted during training in real time, and pre-input information about a standardized walking pattern appropriate for the training of the walking trainee.

[0053] In addition, FIG. **4** is a flowchart showing an operating method of a robot for gait training in accordance with a second embodiment of the present invention, FIG. **5** is a flowchart showing an example of an operating method of automatically adjusting lengths of segments of a walking-assist robot, FIG. **6** is a flowchart showing an operating method of a robot for gait training in accordance with a third embodiment of the present invention, FIG. **7** is a graph showing a relationship between a sensing state of a pressure sensor and a walking cycle and stride, FIG. **8** is a flowchart showing an operating method of a robot for gait training in accordance with a fourth embodiment of the present invention, FIG. **9** is a graph showing a real-time sensing state of a pressure sensor according to a standard walking pattern, and FIG. **10** is a flowchart showing an operating method of a robot for gait training in accordance with a fifth embodiment of the present invention.

[0054] Further, FIG. **11** is a flowchart showing a process of selectively operating in a gait training mode and in a walking test mode, FIG. **12** is a schematic view showing an example of a remote controller, FIG. **13** is a block diagram showing an information and signal transmission relationship between a remote controller, a controller, and a walking-assist robot in a walking test mode, FIGS. **14** and **15** are graphs showing a process of finding a critical point of usability of the walking trainee's joints by repeating an operation in which the respective joints of the walking-assist robot are individually or synchronously driven in a forward direction and changed to be driven in a reverse direction at an arbitrary position according to a tracking walking pattern preset in a walking test mode, and FIG. **16** is a graph showing a walking pattern reconstructed using a critical point of joint usability of the walking trainee.

[0055] As shown in FIG. **1**, a robot for gait training in accordance with the present invention includes a walking-assist robot **100**, a treadmill **200**, a load hoist **300**, and a controller **400**. The treadmill **200** is driven at a speed corresponding to a walking speed of a walking trainee who wears the walking-assist robot **100** and is in training, and the load hoist **300** upwardly supports the walking trainee's body to a designated hoisting level.

[0056] The controller **400** receives information or a command required to drive the walking-assist robot **100**, the treadmill **200** and the load hoist **300**, controls drive states of the walking-assist robot **100**, the treadmill **200** and the load hoist **300** and selectively stores them, and outputs information generated during drive of the walking-assist robot **100**, the treadmill **200** and the load hoist **300** and selectively stores them.

[0057] The walking-assist robot **100** includes joints corresponding to the walking trainee's joints and put on the legs of the walking trainee who needs the gait training, and has a structure that can adjust positions and angles of joints of the walking-assist robot **100**, and lengths of segments formed between the joints. The walking-assist robot **100** may selectively include at least one joint of the hip joints, knee joints and ankle joints, may be put on only one leg, or may be put on both legs depending on necessities of the walking trainee.

[0058] The structure and operating theory of the walking-assist robot **100** are known in the art of manufacturing a robot including joints corresponding to legs of a human body and driven in specific patterns, and thus detailed descriptions thereof are omitted. The walking-assist robot is not limited to a specific structure and shape, but may have an appropriate structure selectively applied depending on a disability level and a training state of the walking trainee, a place at which the robot is used, and so on.

[0059] The structure and operating theory of the treadmill **200** providing a conveyor belt floor moving at a designated speed so that the walking trainee can continuously perform the gait training in a fixed position are also known in the art, and thus detailed descriptions thereof are omitted. The structure and operating theory of the load hoist **300** for upwardly supporting the walking trainee's body are disclosed in Korean Patent Application No. 2008-21889, entitled "Load-cell Detection Mechanism, Support Frame for Walking-assist Robot and Hoist for Walking-assist Robot including the same" (Korean published application 10-2009-096828, published on 16 Sep. 2009), and thus detailed descriptions thereof are also omitted.

[0060] The controller **400** generally includes an input unit **410**, an information storage device (not shown), a control unit (not shown), and a monitor **420**.

[0061] The input part **410** of the controller **400** includes a communication terminal connected to a communication network that enables transmission of information from the control unit or the information storage device of the controller **400** or between a plurality of controllers **400** installed in different places (for example, different hospitals or physical therapy rooms) to receive information or commands about the walking trainee's body size, and a speed, angle and rotational force of each joint needed for the training for a walking trainee from another controller **400** or a network server, or includes a terminal that can input numbers, etc., into the controller **400** to directly receive information or commands from a user.

[0062] The input unit **410** of the controller **400** includes a main body **411** cased with the information storage device, the control unit, and the monitor **420** of the controller **400** to maintain a state installed at a fixed position, and providing an input terminal capable of allowing a user to directly input information and commands into the information storage device or the control unit of the controller **400**, and a wireless input unit **412***b* installed at a remote controller **412** (See FIG. **12**) disposed at an arbitrary position distant from the main body **411**, and transmitting information or commands to the information storage device or the control unit of the controller **400**.

[0063] The information storage device of the controller **400** selectively classifies and stores information or commands received through the input unit **410** or the control unit, and information generated during a driving process of the walking-assist robot **100**, the treadmill **200** and the load hoist **300**, and the control unit of the controller **400** controls driving states of the walking-assist robot **100**, the treadmill **200** and the load hoist **300** according to information or commands received through the input unit **410** or transmitted from the information storage device of the controller.

[0064] The monitor **420** of the controller numerically or graphically displays information or commands received through the input unit **410**, driving states of the information storage device, the walking-assist robot **100**, the treadmill **200** and the load hoist **300** under control of the control unit, information or commands stored in the information storage device during the gait training, and information transmitted from the information storage device, the walking-assist robot **100**, the treadmill **200** and the load hoist **300**.

[0065] Similarly to the input unit **410** of the controller, the monitor **420** of the controller also includes a main body **421** cased with the information storage device and the control unit of the controller **400** and the main body **411** of the input unit to maintain a state installed at a fixed position, and a wireless monitor **412***a* of the remote controller disposed at an arbitrary position distant from the main body **421** of the monitor, and receiving and displaying information or commands from the input unit **410**, the information storage device or the control unit of the controller in a wireless manner.

[0066] Since the commands required to drive the walking-assist robot **100** can be inputted in real time even at a position distant from the main body of the controller **400** using the remote controller **412**, a therapist can control the walking-assist robot **100** to more effectively perform the gait training while specifically checking a walking state of the walking trainee at various positions.

[0067] An operation method of a robot for gait training in accordance with the present invention relates to a method of operating a robot for gait training as explained above, and, as shown in FIG. **2**, generally includes an information input step, a robot driving step, a training data generating step, and a training data output step. In the robot driving step, the walking-assist robot **100**, the treadmill **200** and the load hoist **300** are specifically driven according to information received in the information input step. In the training data generating step, information about the respective driving states from the walking-assist robot **100**, the treadmill **200** and the load hoist **300** while driving are received and selectively stored. In the training data output step, information generated in the training data generating step is output on a screen.

[0068] In the information input step, the walking trainee's body size, information about a walking pattern acquired by the gait training or the test, and information or commands needed to drive and set the walking-assist robot **100**, the treadmill **200** and the load hoist **300** are transmitted from a server of a network system or the information storage device of the controller **400**, or inputted by operating an input terminal of the input unit **410** of the controller.

[0069] In the robot driving step, the walking-assist robot **100**, the treadmill **200** and the load hoist **300** are specifically driven according to the information or commands input in the information input step, and information about a walking state of the walking or a driving state of the device trainee at this time is received from detection terminals installed at the walking-assist robot **100** and the load hoist **300** in real time to control and drive the walking-assist robot **100**, the treadmill **200** and the load hoist **300** according to the walking state of the walking trainee in a mutual relationship.

[0070] In the training data generating step, both information about a speed, angle and torque of each joint of the walking trainee who performs the gait training according to a specific pattern in the robot driving step and information about the respective drive states are received from the walking-assist robot **100**, the treadmill **200** and the load hoist **300** in real time, and the information input in real time is selectively classified, arranged and stored in the information storage device of the controller.

[0071] In the training data output step, the information inputted or stored in the training data generating step is output on a screen in real time through the main body **421** of the monitor of the controller or the wireless monitor **412***a* in an appropriate types of numbers, tables, graphs, and figures so that the walking trainee and a therapist can check the angle, speed, torque and floor contact state of each joint of the walking trainee during a gait training

[0072] As shown in FIG. **3**, when the information about the angle, speed, rotational force and hoisting level of each joint inputted in real time in the training data generating step is output on a screen with the pre-input information about the angle, speed, rotational force and hoisting level of a standard type appropriate for the walking trainee in the information input step, the walking trainee and the therapist can check and compare the standard walking pattern appropriate for the walking trainee and the currently performed walking on the basis of objective indices, and analyze and determine whether the walking trainee correctly performs the gait training and what walking pattern is more appropriate for the walking trainer.

[0073] In operating the robot for gait training as explained above, since the walking-assist robot **100** has a structure including a position sensor (not shown) for transmitting a position of each joint of the walking-assist robot **100** to the control unit of the controller **400** and a gear member (not shown) for receiving a signal from the control unit of the controller **400** to adjust the position of each joint and the lengths of the segments of the walking-assist robot **100**, in the robot driving step, as shown in FIG. **4**, the lengths of the segments of the walking-assist robot **100** can be automatically adjusted according to the walking trainee's body size by a joint position input step, a segment length calculation step, a length comparison and calculation step, and a segment length adjustment step.

[0074] In the joint position input step, the position of each joint of the walking-assist robot **100** is inputted from the position sensor of the walking-assist robot **100**. In the segment length calculation step, a relative distance between position data of the respective joints inputted in the joint position input step is calculated to obtain the lengths of the segments of the walking-assist robot **100**.

[0075] In the length comparison and calculation step, the length of the segment obtained in the segment length calculation step is compared with the walking trainee's body size inputted in the information input step to calculate a difference therebetween. In the segment length adjustment step, a driving direction and displacement of the gear member of the walking-assist robot **100** are adjusted according to the difference obtained in the length comparison and calculating step to locate each joint of the walking-assist robot **100** at a position corresponding to each joint of the walking trainee.

[0076] As shown in FIG. **5**, when identification (ID) of the walking trainee is inputted and a stored record of the corresponding ID exists, the stored record of the ID is called in. When the ID does not exist or the stored record of the ID does not exist, information about the walking trainee's body size such as a height, a thigh length, a shank length, and an ankle height of the walking trainee is directly inputted. Then, the gear member for adjusting the segment lengths of the walking-assist robot **100** is automatically driven under control of the controller **400** to adjust the segment lengths of the walking-assist robot **100** to the segment lengths of the walking trainee, preventing error occurrence caused by manual adjustment of the segment lengths of the conventional walking-assist robot and thus remarkably improving effectiveness of time and manpower.

[0077] In the information input step, by using a communication network that allows transmission of information between the information storage device of the controller **400** and a plurality of controllers **400**, when the walking trainee performs the gait training at different times and places, required information can be called from the information storage device of the controller **400**, the server connected to the communication network, or another controller **400** to be used for the gait training, without re-input of the patient's body size or training condition every time. As a result, the segment length of the walking-assist robot can be automatically adjusted according to the walking trainee's body size by only inputting the walking trainee's ID, information about training achievement and a training method of the walking trainee can be checked, and the training in a walking pattern appropriate for the walking trainee can performed on the basis of the information, maintaining a consistent treatment.

[0078] In operating the robot for gait training in accordance with the present invention as explained above, since the walking-assist robot **100** has a structure including a pressure sensor (not shown) for transmitting presence of a contact between the walking trainee's sole and the treadmill **200** to the control unit of the controller **400**, the walking speed of the walking trainee and the conveyor belt driving speed of the treadmill **200** can be automatically synchronized through a contact signal input step, a walking speed calculation step, and a two leg speed synchronization step in the robot driving step as shown in FIG. **6** or through a contact signal input step, a contact time comparison and calculation step, and a one leg speed synchronization step as shown in FIG. **8**.

[0079] As shown in FIG. **6**, the robot driving step includes a sequence of the contact signal input step, the walking speed calculation step and the two leg speed synchronization step. In the contact signal input step, a signal for contact between the walking trainee's sole and the treadmill **200** is inputted from the pressure sensor of the walking-assist robot **100** in real time. In the walking speed calculation step, a walking cycle is determined by the time difference when each two legs of the walking trainee contacts the treadmill **200** in one step, and a stride between two legs is divided by the walking cycle to obtain the walking speed of the walking trainee in real time or periodically. In the two leg speed synchronization step, the treadmill **200** is driven at the same speed as the walking speed obtained in the walking speed calculation step.

[0080] FIG. **7** shows that, in the sequential steps of the contact presence input step, the walking speed calculation step, and the both leg speed synchronization step, a difference between sensing times of the right and left legs and a positional difference between the right and left legs (section T) during one stride correspond to 50% of the entire walking cycle and the stride. The treadmill **200** is driven at a speed in which the stride corresponding to the section T is divided by the walking cycle corresponding to the section T, and synchronized to the walking speed of the walking trainee.

[0081] In a state in which the gait training is performed in a certain pattern with the walking-assist robot **100** put on both legs, the contact on the treadmill **200** of both legs can be sensed to synchronize the driving speed of the treadmill **200**. As the walking speed of one stride is used as a calculation basis, the speed of the treadmill **200** may be synchronized at each stride, or the walking speed of two or more strides may be calculated to synchronize the speed of the treadmill **200** every two strides, i.e., every walking cycle.

[0082] As shown in FIG. **8**, the robot driving step includes a contact signal input step, a contact time comparison and calculation step, and a one leg speed synchronization step, which are sequentially performed. In the contact signal input step, signals of contact between the walking trainee's both legs and the treadmill **200** are inputted from the pressure sensor of the walking-assist robot **100** in real time. In the contact time comparison and calculation step, contact and separation times of one of the walking trainee's legs from the treadmill **200** is compared with a reference times predetermined through the information input step to calculate a difference therebetween. In the one leg speed synchronization step, the driving speed of the treadmill **200** is adjusted according to the difference obtained in the contact time comparison and calculation step to drive the treadmill **200** at the same speed as the walking speed of one of the walking trainee's both legs.

[0083] In the sequential steps of the contact presence input step, the contact time comparison and calculation step, and the one leg speed synchronization step, FIG. **9** shows a reference time previously inputted and designated through the information input step and used as a reference in comparing with the current sensing time and position in the contact time comparison and calculation step. A leg-contact period, which refers to a state in which the leg is in contact with the ground, is generally 60% of the total walking cycle in normal walking, and a leg-separation period, which refers to a state in which the leg is spaced apart from the ground, is generally 40% of the total walking cycle in normal walking On the basis of the above, FIG. **9** shows appropriate sensing ON/OFF time of the leg-contact period and the leg-separation period on a walking pattern (a hip joint angle walking pattern and a knee joint angle walking pattern shown in FIG. **9**) standardized to training for the walking trainee.

[0084] Therefore, the reference time compared with the current walking in the contact time comparison and calculation step is a time that the sensing state of the pressure sensor is shifted in a pattern as shown in FIG. **9**. When the pressure state is shifted to a shorter time or a farther distance in comparison with the reference time and position, a speed of the treadmill **200** becomes faster than the current driving speed in proportion to the difference, and when the pressure state is shifted to a longer time or a shorter distance, the speed of the treadmill **200** becomes slower than the current driving speed, synchronizing the speed of the treadmill **200** to the walking speed of the walking trainee.

[0085] In a state in which the walking trainee wears the walking-assist robot **100** and performs the gait training on only one leg because only one leg requires the gait training, since a moving speed of a normal leg with no robot, which has a variable speed, must be considered as a major factor to avoid an immoderate walking, the speed of the treadmill **200** is preferably synchronized to the walking speed through the contact time comparison and calculation step and the one leg speed synchronization step as explained above.

[0086] As described above, the driving speed of the treadmill **200** can be synchronized to the walking speed of the walking trainee by calculating a walking speed using a sensing cycle of the pressure sensor installed at the walking trainee's legs and a stride, or by comparing a sensing time and position of the pressure sensor installed at one leg with a preset arbitrary time and position. Therefore, it is possible to prevent instability of walking due to a leg-drag during the gait training or a relative position difference to the conveyor belt floor, and thus, it is possible for the walking trainee to perform the gait training stably in a designated space, regardless of the number and position of the walking-assist robots put on the walking trainee.

[0087] In operating the robot for gait training in accordance with the present invention as explained above, since the load hoist **300** includes a harness **310** put on the walking trainee's body with its lower part, a harness driving unit **320** having a drive means for adjusting a vertical length of the harness **310** using the control unit of the controller **400**, and a load sensor for transmitting the value of a load applied to the harness to the control unit of the controller **400**, it is possible in the robot driving step to hoist the walking trainee who cannot easily perform the gait training with his/her own weight put on his/her legs uniformly throughout a load input step, a load comparison and calculation step and a designated hoist level maintaining step as shown in FIG. **10**.

[0088] In the load input step, a load applied to the harness **310** is inputted from the load sensor of the load hoist **300** in real time. In the load comparison and calculation step, the load inputted in the load input step is compared with a designated hoist level inputted in the information input step to calculate a difference therebetween. In the designated hoist level maintaining step, a driving direction and a driving time of the harness driving unit **310** of the load hoist **300** are adjusted according to the difference obtained in the load comparison and calculation step such that the hoist level of the walking trainee is adjusted to correspond to the designated hoist level by length adjustment of the harness **310**.

[0089] In applying an operating method of a robot for gait training in accordance with the present invention as described above, a walking test mode and a gait training mode are applied selectively as shown in FIG. **11**.

[0090] The walking test mode is an operating mode in which the robot driving step, the training data generating step and the training data output step are performed in real time while a progress command in a forward direction or a reverse direction for the walking-assist robot **100** is inputted in the information input step, whereas driving of the walking-assist robot **100** is stopped in a state in which a command of a progress direction for the walking-assist robot **100** is not inputted.

[0091] The walking test mode is an operating mode in which the walking-assist robot can be driven in real time only while a user operates the robot so that the user can rapidly transfer the walking states in real time and inspect appropriateness of each pattern. The walking test mode can be operated either in an individual drive mode in which the respective joints corresponding to the hip joint, the knee joint and the ankle joint of the walking-assist robot **100** are individually moved, or in a combined drive mode in which the respective joints corresponding to the hip joint, the knee joint and the ankle joint of the walking-assist robot **100** are simultaneously moved. As such, it is possible to diagnose the walking tests more precisely and clearly by subdividing the tests into individual tests of respective joints and the combined tests correlating all the related joints together.

[0092] In the walking test mode, the input unit **410** of the controller may be the remote controller **412** having a wireless input terminal capable of transmitting information or commands to the information storage device or the control unit of the controller **400** in a wireless manner so that a therapist can control a drive state of the walking-assist robot in real time at various positions where the training state of the walking trainee can be readily checked. Of course, for the gait training mode, the same effect may be accomplished using the remote controller **412**.

[0093] As shown in FIG. **12**, the remote controller **412** may include a wireless input unit **412***a* for transmitting an input command of progressing the walking-assist robot **100** in a forward direction or a reverse direction to the information storage device or the control unit of the controller **400** through a touch operation in real time, and a wireless monitor **412***b* for receiving information about a walking progress state of the walking-assist robot **100** in the forward direction or the reverse direction, current time in the walking cycle, and a hip joint angle, a knee joint angle and an ankle joint angle at the corresponding time, from the information storage device or the control unit of the controller **400**, and for displaying the information in real time.

[0094] FIG. **13** is a block diagram showing an information and signal transmission relationship between the remote controller **412**, the controller **400** and the walking-assist robot **100**. A walking trainee or a therapist can input a forward direction progress command into the controller **400** through the wireless input unit **412***a* of the remote controller to individually or combinedly drive the respective joints of the hip joint, the knee joint and the ankle joint of the walking-assist robot **100**, so that the position information of each joint can be received from the position sensor to be selectively stored and information about times in the entire walking cycle and positions of the respective joints can be checked through the wireless monitor **412***b* of the remote controller.

[0095] The gait training mode is an operating mode in which the robot driving step, the training data generating step and the training data output step are continuously performed according to a command primarily inputted in the information input step until another command is re-input in the information input step, when the command for driving the walking-assist robot **100**, the treadmill **200** and the load hoist **300** in a specific pattern is primarily input in the information input step. That is a general gait training mode in which a standardized walking pattern appropriate for the training for the walking trainee is applied and tracked to perform continuous gait training.

[0096] In the case where the walking test mode and the gait training mode are selectively operated as described above, when a training performance ability of the walking trainee is improved or lowered and requires change or modification of the walking pattern before continuous performance of the gait training according to a specific walking pattern in the gait training mode or during the gait training in the gait training mode, the walking test mode is operated to independently or synchronously drive the respective joints of the walking-assist robot **100**, checking available criteria of the respective joints of the walking trainee and finding out a walking pattern appropriate for the gait training of the walking trainee. Therefore, the appropriate walking pattern found out in the walking test mode can be applied to the gait training mode to perform the actual gait training.

[0097] A method of finding out a walking pattern appropriate for the gait training of the walking trainee in the walking test mode is described in more detail. In a state in which an input terminal of the wireless input unit **412** of the remote controller **412** that represents a forward direction is pushed by a finger of an operator, the respective joints of the walking-assist robot **100** are driven in the forward direction according to the specific walking pattern as shown in FIGS. **14** and **15**. If a patient feels discomfort or does not wish to progress further, the operator instantly removes the finger from the wireless input unit **412***b* of the remote controller to stop the progress, and then pushes an input terminal of the wireless input unit **412***b* of the remote controller representing a reverse direction to reversely progress the robot until the patient is relieved from the discomfort, and then, progress the robot by a short section in the forward direction. By repeating the above steps, it is possible to find usability limits of the walking trainee's joints.

[0098] By finding the walking pattern appropriate for the gait training of the walking trainee using the above method, it is possible to check and store the moving state of each joint through the wireless monitor **412***a* of the remote controller **412** and a main body **421** of the monitor in real time, analyze the training more clearly by objective indices. In applying the gait training mode, it is possible to apply a reconstructed walking pattern to effectively perform the gait training within a range not exceeding the usability limit of the walking trainee's joints, as shown in FIG. **16**.

[0099] According to the operating method of a robot for gait training in accordance with the present invention, it is possible to receive information or commands required to drive the robot and automatically drive the robot according to the information or commands, display the driving state of the robot with data of an ideal pattern, and independently or synchronously drive each joint of the robot using the remote controller in the walking test mode to apply various driving patterns, thereby finding out causes of the problems. Thus, the operating method may be variously applied to walking analysis of other bipedal walking robots as well as the walking-assist robot **100**.

[0100] It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention covers the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A robot for gait training, comprising:

a walking-assist robot (**100**), for putting on the legs of a walking trainee;

a treadmill (**200**) with a conveyor belt floor which moves at a designated speed, for the walking trainee to continuously perform gait training at a fixed position;

a load-hoist (**300**), for upwardly supporting a body of the walking trainee; and

a controller (**400**) including:

an input unit (**410**) for receiving or inputting information or commands about the size of the body of the walking trainee, and about speed, angle and rotational force of each joint required for training of the walking trainee;

an information storage device for selectively storing the information or commands received through the input unit (**410**) and information generated during a driving process of the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**);

a control unit for controlling driving states of the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**) according to the information or commands input through the input unit (**410**) or transmitted from the information storage device; and

a monitor (**420**) for numerically or graphically displaying the information transmitted from the walking-assist robot (**100**), the treadmill (**200**), the load hoist (**300**) and the information storage device.

2. The robot for gait training according to claim **1**, wherein the walking-assist robot (**100**) comprises:

a position sensor for transmitting a position of each joint of the walking-assist robot (**100**) to the control unit of the controller (**400**); and

a gear member for receiving a signal from the control unit of the controller (**400**) and adjusting the position of each joint and lengths of segments of the walking-assist robot (**100**).

3. The robot for gait training according to claim **1**, wherein the walking-assist robot (**100**) comprises a pressure sensor for transmitting the signal for a contact between a sole of the walking trainee and the treadmill (**200**) to the control unit of the controller (**400**).

4. The robot for gait training according to claim **1**, wherein the load hoist (**300**) comprises:

a harness (**310**), for putting on the body of the walking trainee with a lower part thereof;

a harness driving unit (**320**) for receiving a signal from the control unit of the controller (**400**) and having a drive means for adjusting a vertical length of the harness (**310**); and

a load sensor for transmitting a value of a load applied to the harness (**310**) to the control unit of the controller (**400**).

5. The robot for gait training according to claim **1**, wherein the input unit (**410**) of the controller comprises:

a main body (**411**) cased with the information storage device, the monitor (**420**) and the control unit of the controller (**400**), and having an input terminal allowing a direct input of information or commands to the information storage device or the control unit of the controller (**400**); and

a remote controller (**412**) having a wireless input terminal for transmitting the information or commands to the information storage device or the control unit of the controller (**400**).

6. The robot for gait training according to claim **1**, further comprising a remote controller (**412**) including:

a wireless input unit (**412***a*) for transmitting an input command of progressing the walking-assist robot (**100**) in a forward direction or a reverse direction to the information storage device or the control unit of the controller (**400**) through a touch operation in real time; and

a wireless monitor (**412***b*) for displaying in real time a progress state of the walking-assist robot (**100**) in a forward direction or a reverse direction, a hip joint angle, a knee joint angle, an ankle joint angle, and the current time in the designated walking cycle.

7. An operating method of a robot for gait training, the robot comprising a walking-assist robot (**100**) for putting on the legs of a walking trainee, a treadmill (**200**) for providing a conveyor belt floor moving at a designated speed in order for the walking trainee to continuously perform gait training at a fixed position, a load hoist (**300**) for upwardly supporting the body of the walking trainee, and a controller (**400**) for receiving and selectively storing information about the size of the body of the walking trainee, and speed, angle and rotational force of each joint required for training of the walking trainee, and numerically or graphically displaying the information and commands, and controlling driving states of the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**), the operating method comprising:

an information input step of acquiring the size of the body of the walking trainee, information about a walking pattern obtained through a gait training or a walking test, and information or commands required to drive and set the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**) by transferring them from a server of a network system or an information storage device of the controller (**400**) or by receiving them through an operation of an input terminal of an input unit (**410**) of the controller;

a robot driving step of driving the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**) in a specific pattern specified by the information or commands input in the information input step;

a training data generating step of receiving information about speed, angle and torque of each joint of the walking trainee under the gait training in the specific pattern in the robot driving step in real time, and selectively classifying and storing the information inputted in real time in the information storage of the controller; and

a training data output step of outputting the information inputted or stored in the training data generating step on a screen of the monitor (**420**) of the controller in real time.

8. The operating method according to claim **7**, wherein the walking-assist robot (**100**) comprises a position sensor for transmitting a position of each joint of the walking-assist robot (**100**) to the control unit of the controller (**400**), and a gear member for adjusting a position of each joint and lengths of segments of the walking-assist robot (**100**) depending on a gearing state therebetween, and

the robot driving step comprises:

a joint position input step of receiving the position of each joint of the walking-assist robot (**100**) from the position sensor of the walking-assist robot (**100**);

a segment length calculation step of calculating relative distances between positions of the respective joints input in the joint position input step and obtaining the lengths of the segments of the walking-assist robot (**100**);

a length comparison and calculation step of comparing the lengths of the segments obtained in the segment length calculation step and the size data of the body of the walking trainee inputted in the information input step and calculating differences therebetween; and

a segment length adjustment step of adjusting the driving direction and displacement of the gear member of the walking-assist robot (**100**) according to the differences obtained in the length comparison and calculation step and locating each joint of the walking-assist robot (**100**) at the position of each corresponding joint of the walking trainee.

9. The operating method according to **7**, wherein the walking-assist robot (**100**) comprises a pressure sensor for transmitting a signal for contact between a sole of the walking trainee and the treadmill (**200**) to the control unit of the controller (**400**), and

the robot driving step comprises:

a contact signal input step of receiving a signal for contact between the sole of the walking trainee and the treadmill (**200**) from the pressure sensor of the walking-assist robot (**100**) in real time;

a walking speed calculation step of calculating a walking speed of the walking trainee by dividing a stride between two legs by a walking cycle defined by a time difference of the contacts of the two legs with the treadmill (**200**) during one stride of the walking trainee in real time or periodically; and

a both leg speed synchronization step of driving the treadmill at the same speed as the walking speed obtained in the walking speed calculating step.

10. The operating method according to claim **7**, wherein the walking-assist robot (**100**) comprises a pressure sensor for transmitting a signal for contact between a sole of the walking trainee and the treadmill (**200**) to the control unit of the controller (**400**), and

the robot driving step comprises:

a contact signal input step of receiving the contact presence between the sole of the walking trainee and the treadmill (**200**) from the pressure sensor of the walking-assist robot (**100**) in real time;

a contact time comparison and calculation step of comparing times of one leg of the walking trainee contacting with and separating from the treadmill (**200**) with reference times predetermined through the information input step, and calculating difference therebetween; and

a one leg speed synchronization step of adjusting a driving speed of the treadmill (**200**) according to the difference obtained in the contact presence comparison and calculation step and driving the treadmill (**200**) at the same speed as the walking speed of one of the two legs of the walking trainee.

11. The operating method according to claim **7**, wherein the load hoist (**300**) comprises a harness (**310**) put on the body of the walking trainee with a lower part thereof, a harness driving unit (**320**) having a drive means for adjusting a vertical length of the harness (**310**), and a load sensor for transmitting the value of a load applied to the harness (**310**) to the control unit of the controller (**400**), and

the robot driving step comprises:

a load input step of receiving the value of a load applied to the harness (**310**) from the load sensor of the load hoist (**300**) in real time;

a load comparison and calculation step of comparing the load inputted in the load input step and a designated hoist level inputted in the information input step and calculating difference therebetween; and

a designated hoist level maintaining step of adjusting the driving direction and driving time of the harness driving unit (**320**) of the load hoist (**300**) according to the difference obtained in the load comparison and calculation step and adjusting the hoist level of the walking trainee to the designated hoist level by adjusting the length of the harness (**310**).

12. The operating method according to claim **7**, wherein the method is selectively operated either in a walking test mode or in a gait training mode,

in the walking test mode, the robot driving step, the training data generating step and the training data output step are performed in real time during receipt of a progress command of a forward direction or a reverse direction for the walking-assist robot (**100**) in the information input step, whereas driving of the walking-assist robot (**100**) is stopped in a state in which the command of the progress direction for the walking-assist robot (**100**) is not inputted; and

in the gait training mode, when a command for driving the walking-assist robot (**100**), the treadmill (**200**) and the load hoist (**300**) in a specific pattern is primarily input in the information input step, the robot driving step, the training data generating step and the training data output step are continuously performed according to the command primarily inputted in the information input step until another command is re-inputted in the information input step.

13. The operating method according to claim **12**, wherein the walking test mode is selectively operated either in an individual drive mode of individually moving each joint corresponding to a hip joint, a knee joint and an ankle joint of the walking-assist robot (**100**); or

in a combined drive mode of simultaneously moving the respective joints of the walking-assist robot (**100**) corresponding to the hip joint, knee joint and ankle joint.

14. The operating method according to claim **12**, wherein, in the walking test mode, the input unit (**410**) of the controller is a remote controller (**412**) for wirelessly transmitting the information or commands to the information storage device or the control unit of the controller (**400**).

15. The operating method according to claim **14**, wherein the remote controller (**412**) comprises:

a wireless input unit (**412***a*) for transmitting an input command of progressing the walking-assist robot (**100**) in a forward direction or a reverse direction to the information storage device or the control unit of the controller (**400**) through a touch operation in real time; and

a wireless monitor (**412***b*) for receiving information about a walking progress state of the walking-assist robot (**100**) in the forward direction or the reverse direction, the time in the walking cycle, and a hip joint angle, a knee joint angle and an ankle joint angle at the corresponding time, from the information storage device or the control unit of the controller (**400**) and displaying the information in real time.

16. The operating method according to claim **7**, wherein, in the training data output step, both the information about the angle, speed, rotational force and hoist level of each joint in a standard type appropriate for the walking trainee previously inputted in the information input step and the information about the angle, speed, rotational force, and hoist level of each joint inputted in real time in the training data generating step are displayed together on one screen.

* * * * *

(12) 특허협력조약에 의하여 공개된 국제출원

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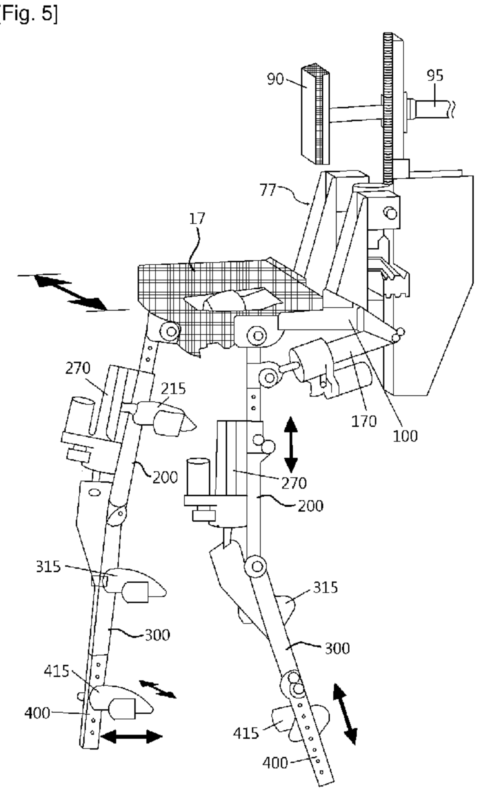
(54) Title: ACTIVE ROBOTIC GAIT-TRAINING SYSTEM AND METHOD

(54) 발명의 명칭 : 능동적 로보틱 보행 훈련 시스템 및 방법

[Fig. 5]



(57) Abstract: The present invention relates to an active robotic gait-training system and method, which involve measuring the tilt of a lower leg to estimate a gait cycle and enable a hip joint and a knee joint to operate by means of an actuator in accordance with the gait cycle, and which enable an ankle joint to operate by functional electrical stimulation (FES), thus enabling more active gait training for a person with dysbasia in accordance with the remaining walking ability of the person with dysbasia. According to the present invention, a robot-assisted gait-training system, including a thigh support unit, a hip joint support unit and a lower leg support unit, comprises: a toe-fixing ring which is arranged at the lower end of the lower leg support unit and to which a string, which is connected to a foot strap for covering a foot (tiptoe) part, is fixed; a tilt sensor attached to the lower end of the lower leg support unit or to one side of the foot strap; a control unit which generates an FES control signal, a hip joint angle control signal, and a knee joint angle control signal from the tilt signal received from the tilt sensor; a first linear actuator which receives the hip joint angle control signal from the control unit, and rotates the thigh support unit at a hip joint unit, which is a coupling unit between the thigh support unit and the hip joint support unit, in accordance with the hip joint angle control signal; and a second linear actuator which receives the knee joint angle control signal from the control unit, and rotates the lower leg support unit at a knee joint unit, which is a coupling unit between the lower leg support unit and the thigh support unit, in accordance with the knee joint angle control signal.

(57) 요약서:

[다음 쪽 계속]

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공개:

— 국제조사보고서 없이 공개하며 보고서 접수 후 이를 별도 공개함 (규칙 48.2(g))

본 발명은 하퇴부의 기울기를 측정하여 보행주기를 추정하고, 보행주기에 따라, 엑튜레이터에 의해 엉덩이 관절 및 무릎관절을 동작시키고, 기능적 전기 자극(FES)에 의해 발목관절이 동작하도록 하여, 보행장애인의 잔존 보행능력을 기반으로 보다 능동적 보행훈련이 가능하게 하는 능동적 로보틱 보행 훈련 시스템 및 방법에 관한 것이다. 본 발명은, 대퇴지지부, 고관절 지지부, 하퇴지지부를 포함하여 이루어진 로봇-보조형 보행훈련장치에 있어서, 하퇴지지부의 하단에 위치되며, 앞발(발끝)부분을 감싸는 앞발 스트랩과 연결된 선이 고정되는 발끝고정 고리; 하퇴지지부의 하단 또는 앞발 스트랩의 일측에 부착된 기울기 센서; 상기 기울기 센서로부터 수신된 기울기 신호로부터 FES 제어신호, 고관절 각도 제어신호, 무릎관절 각도 제어신호를 생성하는 제어부; 상기 제어부로부터 상기 고관절 각도 제어신호를 수신하고, 상기 대퇴지지부와 상기 고관절 지지부의 결합부인 고관절부에서, 상기 고관절 각도 제어신호에 따라 상기 대퇴지지부를 회동시키는 제 1 선형 액튜에이터; 상기 제어부로부터 상기 무릎관절 각도 제어신호를 수신하고, 상기 하퇴지지부와 상기 대퇴 지지부의 결합부인 무릎관절부에서, 상기 무릎관절 각도 제어신호에 따라 상기 하퇴지지부를 회동시키는 제 2 선형 액튜에이터;를 포함하여 이루어진 것을 특징으로 한다.

명세서

발명의 명칭: 능동적 로보틱 보행 훈련 시스템 및 방법

기술분야

[1] 본 발명은 능동적 로보틱 보행 훈련 시스템 및 방법에 관한 것으로서, 보다 상세하게는 하퇴부의 기울기를 측정하여 보행주기를 추정하고, 보행주기에 따라, 엑튜레이터에 의해 엉덩이 관절 및 무릎관절을 동작시키고, 기능적 전기자극(FES)에 의해 발목관절이 동작하도록 하여, 보행장애인의 잔존 보행능력을 기반으로 보다 능동적 보행훈련이 가능하게 하는 능동적 로보틱 보행 훈련 시스템 및 방법 에 관한 것이다.

배경기술

[2] 보행은 인간의 고유한 신체적 기능 중 하나로, 가장 일반적인 운동이자 사람이 매일 기본적으로 하는 활동이다.

[3] 일반적으로 정상인의 보행주기는 두가지 주기로 대별되는데, 이는 입각기와 유각기이다. 입각기는 발이 지면에 닿아있는 시기로, 초기접지기, 발바닥접지기, 중간 입각기, 발뒤축들림기, 발가락들림기로 이루어진다. 유각기는 발이 지면에서 떨어져 나아가는 시기로, 발가락들림기, 중간 유각기, 다시 초기접지기로 이루어진다. 정상보행에 있어서는 입각기가 약 60%, 유각기가 약 40%를 차지한다.

[4] 보행능력을 상실한 보행장애인들에게 보행훈련은 독립의 수준과 좋은 삶의 질을 향상시키는 데 있어 매우 중요한 부분을 차지한다.

[5] 보행장애인의 보행능력 회복을 위한 재활훈련을 위해서는 여러 분야의 전문가들의 포괄적인 도움이 필요하며 특히 환자들의 균형감각을 향상시키고, 인내성을 높이기 위해 반복적이고 체계적인 보행훈련이 요구된다.

[6] 보행장애인의 약 90%가 후천적 장애에 의한 것이며, 후천적 장애 원인의 50% 정도가 각종 질환으로 인하여 발생되며 그 중 뇌졸중이 가장 높은 비율을 나타내고 있다. 뇌졸중 후 초기에는 51%의 환자가 전혀 걸을 수 없고 12%는 부축을 받아 걸을 수 있으며 37%가 독립적 보행이 가능한 것으로 보고되어 있다. 재활치료 후 64%에서는 독립적 보행이 가능하도록 회복이 되지만 나머지 36%는 보행이 불가능하거나 의존적인 상태로 남게 되며, 보행 기능이 회복된 경우에도 여러가지 운동기능의 장해로 인한 비정상적 보행 패턴을 보이게 된다.

[7] 특히, 보행장애인에 따라 보행 가능한 정도가 다르므로, 일률적인 보행훈련을 하는 경우보다, 본인의 잔존 감각을 이용하여 보행훈련을 하는 경우가 보다 높은 보행훈련효과를 가져온다.

[8] 이를 위해서는 보행장애인이 현재 어느 정도의 보행이 가능한지에 대한 정확한 판단이 필요하며, 이 판단에 따른 보행훈련이 필요하다.

[9] 종래의 경우에는 치료사의 촉진과 감각 자극을 이용하여 보행장애인의

보행정도를 판단하였다.

[10] 80년대 중반에 체중지지(body weight support)를 통한 트레드밀(treadmill)에서의 보행훈련을 제안되었고, 이렇게 함에 의해 임상적으로 그 치료효과가 있다고 보고되었다.

[11] 그러나, 종래에는, 보행장애인이 트레드밀 위에서 훈련하는 동안, 한두 명의 치료사가 보행장애인의 사지와 체간의 움직임을 잡아주면서, 보행을 유도해야 하는 단점이 있었다.

[12] 또한, 종래에 로봇 관절에 의해 다리 관절이 수동적으로 움직이는 수동적 보행 훈련 로봇이 노약자 및 장애인을 위하여 제안된 바 있으나, 환자가 의도하는 보행 경로와 정확하게 일치하지 못함은 물론, 정상적인 보행 패턴에 맞는 재활을 위한 근본적인 보행훈련을 할 수 없었다.

[13] 그러므로, 보행장애인의 잔존감각을 이용하여 능동적 보행훈련이 가능하고, 정상보행 패턴에 맞는 관절운동을 제공하는 보행훈련 시스템이 요망된다.

[14] 따라서, 본 발명은 하퇴부의 기울기를 측정하여 보행주기를 추정하고, 보행주기에 따라, 엑츄레이터에 의해 엉덩이 관절 및 무릎관절을 동작시키고, 또한 기능적 전기 자극(FES)에 의해 발목관절이 동작하도록 하여, 보행장애인의 잔존 보행능력을 기반으로 보다 능동적 보행훈련이 가능하게 하는 능동적 로보틱 보행 훈련 시스템 및 방법을 제안한다.

발명의 상세한 설명

기술적 과제

[15] 본 발명이 해결하고자 하는 과제는, 하퇴부의 기울기를 측정하여 보행주기를 추정하고, 보행주기에 따라, 엑츄레이터에 의해 엉덩이 관절 및 무릎관절을 동작시키고, 기능적 전기 자극(FES)에 의해 발목관절이 동작하도록 하여, 보다 능동적 보행훈련이 가능하게 하는 능동적 로보틱 보행 훈련 시스템 및 방법을 제공하는 것이다.

[16] 본 발명이 해결하고자 하는 다른 과제는, 치료사의 보조활동 없이, 보행장애인의 능동적 보행훈련을 가능하게 하되, 정상보행 패턴에 맞는 관절운동을 제공하는 능동적 로보틱 보행 훈련 시스템 및 방법을 제공하는 것이다.

과제 해결 수단

[17] 본 발명의 과제를 해결하기위해, 본 발명은, 대퇴부에 위치되며, 대퇴부와 같은 길이, 같은 방향을 이루는 대퇴지지부; 둔부에 위치되며, 일단이 상기 대퇴지지부의 상단에 장착되되, 상기 대퇴지지부가 회동가능하도록 장착되는 고관절 지지부; 하퇴부에 위치되며, 상기 대퇴지지부의 하단에 장착되되, 회동가능하도록 장착되는 하퇴지지부;를 포함하여 이루어진 로보틱 보행 훈련 시스템에 있어서, 하퇴지지부의 하단에 위치되며, 앞발(발끝)부분을 감싸는 앞발 스트랩과 연결된 선이 고정되는 발끝고정 고리; 하퇴지지부의 하단 또는 앞발

스트랩의 일측에 부착된 기울기 센서; 상기 기울기 센서로부터 수신된 기울기 신호로부터 발목관절의 저굴근 또는 배굴근을 기능적 전기자극(FES)하기 위한 FES 제어신호를 생성하는 제어부; 상기 제어부로부터 수신된 FES 제어신호에 따라 발목관절의 저굴근 또는 배굴근을 기능적 전기자극(FES)을 하도록 이루어진 FES부;를 포함하여 이루어진 것을 특징으로 한다.

[18] 또한, 본 발명은, 본 발명은, 대퇴부에 위치되며, 대퇴부와 같은 길이, 같은 방향을 이루는 대퇴지지부; 둔부에 위치되며, 일단이 상기 대퇴지지부의 상단에 장착되되, 상기 대퇴지지부가 회동가능하도록 장착되는 고관절 지지부; 하퇴부에 위치되며, 상기 대퇴지지부의 하단에 장착되되, 회동가능하도록 장착되는 하퇴지지부;를 포함하여 이루어진 로보틱 보행 훈련 시스템에 있어서, 하퇴지지부의 하단에 위치되며, 앞발(발끝)부분을 감싸는 앞발 스트랩과 연결된 선이 고정되는 발끝고정 고리; 하퇴지지부의 하단 또는 앞발 스트랩의 일측에 부착된 기울기 센서; 상기 기울기 센서로부터 수신된 기울기 신호로부터 고관절 각도 제어신호를 생성하는 제어부;상기 제어부로부터 상기 고관절 각도 제어신호를 수신하고, 상기 대퇴지지부와 상기 고관절 지지부의 결합부인 고관절부에서, 상기 고관절 각도 제어신호에 따라 상기 대퇴지지부가 회동하도록 제1 선형 액튜에이터를 구동시키는 제1 선형 액튜에이터 구동부;를 포함하여 이루어진 것을 특징으로 한다.

[19] 또한, 본 발명은, 대퇴부에 위치되며, 대퇴부와 같은 길이, 같은 방향을 이루는 대퇴지지부; 둔부에 위치되며, 일단이 상기 대퇴지지부의 상단에 장착되되, 상기 대퇴지지부가 회동가능하도록 장착되는 고관절 지지부; 하퇴부에 위치되며, 상기 대퇴지지부의 하단에 장착되되, 회동가능하도록 장착되는 하퇴지지부;를 포함하여 이루어진 로보틱 보행 훈련 시스템에 있어서, 하퇴지지부의 하단에 위치되며, 앞발(발끝)부분을 감싸는 앞발 스트랩과 연결된 선이 고정되는 발끝고정 고리; 하퇴지지부의 하단 또는 앞발 스트랩의 일측에 부착된 기울기 센서; 상기 기울기 센서로부터 수신된 기울기 신호로부터 무릎관절 각도 제어신호를 생성하는 제어부;상기 제어부로부터 상기 무릎관절 각도 제어신호를 수신하고, 상기 하퇴지지부와 상기 대퇴 지지부의 결합부인 무릎관절부에서, 상기 무릎관절 각도 제어신호에 따라 상기 하퇴지지부가 회동하도록 제2 선형 액튜에이터를 구동시키는 제2 선형 액튜에이터 구동부;를 포함하여 이루어진 것을 특징으로 한다.

[20] 상기 제어부는 기울기 신호로부터 보행주기를 추정하고, 기 저장된 고관절 구동 패턴으로부터, 추정된 보행주기에 따른 고관절 각도 제어신호를 생성하며, 상기 제어부는 기울기 신호로부터 보행주기를 추정하고, 기 저장된 무릎관절 구동 패턴으로부터, 추정된 보행주기에 따른 무릎관절 각도 제어신호를 생성한다.

[21] 제1 선형 액튜에이터는, 일단이 고관절지지부의 일단에 장착되어 있으며, 다른 일단은 대퇴지지부의 상단에 장착되며, 제2 선형 액튜에이터는, 일단이

대퇴지지부에 장착되어 있으며, 다른 일단은 하퇴지지부의 상단에 장착된다.

[22] 고관절부는 대퇴지지부가 회동된 각도를 측정하기위한 제1 인코더가 장착되어 있으며, 무릎관절부는 하퇴지지부가 회동된 각도를 측정하기위한 제2 인코더가 장착되어 있다.

[23] 제어부는 기울기 신호로부터 보행주기를 추정하고, 제1 인코더로부터 고관절 각도신호를 수신하여, 기 저장된 고관절 구동 패턴으로부터, 추정된 보행주기에 따른 고관절 각도 제어신호를 생성하며, 또한, 상기 제어부는 기울기 신호로부터 보행주기를 추정하고, 제2 인코더로부터 무릎관절 각도신호를 수신하여, 기 저장된 무릎관절 구동 패턴으로부터, 추정된 보행주기에 따른 무릎관절 각도 제어신호를 생성한다.

[24] 제1 선형 액튜에이터와 대퇴지지부의 사이에 제1로드셀이 장착되며, 제2 선형 액튜에이터와 하퇴지지부의 사이에 제2로드셀이 장착되어 있다.

[25] 상기 대퇴지지부, 상기 고관절 지지부, 상기 하퇴지지부가 일측 다리를 위한 로봇-보조형 보행훈련장치를 이루며, 좌우측 다리를 위한 한쌍의 로봇-보조형 보행훈련장치와, 상기 한쌍의 로봇-보조형 보행훈련장치를 장착하고 보행훈련을 하기위한 트레드밀을 더 구비한다.

[26] 또한, 하니스; 하니스에 장착된 로우프가 거치는 도르래를 장착하기 위한 프레임; 상기 도르래를 거친 로우프의 일단에 장착된 추;를 더 구비한다.

[27] 대퇴지지부가 대퇴부와 결합하기 위한 대퇴부 스트랩이 대퇴지지부에 장착되어 있으며,하퇴지지부 상단과 하퇴부가 결합하기 위한 하퇴부 스트랩과, 하퇴지지부 하단과 발목이 결합하기 위한 발목 스트랩이 장착되어 있다.

[28] 또한 본 발명은, 보행장애자의 보행패턴을 수집하고 동작을 분석하는 보행패턴 수집단계; 보행패턴 수집단계에서, 수집된 보행패턴 및 분석결과를 보행장애자별로 저장하는 보행장애자별 데이터베이스화 단계; 보행장애자별 데이터베이스화 단계로부터 저장된 보행패턴들로 부터, FES제어신호, 고관절부 및 무릎관절부를 구동시키는 액튜에이터 제어신호를 생성하여 출력하는 시스템 제어단계;를 포함하는 로보틱 보행 훈련 시스템의 구동방법에 있어서, 보행패턴 수집단계는, 보행훈련대상의 개인 정보가 입력되면, 보행장애자의 보행으로부터 보행패턴을 수집되는 보행패턴 수집단계; 보행패턴 수집단계에서 수집된 데이터에서, 관절각도, 보행시점을 포함하는 보행 이벤트(gait event), 보행주기, 보행속도를 검출하는 보행 파라미터검출단계; 보행 파라미터검출단계에서 검출된, 보행주기를 포함하는 보행 파라미터로부터, 보행훈련시 사용될 훈련용 보행패턴을 생성하는 훈련용 보행패턴 생성단계;를 포함하여 이루어진 것을 특징으로 한다.

[29] 보행장애자별 데이터베이스화 단계는, 기 저장된 보행패턴 중 설정된 초기 보행패턴을 읽어들이는 초기 보행패턴설정단계; 초기 보행패턴설정단계에서 읽어들인 초기 보행패턴과, 상기 훈련용 보행패턴 생성단계에서 생성한 훈련용 보행패턴과 기 저장된 보행장애자 데이터베이스을 이용하여, 훈련용

보행패턴을 재 조정하는 개인 적응 훈련 패턴 생성단계;개인 적응 훈련 패턴 생성단계에서 생성된 훈련용 보행패턴의 정보를 갱신, 저장하는 데이타베이스 업데이트 단계;를 포함하여 이루어진다.

[30] 시스템 제어단계는, 설정된 훈련레벨 강도에 따라, FES 센서의 자극위치, 자극속도를 설정하는 FES 센서 설정단계; 보행장애자가 탑승되지 않은 보행 훈련 장치로, 설정된 보행훈련 패턴으로 보행훈련 시뮬레이션이 행하여지고 장비구동상황을 점검하여 이상여부를 판단하는 보행훈련 시뮬레이션단계;를 포함하여 이루어진 다.

발명의 효과

[31] 본 발명의 능동적 로보틱 보행 훈련 시스템 및 방법에 따르면, 하퇴부의 기울기를 측정하여 보행주기를 추정하고, 보행주기에 따라, 엑튜레이터에 의해 엉덩이 관절 및 무릎관절을 동작시키고, 기능적 전기 자극(FES)에 의해 발목관절이 동작하도록 하여, 본인의 페이스에 맞춘 맞춤형 훈련이 가능하며, 자신의 의지에 따른 보행훈련이 가능하여, 보다 능동적 보행훈련이 가능하다.

[32] 또한, 본 발명은 치료사의 보조활동 없이, 보행장애인의 능동적 보행훈련을 가능하게 하되, 정상보행 패턴에 맞는 관절운동을 제공하는 능동적 로보틱 보행 훈련이 가능하다.

도면의 간단한 설명

[33] 도 1은 본 발명의 능동적 로보틱 보행 훈련 시스템을 개략적으로 설명하기위한 개념도이다.

[34] 도 2는 본 발명에 의한 로봇-보조형 보행 훈련 장치의 구성을 설명하는 구성도이다.

[35] 도 3은 도 2의 로봇-보조형 보행 훈련 장치의 구동된 상태의 일예이다.

[36] 도 4는 도 2의 로봇-보조형 보행 훈련 장치가 구동되는 작용원리를 나타내는 도면이다.

[37] 도 5는 본 발명의 좌우측 다리의 로봇-보조형 보행 훈련 장치가 통합된 로보틱 보행 훈련 시스템을 설명하는 설명도이다.

[38] 도 6은 본 발명의 능동적 로보틱 보행 훈련 시스템의 사용상태를 설명하기위한 설명도이다.

[39] 도 7은 본 발명에서 스트랩과 일체화된 FES부의 일예이다.

[40] 도 8은 본 발명에서 FES부를 스트랩 등을 이용하여 장착한 예를 나타낸다.

[41] 도 9는 본 발명의 능동적 로보틱 보행 훈련 시스템을 제어하는 구성을 개략적으로 설명하기 위한 블럭도이다.

[42] 도 10은 도 9의 메인 연산처리부의 구성을 개략적으로 설명하기위한 블럭도이다.

[43] 도 11은 본 발명의 능동적 로보틱 보행 훈련 시스템의 구동방법을 개략적으로 설명하기위한 설명도이다.

발명의 실시를 위한 최선의 형태

[44] 이하, 본 발명의 일실시예에 의한 능동적 로보틱 보행 훈련 시스템 및 방법을 첨부된 도면을 참조하여 상세히 설명한다.

[45] 도 1은 본 발명의 능동적 로보틱 보행 훈련 시스템을 개략적으로 설명하기위한 개념도이다.

[46] 보행장애인인 훈련자가 로봇-보조형 보행훈련장치(10)를 양 다리에 각각 착용하고, 트레드밀(60)에서 훈련을 행하도록 이루어진다.

[47] 로봇-보조형 보행훈련장치(10)는 엉덩이관절부(20), 무릎관절부(30), 발목스트랩(415), FES부(50), 기울기센서(미도시)를 포함한다.

[48] 기울기센서(미도시)는 로봇-보조형 보행훈련장치(10)에 장착되어 히퇴부(또는 발)의 기울기를 검출한다.

[49] 엉덩이관절부(20)는 엉덩이의 관절을 액튜에이터(모터) 구동에 의해 소정 각도로 회전시키도록 이루어지되, 제어부(미도시)로부터 기 설정된 보행주기 동안의 엉덩이관절 구동 패턴(25)에 따른 엉덩이관절 액튜에이터 구동신호를 수신하여 구동된다.

[50] 무릎관절부(30)는 무릎의 관절을 액튜에이터(모터) 구동에 의해 소정 각도로 회전시키도록 이루어지되, 제어부(미도시)로부터 기 설정된 보행주기 동안의 무릎관절 구동 패턴(35)에 따른 무릎관절 액튜에이터 구동신호를 수신하여 구동된다.

[51] 발목스트랩(415)는 로봇-보조형 보행훈련장치(10)를 다리에 장착하기 위한 수단 중 하나로 로봇-보조형 보행훈련장치(10)의 하단을 발목에 고정 장착한다.

[52] FES부(50)는 발목관절 저/배굴근에 기능적 전기 자극(FES)을 가하기 위한 수단으로, 제어부(미도시)로부터 기 설정된 기능적 전기자극 패턴(55)에 따른 전기자극신호를 수신하여 구동된다. 기 설정된 기능적 전기자극 패턴(55)는 펄스열로 이루어질 수 있다. FES부(50)는 발목부분 또는 발등부분 등에 위치될 수 있다.

[53] ROM 곡선에서 발끝이 떨어지는 시기에 FES부(50)는 구동되며, 발끝이 떨어지는 시기는 1 보행주기의 전체를 100%라고 할때 60%의 지점이라 할 수 있다

[54] 제어부(미도시)는 기울기센서(미도시)로부터 수신된 신호로부터 현재 보행주기를 판정하고, 판정된 보행주기에 따라 엉덩이관절부(20), 무릎관절부(30), FES부(50)를 구동시키되, 엉덩이관절부(20)는 기 설정된 보행주기 동안의 엉덩이관절 구동 패턴(25)에 따라 구동시키고, 무릎관절부(30)는 기 설정된 보행주기 동안의 무릎관절 구동 패턴(35)에 따라 구동시키고, FES부(50)는 기 설정된 기능적 전기자극 패턴(55)에 따라 발목관절 관련 근육을 자극한다.

[55] 즉, 로봇-보조형 보행훈련장치(10)는 서보모터에 의해 구동되는 선형

액츄에이터를 사용하여 척수 손상 혹은 뇌졸중 환자와 같은 보행장애인의 엉덩관절과 무릎관절을 정상보행 특성에 맞게 수동적 보행훈련을 제어하고, 기울기 센서를 이용하여 마비 환자의 보행주기를 검출하여 이에 맞추어 발목관절 저/배굴근에 기능적 전기 자극(FES)을 가하여 능동적 보행훈련을 유도할 수 있다. 엉덩이관절 구동 패턴(25)은 보행장애인의 정상보행 특성에 맞게 엉덩관절을 구동하는 액튜에이터의 구동을 나타내고, 무릎관절 구동 패턴(35)은 보행장애인의 정상보행 특성에 맞게 무릎관절을 구동하는 액튜에이터의 구동을 나타낸다. 기 설정된 기능적 전기자극 패턴(55)은 보행장애인의 정상보행 특성에 맞게 발목관절 저/배굴근에 기능적 전기 자극(FES)을 가하여 능동적 보행훈련을 유도하는 작용을 나타낸다.

[56] 도 2는 본 발명에 의한 로봇-보조형 보행 훈련 장치의 구성을 설명하는 구성도이고, 도 3은 도 2의 로봇-보조형 보행 훈련 장치의 구동된 상태의 일예이다.

[57] 로봇-보조형 보행 훈련 장치(10)는 고관절지지부(100), 대퇴지지부(200), 하퇴지지부(300), 발목지지부(400), 고관절부(150), 무릎관절부(250)을 포함하여 이루어진다.

[58] 고관절지지부(100)는 인체의 좌우측의 엉덩이 부위, 즉 둔부에 위치에 장착며, 고관절부(150)에 장착된 대퇴지지부(200)가 제1 선형 액튜에이터(170)에 의해 회동되도록 지지하여 준다. 고관절지지부(100)의 일측단에는 고관절부(150)가 장착되어 있다.

[59] 고관절(엉덩이 관절)부(150)는 고관절지지부(100)와 대퇴지지부(200)의 사이에 장착된다. 고관절부(150)에 고관절지지부(100)는 고정 장착되며, 고관절부(150)에 대퇴지지부(200)는 회동가능하도록 장착된다. 즉,고관절부(150)는 고관절지지부(100)와 대퇴지지부(200)를 회전 가능하도록 결합하는 조인트로 구성된다. 고관절부(150)에는, 관절 회전각을 측정하는 제1 회전각 인코더(155)가 장착될 수 있다. 제1 회전각 인코더(155)는 보행장애인의 관절 회전각을 반복적으로 측정함으로써 보행특성을 파악하기 위한 신호를 출력하고, 이 신호를 통하여 보행장애인의 보행특성에 따라 고관절부(150)를 구동하는 제어신호가 가공될 수 있다.

[60] 제1 선형 액튜에이터(170)는 피스톤(172), 실린더(174), 기어부(176), 서보모터(178)를 포함하여 이루어져 선형운동(직선운동)을 하는 액튜에이터로, 일측은 고관절지지부(100)의 일단에 장착되어 있으며, 다른 일측은 제1로드셀(180)을 통해 대퇴지지부(200)의 상단에 장착되어 있다. 경우에 따라서, 제1로드셀(180)은 생략될 수 있다.

[61] 피스톤(172)은 나사산을 가진 피스톤으로, 일단은 제1로드셀(180)을 통해 대퇴지지부(200)에 고정되고, 다른 일단은 고관절지지부(100)에 고정된 실린더(174) 내에 수용된다.

[62] 실린더(174)는 피스톤(172)을 수용하는 실린더로, 일단은 고관절지지부(100)에

고정되며, 다른 일단은 실린더(174) 내에 수용된 피스톤(172)과 연결된 제1로드셀(180)을 통해 대퇴지지부(200)에 고정된다.

[63] 기어부(176)는 피스톤(172)의 나사산에 회전가능하도록 관통 결합된다.

[64] 피스톤(172), 실린더(174), 기어부(176)를 볼스크류라 할 수 있으며, 볼스크류는 서보모터(178)의 회전을 직선운동으로 바꾸어 주는 수단이다.

[65] 서보모터(178)는 기어부(176)를 회전 구동시켜 피스톤(172)을 실린더(174)의 내외로 왕복이동시킨다.

[66] 제1로드셀(180)은 고관절부(150)에서 대퇴지지부(200)를 들어올리는 데 가해진 힘(하중)을 측정한다. 즉, 제1 선형 액튜에이터(170)에서 고관절(엉덩이관절)에 가해지는 힘을 측정한다.

[67] 대퇴지지부(200)는 인체의 좌우측의 대퇴부 위치에 장착되며, 일단은 고관절부(150)에 회동가능하게 장착되어 있으며, 다른 일단은 무릎관절부(250)에 고정된다. 대퇴지지부(200)는 제1 선형 액튜에이터(170)에 의해 회동되며, 이렇게 회동되는 것에 대퇴부를 올리거나 내리는 것과 같은 동작이 이루어지게 된다. 또한 대퇴지지부(200)는 무릎관절부(250)에 장착된 하퇴지지부(300)가 제2 선형 액튜에이터(270)에 의해 회동되도록 지지하여 준다. 대퇴지지부(200)는 인체의 대퇴부에 스트랩에 의해 고정된다.

[68] 대퇴지지부(200)는 대퇴부를 지지하는 것으로 사람에 따라 대퇴길이가 다를 수 있으므로, 대퇴지지부(200)가 둘로 나눈 상단 대퇴지지부(225)와 하단 대퇴지지부 사이에 위치되는 대퇴 연장부(210)을 더 구비한다.

[69] 대퇴 연장부(210)는 일단이 상단 대퇴지지부(225)에 고정되어 있는 막대형태로, 다수의 홀(220)을 구비한다. 대퇴 연장부(210)의 다른 일단이 하단 대퇴지지부(230)에 삽입되어, 하단 대퇴지지부(230)의 외측의 홀과 나사 결합하도록 이루어져 있다. 대퇴 연장부(210)를 통해 길이가 변화될 수 있다.

[70] 무릎관절부(250)는 대퇴지지부(200)와 하퇴지지부(300)의 사이에 장착된다. 무릎관절부(250)에 대퇴지지부(200)는 고정 장착되며, 무릎관절부(250)에 하퇴지지부(300)는 회동가능하도록 장착된다.

[71] 무릎관절부(250)에는, 관절 회전각을 측정하는 제2 회전각 인코더(250)가 장착될 수 있다. 제2 회전각 인코더(250)는 보행장애인의 관절 회전각을 반복적으로 측정함으로써 보행특성을 파악하기 위한 신호를 출력하고, 이 신호를 통하여 보행장애인의 보행특성에 따라 무릎관절부(250)를 구동하는 제어신호가 가공될 수 있다.

[72] 제2 선형 액튜에이터(270)는 피스톤(272), 실린더(274), 기어부(276), 서보모터(278)를 포함하여 이루어져 선형운동(직선운동)을 하는 액튜에이터로, 일측은 대퇴지지부(200)에 장착되어 있으며, 다른 일측은 제2로드셀(280)을 통해 하퇴지지부(300)의 상단에 장착되어 있다. 경우에 따라서, 제2로드셀(280)은 생략될 수 있다.

[73] 피스톤(272)은 나사산을 가진 피스톤으로, 일단은 제2로드셀(280)을 통해

하퇴지지부(300)에 고정되고, 다른 일단은 대퇴지지부(200)에 고정된 실린더(274) 내에 수용된다.

[74] 실린더(274)는 피스톤(272)을 수용하는 실린더로, 일단은 대퇴지지부(200)에 고정되며, 다른 일단은 실린더(274) 내에 수용된 피스톤(272)과 연결된 제2로드셀(280)을 통해 하퇴지지부(300)에 고정된다.

[75] 기어부(276)는 피스톤(272)의 나사산에 회전가능하도록 관통 결합된다.

[76] 피스톤(272), 실린더(274), 기어부(276)를 볼스크류라 할 수 있으며, 볼스크류는 서보모터(278)의 회전을 직선운동으로 바꾸어 주는 수단이다.

[77] 서보모터(278)는 기어부(276)를 회전 구동시켜 피스톤(272)을 실린더(274)의 내외로 왕복이동시킨다.

[78] 제2로드셀(280)은 고관절부(150)에서 하퇴지지부(300)를 이동시키는 데 가해진 힘(하중)을 측정한다. 즉, 제2 선형 액튜에이터(270)에서 가해진 힘을 측정한다.

[79] 하퇴지지부(300)는 인체의 좌우측의 하퇴부 위치에 장착되며, 일단은 무릎관절부(250)에 회동가능하게 장착되며, 다른 일단은 발목지지부(400)과 연결된다. 하퇴지지부(300)는 제2 선형 액튜에이터(270)에 의해 회동되며, 이렇게 회동되는 것에 다리를 올리고 내리는 것과 같은 동작이 이루어지게 된다. 하퇴지지부(300)는 인체의 종아리에 대응하는 부분으로서 종아리와 스트랩으로 고정될 수 있다.

[80] 발목지지부(400)는 일단이 하퇴지지부(300)와 연결되며, 발끝고정 고리(440)가 장착되어 있다. 발목지지부(400)는 발목스트랩을 구비하여, 발목지지부(400)를 발목에 고정할 수 있다.

[81] 발끝고정 고리(440)는 발끝(앞발)부분을 감싼 발끝 보호대(앞발 스트랩)(미도시)에 연결된 선이 발끝고정 고리(440)를 통하게 하여 발끝(앞발)부분을 고정한다.

[82] 발끝고정 고리(440)를 통해 FES 자극부(미도시)가 발에 장착될 수 있다.

[83] 발목 연장부(445)는 일단이 발목지지부(400)에 내에 장착된 막대형태로, 다수의 홀(220)을 구비하여, 발목지지부(400)의 외측의 홀과 나사 결합하도록 이루어져, 발목지지부(400)가 길이가 변화될 수 있다. 경우에 따라서는 발목 연장부(445)를 생략할 수 있다.

[84] 도 4는 도 2의 로봇-보조형 보행 훈련 장치가 구동되는 작용원리를 나타내는 도면이다.

[85] 제1 선형 액튜에이터(170)이 고관절부(150) 또는 제1로드셀(180) 측으로 움직이면 고관절부(150)는 시계도는 방향으로 움직이고, 대퇴지지부(200)은 상방향, 즉 대퇴부를 들어올리는 방향으로 움직인다. 제1 선형 액튜에이터(170)가 반대측으로 움직이면, 결과적으로 대퇴지지부(200)은 하방향, 즉 대퇴부를 내리는 방향으로 움직인다.

[86] 제2 선형 액튜에이터(270)가 고관절부(150)측으로 움직이면, 무릎관절부(250)는 시계도는 방향으로 움직이고, 하퇴지지부(300)는 상방향, 즉

하퇴부(종아리)를 들어올리는 방향으로 움직인다. 제2 선형 액튜에이터(270)가 발목부(400)측으로 움직이면, 결과적으로 하퇴지지부(300)은 하방향, 즉 하퇴부를 내리는 방향으로 움직인다.

[87] 도 5는 본 발명의 좌우측 다리의 로봇-보조형 보행 훈련 장치가 통합된 로보틱 보행 훈련 시스템을 설명하는 설명도이다.

[88] 좌우측 다리의 로봇-보조형 보행 훈련 장치(10)에서 고관절지지부(100)의 일단(고관절부(150)와는 반대되는 단부)이 통합고정단(77)에 장착, 고정되며, 통합고정단(70)의 일측에는 등지지부(90)을 장착하여, 본 로보틱 보행 훈련 시스템을 착용시 등을 받쳐주도록 이루어져 있다. 또한 통합고정단(70)은 프레임연결부(95)를 통해 로보틱 보행 훈련 시스템의 프레임과 연결되어 있다. 프레임은 하네스 등을 장착하기위한 프레임이다.

[89] 좌우측 다리의 로봇-보조형 보행 훈련 장치(10)은 대퇴스트랩(215), 하퇴스트랩(315), 발목스트랩(415)를 구비하여, 다리와 로봇-보조형 보행 훈련 장치(10)를 결합한다.

[90] 엉덩이 좌우양측에 위치되는 둔부가이드(17)는 로봇-보조형 보행 훈련 장치(10)의 상단에 위치하여 둔부에 고정하고 로봇-보조형 보행 훈련 장치(10)가 피부를 눌러 아픈것을 완화하기위한 쿠션역할을 한다.

[91] 즉, 본 발명에 의한 하이브리드 로봇-보조형 보행 훈련 장치는, 보행장애인으로 하여금 다리의 관절 부위를 움직이기 위한 근력을 보강함으로써 보행 훈련이 가능하도록 하는 보행 훈련 장치로서, 인체의 허리 및 엉덩이 부위, 대퇴부, 종아리와 각각 결합되는 고관절지지부(100), 대퇴지지부(200), 하퇴지지부(300)를 포함하며, 각 지지부를 회전 가능하도록 결합시키는 고관절부(150), 무릎관절부(250)를 포함한다. 고관절지지부(100)는 인체의 허리 및 엉덩이 부위에 대응하는 부분으로서, 단순히 대퇴지지부(200) 및 하퇴지지부(300)를 지지하는 기능만을 담당할 수도 있고, 인체의 상체와 스트랩으로 결합하여 인체의 상체의 하중을 지지할 수도 있다. 대퇴지지부(200)는 인체의 대퇴부에 스트랩에 의해 결합되어 대퇴부(허벅다리)를 고정시킨다. 하퇴지지부(300)는 인체의 종아리에 대응하는 부분으로서 종아리와 스트랩으로 결합되어 고정될 수 있다.

[92] 도 6은 본 발명의 능동적 로보틱 보행 훈련 시스템의 사용상태를 설명하기위한 설명도이다.

[93] 보행장애인이 하니스(112)를 장착하고 좌우측다리에 로봇-보조형 보행 훈련 장치(10)를 장착하고, 트레드밀(60)위에서 보행 훈련을 받는다.

[94] 보행장애인의 체중을 지지하기 위해 하니스(112)에 장착된 로우프(114)가 프레임(65) 상에 설치되되, 보행장애인의 상측에 위치된 도르래(116)를 거쳐, 무게를 지탱하기 위한 추(118)와 연결된다. 즉, 보행장애인의 중량을 지지하기 위하여 보행장애인에 착용되는 하니스(112)와, 도르래(116), 추(118)로 이루어지며, 도르래(116)는 하니스(112)에 연결된 로우프(114)를 통하여

보행장애인의 중량을 지지하고, 추(118)는 로우프(114)를 통해 보행장애인의 수직이동을 제어한다.

[95] 보행장애인이 보행훈련중 손을 잡을 수 있는 팔 거치대(70)가 좌우 양측에 있으며, 팔 거치대(70)의 위에는 정지스위치(75)를 구비하여 훈련 중 위급사항이 발생하면 훈련자에 의해 정지가 가능하도록 이루어진다.

[96] 제어부(40)는 기울기센서, 로드셀 등으로부터 수신된 신호로부터 현재 보행자의 상태와 보행주기를 판정하고, 판정된 보행주기에 따라 엉덩이관절부(20), 무릎관절부(30), FES부(50)를 구동시킨다.

[97] 또한 훈련중인 보행장애인은 제어부(40)의 디스플레이부에 출력된 훈련결과의 디스플레이를 보면서 보행훈련을 행할 수 있어서, 바이오피드백의 효과를 가져온다.

[98] 도 7은 본 발명에서 스트랩과 일체화된 FES부의 일예이고, 도 8은 본 발명에서 FES부를 스트랩 등을 이용하여 장착한 예를 나타낸다.

[99] FES부(50)는 제어부(150)에 의하여 하퇴지지부(300)의 하단에 위치하여 인체의 발목부위에 기능적 전기자극(Functional Electric Stimulation)을 가한다. 전기자극부(40)는, 인체의 발목부위에 스트랩 이나 양말에 의해 접촉식으로 전기자극을 가할 수 있다.

[100] 본 발명에 의한 보행 훈련 장치(10)는 고관절부(150)에 관절 회전각을 측정하는 제1 회전각 인코더(155)를 구비하고, 무릎관절부(250)에 관절 회전각을 측정하는 제2 회전각 인코더(250)를 구비하여, 회전각 인코더(155,255)에서 검출된 관절 회전각은 제어부(150)에 송신되고, 제어부(150)는 반복적인 회전각 데이터에 따라 개별 보행장애인마다의 보행특성을 데이터베이스화하고, 각 보행특성에 따라 서보모터들(178, 278)의 회전량 및 회전속도를 구동함으로써 선형 액튜에이터(170, 270)를 제어할 수 있다.

[101] 그리고, 본 발명에 의한 보행 훈련 장치(10)는 상기 고관절부(150)에 가해지는 하중을 측정하는 로드셀 및 상기 무릎관절부(250)에 가해지는 하중을 측정하는 로드셀을 구비할 수 있다. 로드셀은 관절부(150, 250)에 가해지는 하중을 제어부(150)에 송신하고, 제어부(150)는 보해장애인의 보행특성에 따라 적절한 장력을 조절하기 위하여 추(118)를 제어한다. 이로써, 로우프(114) 및 도르레(116)와 결합된 하니스(112)에 가해지는 장력이 제어되고, 개별 보행장애인의 특성에 부합하는 최적화된 보행 훈련이 가능하게 된다.

[102] 그리고, 상기 제2 지지부(25)는 지축에 대한 기울기를 측정하는 기울기센서를 구비하고, 상기 전기자극부(40)는 상기 기울기센서에 의해 측정되는 상기 보행장애인의 보행주기마다 발목관절 저/배굴근에 기능적 전기자극을 가함으로써, 능동적인 보행훈련이 가능하게 된다. 전기자극부(40)는 기울기센서에 의해 측정되는 보행순간을 탐지하여 기능적 전기자극을 출력할 수도 있고, 제어부(150)에서 축적된 각 보행장애인의 보행특성에 대한 데이터베이스로부터 최적화된 보행훈련에 부합하는 보행주기마다 기능적

전기자극을 출력할 수도 있다.

[103] 도 9는 본 발명의 능동적 로보틱 보행 훈련 시스템을 제어하는 구성을 개략적으로 설명하기 위한 블럭도로, 메인 연산처리부(500), FES 구동부(510), 로보틱 보행 제어부(520), 센서부(530), 데이터 저장부(590), 디스플레이부(600)을 포함하여 이루어진다.

[104] 메인 연산처리부(500)는 센서부(530)의 출력신호를 수신하고, 데이터 저장부(590)으로부터 기 저장된 보행주기 패턴들을 수신하여, FES 제어신호, 제1 선형 액튜에이터 제어신호, 제2 선형 액튜에이터 제어신호 등을 생성하여, FES 구동부(510), 로보틱 보행 제어부(520)의 제1 선형 액튜에이터 구동부(570), 제2 선형 액튜에이터 구동부(580)로 전송한다. 또한 수신된 센서부(530)의 출력신호를 데이터 저장부(590)에 저장한다. 메인 연산처리부(500)는 보행훈련자의 보행훈련 결과를 분석하여 디스플레이부(600)로 출력한다.

[105] FES 구동부(510)는 메인 연산처리부(500)는 FES 제어신호에 따라 FES 자극신호를 출력한다.

[106] 로보틱 보행 제어부(520)는 제1 선형 액튜에이터 구동부(570), 제2 선형 액튜에이터 구동부(580)을 포함한다.

[107] 제1 선형 액튜에이터 구동부(570)는 메인 연산처리부(500)로부터 수신된 제1 선형 액튜에이터 제어신호에 의해 제1 선형 액튜에이터(170)를 구동하여, 제1 선형 액튜에이터(170)가 대퇴지지부(200)를 올리거나 내리도록 회동시킨다.

[108] 제2 선형 액튜에이터 구동부(580)는 메인 연산처리부(500)로부터 수신된 제2 선형 액튜에이터 제어신호에 의해 제2 선형 액튜에이터(270)를 구동하여, 제2 선형 액튜에이터(270)가 하퇴지지부(200)를 올리거나 내리도록 회동시킨다.

[109] 센서부(530)는 기울기 센서(540), 로드셀부(550), 인코더부(560)을 포함하여 검출된 신호를 메인 연산처리부(500)로 전송한다.

[110] 기울기 센서(540)는 로봇-보조형 보행훈련장치(10)의 히퇴지지부 또는 발끝(앞발)부분을 감싼 발끝 보호대에 장착되어, 하퇴부의 기울기 또는 발의 기울기를 검출한다.

[111] 로드셀부(550)는 제1로드셀(180)과 제2로드셀(280)을 포함하며, 제1로드셀(180)은 고관절부(150)에서 대퇴지지부(200)를 들어올리는 데 가해진 힘(하중)을 측정하고, 제2로드셀(280)은 무릎관절부(250)에서 하퇴지지부(300)를 들어올리는 데 가해진 힘(하중)을 측정한다.

[112] 인코더부(560)은 제1 회전각 인코더(155), 제2 회전각 인코더(255)를 포함하며, 제1 회전각 인코더(155)은 고관절부의 회전각 측정하는 것으로, 이를 이용하여 제1 선형 액튜에이터 제어신호를 생성하며, 제2 회전각 인코더(255)는 무릎관절부의 회전각 측정하는 것으로, 이를 이용하여 제2 선형 액튜에이터 제어신호를 생성한다. 즉, 인코더부(560)를 통해 보행장애인의 관절 회전각을 반복적으로 측정함으로써 보행특성을 파악하기 위한 신호를 출력하고, 이 신호를 통하여 보행장애인의 보행특성에 따라 고관절부(150) 및

무릎관절부(250)을 구동시키는 제어신호가 가공될 수 있다.

[113] 데이터 저장부(590)는 메인 연산처리부(500)에서 수신된 신호를 저장하고, 디스플레이부(600)는 메인 연산처리부(500)에서 수신된 신호를 출력한다.

[114] 도 10은 도 9의 메인 연산처리부의 구성을 개략적으로 설명하기위한 블럭도로, 동작분석부(502), 환자정보 데이터베이스(504), 시스템 제어부(506)을 포함하여 이루어진다.

[115] 동작분석부(502)는 환자, 즉 보행장애자의 보행패턴을 수집하고 동작을 분석한다.

[116] 환자정보 데이터베이스(504)는 동작분석부(502)에서 수신된 보행패턴 및 분석결과를 환자별로 저장한다.

[117] 시스템 제어부(506)는 환자정보 데이터베이스(504)로부터 보행패턴을 읽어들여, FES제어신호, 제1 선형 액튜에이터 제어신호, 제2 선형 액튜에이터 제어신호를 생성하여, FES 구동부(510), 로보틱 보행 제어부(520)의 제1 선형 액튜에이터 구동부(570), 제2 선형 액튜에이터 구동부(580)로 전송한다.

[118] 도 11은 본 발명의 능동적 로보틱 보행 훈련 시스템의 구동방법을 개략적으로 설명하기위한 설명도이다.

[119] 보행장애자 설정단계로, 보행훈련대상의 보행장애자(환자)를 설정하고, 보행장애자의 기초정보(개인 정보)를 입력한다(S110).

[120] 보행패턴 수집단계로, 보행장애자의 보행을 측정하여 보행패턴을 수집한다(S120).

[121] 보행 파라미터검출단계로, 보행훈련에 관련된 파라미터를 검출하는 것으로, 관절각도, 보행시점을 포함하는 보행 이벤트(gait event), 보행주기, 보행속도를 검출한다(S130).

[122] 훈련용 보행패턴 생성단계로, 보행 파라미터검출단계에서 검출된 파라미터를 이용하여, 보행훈련시 사용할 훈련용 보행패턴으로서, 개인적으로 개별화된 보행패턴을 생성한다(S140).

[123] 보행능력 평가단계로, 기 저장된 데이터를 이용하여 보행 능력을 평가한다(S150).

[124] 보행장애자 설정단계(S110) 내지 보행능력 평가단계(S150)는 동작을 분석하여 보행패턴을 수집하는, 보행패턴 수집단계라 할 수 있다.

[125] 다음은 검출 또는 설정된 데이터들을 보행장애자별 데이터베이스화하는 단계들에 대해서 설명한다.

[126] 사용자 등록정보 로드단계로, 보행훈련시스템의 사용자, 즉 보행장애자의 기초정보(개인 정보)를 읽어들인다(S210).

[127] 초기 보행패턴설정단계로, 보행훈련시스템에서 사용할 초기 보행패턴을 설정한다(S210)

[128] 개인 적응 훈련 패턴 생성단계로, 초기 보행패턴설정단계(S210)에서의 초기 보행패턴과, 훈련용 보행패턴 생성단계(S140)에서 생성한 훈련용 보행패턴과,

기 저장된 보행장애자 데이터베이스을 이용하여, 개인 적응 훈련 패턴을 생성한다(S230).

[129] 데이타베이스 업데이트 단계로, 생성된 개인 적응 훈련 패턴 정보를 저장하고 갱신한다(S240).

[130] 사용자 등록정보 로드단계(S210) 내지 데이타베이스 업데이트 단계(S240)는 보행장애자별 데이터베이스화 단계이라고 할 수 있다.

[131] 다음은 시스템 및 훈련에 따른 제어에 관해 설명한다.

[132] 시스템 초기화단계로, 시스템을 초기화한다(S310).

[133] 사용자 검색단계로, 사용자를 검색하여 인식한다(S320).

[134] 훈련 레벨 설정단계로, 훈련패턴을 사용한 훈련시의 훈련 강도를 설정한다(S330).

[135] 예를들어 6단계로 설정할 경우, 보행 훈련 장치(10)의 좌우 무릎관절부와 좌우 고관절(엉덩이 관절)부의 관절 각도제어를, 정상 보행과 환자 보행의 차의 크기를 6단계로 나누어 보행 훈련한다.

[136] FES 센서 설정단계로, FES 센서의 자극위치, 자극 속도를 설정하고 데이터수집(DAQ)의 속도 등을 설정한다(S340).

[137] 훈련 파라미터 설정단계로, 보행 훈련 장치(10)에서 훈련 파라미터를 설정한다(S350).

[138] 보행훈련 시뮬레이션단계로, 보행 훈련 장치(10)만으로 설정된 보행훈련 패턴으로 보행훈련 시뮬레이션을 행하여 장비구동상황을 확인하며, 만약 문제점이 발견되면 개인 적응 훈련 패턴 생성단계(S230)가서 훈련패턴을 재생성한다(S360).

[139] 보행훈련단계로, 보행훈련을 행하면서 데이터수집도 병행한다(S370).

[140] 보행훈련 결과분석단계로, 보행 훈련이 종료되면(S380), 보행 훈련의 결과를 저장하고 분석한다(S400).

[141] 이렇게 보행훈련 결과분석단계에서 저장된 데이터는 보행패턴 수집단계, 보행장애자별 데이터베이스화 단계에서 차후 이용되게 될것이다.

[142] 이상과 같이 본 발명은 비록 한정된 실시예와 도면에 의해 설명되었으나, 본 발명은 상기의 실시예에 한정되는 것은 아니며, 이는 본 발명이 속하는 분야에서 통상의 지식을 가진 자라면 이러한 기재로부터 다양한 수정 및 변형이 가능하다. 따라서, 본 발명의 사상은 아래에 기재된 특허청구범위에 의해서만 파악되어야 하고, 이의 균등 또는 등가적 변형 모두는 본 발명 사상의 범주에 속한다고 할 것이다.

산업상 이용가능성

[143] 본 발명은 보행장애인의 잔존 보행능력을 기반으로 보다 능동적 보행훈련이 가능하게 하는 능동적 로보틱 보행 훈련 시스템 및 방법에 관한 것으로서, 재활병원 등에서 보행장애인의 보행훈련을 하는 데 이용할 수 있다.

청구범위

[청구항 1] 대퇴부에 위치되며, 대퇴부와 같은 길이, 같은 방향을 이루는 대퇴지지부; 둔부에 위치되며, 일단이 상기 대퇴지지부의 상단에 장착되되, 상기 대퇴지지부가 회동가능하도록 장착되는 고관절 지지부; 하퇴부에 위치되며, 상기 대퇴지지부의 하단에 장착되되, 회동가능하도록 장착되는 하퇴지지부;를 포함하여 이루어진 로보틱 보행 훈련 시스템에 있어서,

하퇴지지부의 하단에 위치되며, 앞발(발끝)부분을 감싸는 앞발 스트랩과 연결된 선이 고정되는 발끝고정 고리;

하퇴지지부의 하단 또는 앞발 스트랩의 일측에 부착된 기울기 센서;

상기 기울기 센서로부터 수신된 기울기 신호로부터 발목관절의 저굴근 또는 배굴근을 기능적 전기자극(FES)하기 위한 FES 제어신호를 생성하는 제어부;

상기 제어부로부터 수신된 FES 제어신호에 따라 발목관절의 저굴근 또는 배굴근을 기능적 전기자극(FES)을 하도록 이루어진 FES부;

를 포함하여 이루어진 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 2] 대퇴부에 위치되며, 대퇴부와 같은 길이, 같은 방향을 이루는 대퇴지지부; 둔부에 위치되며, 일단이 상기 대퇴지지부의 상단에 장착되되, 상기 대퇴지지부가 회동가능하도록 장착되는 고관절 지지부; 하퇴부에 위치되며, 상기 대퇴지지부의 하단에 장착되되, 회동가능하도록 장착되는 하퇴지지부;를 포함하여 이루어진 로보틱 보행 훈련 시스템에 있어서,

하퇴지지부의 하단에 위치되며, 앞발(발끝)부분을 감싸는 앞발 스트랩과 연결된 선이 고정되는 발끝고정 고리;

하퇴지지부의 하단 또는 앞발 스트랩의 일측에 부착된 기울기 센서;

상기 기울기 센서로부터 수신된 기울기 신호로부터 고관절 각도 제어신호를 생성하는 제어부;

상기 제어부로부터 상기 고관절 각도 제어신호를 수신하고, 상기 대퇴지지부와 상기 고관절 지지부의 결합부인 고관절부에서, 상기 고관절 각도 제어신호에 따라 상기 대퇴지지부가 회동하도록 제1 선형 액튜에이터를 구동시키는 제1 선형 액튜에이터 구동부;

를 포함하여 이루어진 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 3] 대퇴부에 위치되며, 대퇴부와 같은 길이, 같은 방향을 이루는 대퇴지지부; 둔부에 위치되며, 일단이 상기 대퇴지지부의 상단에 장착되되, 상기 대퇴지지부가 회동가능하도록 장착되는 고관절 지지부; 하퇴부에 위치되며, 상기 대퇴지지부의 하단에 장착되되, 회동가능하도록 장착되는 하퇴지지부;를 포함하여 이루어진 로보틱 보행 훈련 시스템에 있어서,
하퇴지지부의 하단에 위치되며, 앞발(발끝)부분을 감싸는 앞발 스트랩과 연결된 선이 고정되는 발끝고정 고리;
하퇴지지부의 하단 또는 앞발 스트랩의 일측에 부착된 기울기 센서;
상기 기울기 센서로부터 수신된 기울기 신호로부터 무릎관절 각도 제어신호를 생성하는 제어부;
상기 제어부로부터 상기 무릎관절 각도 제어신호를 수신하고, 상기 하퇴지지부와 상기 대퇴 지지부의 결합부인 무릎관절부에서, 상기 무릎관절 각도 제어신호에 따라 상기 하퇴지지부가 회동하도록 제2 선형 액튜에이터를 구동시키는 제2 선형 액튜에이터 구동부;
를 포함하여 이루어진 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 4] 제2항 또는 제3항 중 어느 한 항에 있어서,
상기 제어부는 상기 기울기 센서로부터 수신된 기울기 신호로부터 발목관절의 저굴근 또는 배굴근을 기능적 전기자극(FES)하기 위한 FES 제어신호를 생성하며,
상기 제어부로부터 수신된 FES 제어신호에 따라 발목관절의 저굴근 또는 배굴근을 기능적 전기자극(FES)을 하도록 이루어진 FES부를 더 구비하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 5] 제1항에 있어서,
상기 제어부는 상기 기울기 센서로부터 수신된 기울기 신호로부터 고관절 각도 제어신호와 무릎관절 각도 제어신호를 생성하며,
상기 제어부로부터 상기 고관절 각도 제어신호를 수신하고, 상기 대퇴지지부와 상기 고관절 지지부의 결합부인 고관절부에서, 상기 고관절 각도 제어신호에 따라 상기 대퇴지지부가 회동하도록 제1 선형 액튜에이터를 구비하며,
상기 제어부로부터 상기 무릎관절 각도 제어신호를 수신하고, 상기 하퇴지지부와 상기 대퇴 지지부의 결합부인 무릎관절부에서, 상기 무릎관절 각도 제어신호에 따라 상기 하퇴지지부가 회동하도록 제2 선형 액튜에이터를 구동시키는 제2 선형

액튜에이터 구동부를 더 구비하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 6] 제5항에 있어서,
상기 제어부는 기울기 신호로부터 보행주기를 추정하고, 기 저장된 고관절 구동 패턴으로부터, 추정된 보행주기에 따른 고관절 각도 제어신호를 생성하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 7] 제5항에 있어서,
상기 제어부는 기울기 신호로부터 보행주기를 추정하고, 기 저장된 무릎관절 구동 패턴으로부터, 추정된 보행주기에 따른 무릎관절 각도 제어신호를 생성하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 8] 제2항에 있어서
상기 제어부는 상기 기울기 센서로부터 수신된 기울기 신호로부터 무릎관절 각도 제어신호를 생성하며,
상기 제어부로부터 상기 무릎관절 각도 제어신호를 수신하고,
상기 하퇴지지부와 상기 대퇴 지지부의 결합부인 무릎관절부에서,
상기 무릎관절 각도 제어신호에 따라 상기 하퇴지지부가 회동하도록 제2 선형 액튜에이터를 구동시키는 제2 선형 액튜에이터 구동부를 더 구비하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 9] 제2항에 있어서,
제1 선형 액튜에이터는, 일단이 고관절지지부의 일단에 장착되어 있으며, 다른 일단은 대퇴지지부의 상단에 장착되는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 10] 제3항에 있어서,
제2 선형 액튜에이터는, 일단이 대퇴지지부에 장착되어 있으며, 다른 일단은 하퇴지지부의 상단에 장착되는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 11] 제2항에 있어서,
고관절부는 대퇴지지부가 회동된 각도를 측정하기위한 제1 인코더가 장착되어 있는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 12] 제3항에 있어서,
무릎관절부는 하퇴지지부가 회동된 각도를 측정하기위한 제2 인코더가 장착되어 있는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 13] 제11항에 있어서

제어부는 기울기 신호로부터 보행주기를 추정하고, 제1 인코더로부터 고관절 각도신호를 수신하여, 기 저장된 고관절 구동 패턴으로부터, 추정된 보행주기에 따른 고관절 각도 제어신호를 생성하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 14] 제12항에 있어서,
상기 제어부는 기울기 신호로부터 보행주기를 추정하고, 제2 인코더로부터 무릎관절 각도신호를 수신하여, 기 저장된 무릎관절 구동 패턴으로부터, 추정된 보행주기에 따른 무릎관절 각도 제어신호를 생성하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 15] 제9항에 있어서
제1 선형 액튜에이터와 대퇴지지부의 사이에 로드셀이 장착되는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 16] 제10항에 있어서,
제2 선형 액튜에이터와 하퇴지지부의 사이에 로드셀이 장착되는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 17] 제5항에 있어서,
고관절부와 무릎관절부에 각각 인코더를 구비한 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 18] 제5항에 있어서,
제1 선형 액튜에이터와 대퇴지지부의 사이에 제1로드셀이 장착되며, 제2 선형 액튜에이터와 하퇴지지부의 사이에 제2로드셀이 장착되는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 19] 제5항에 있어서,
상기 대퇴지지부, 상기 고관절 지지부, 상기 하퇴지지부가 일측 다리를 위한 로봇-보조형 보행훈련장치를 이루며,
좌우측 다리를 위한 한쌍의 로봇-보조형 보행훈련장치와,
상기 한쌍의 로봇-보조형 보행훈련장치를 장착하고 보행훈련을 하기위한 트레드밀;
를 더 구비하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 20] 제19항에 있어서,
하니스;
하니스에 장착된 로우프가 거치는 도르래를 장착하기 위한 프레임;
상기 도르래를 거친 로우프의 일단에 장착된 추;
를 더 구비하는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

[청구항 21] 제5항에 있어서,
대퇴지지부가 대퇴부와 결합하기 위한 대퇴부 스트랩이 대퇴지지부에 장착되어 있으며,
하퇴지지부 상단과 하퇴부가 결합하기 위한 하퇴부 스트랩과,
하퇴지지부 하단과 발목이 결합하기 위한 발목 스트랩이 장착되어 있는 것을 특징으로 하는 로보틱 보행 훈련 시스템.

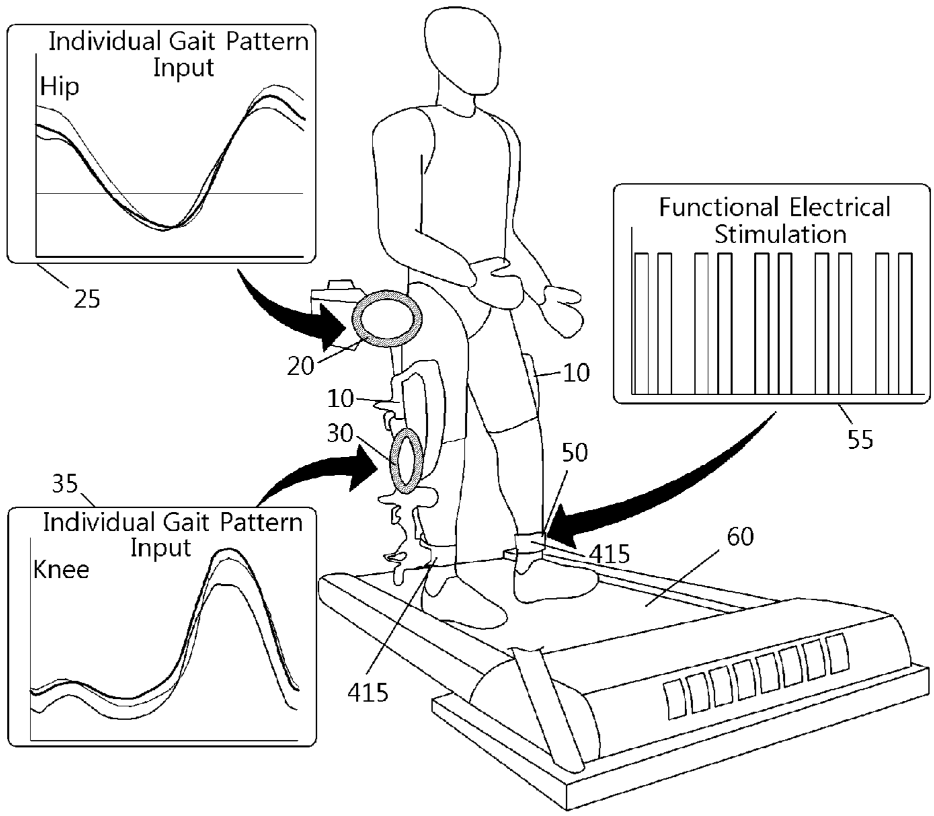
[청구항 22] 보행장애자의 보행패턴을 수집하고 동작을 분석하는 보행패턴 수집단계;
보행패턴 수집단계에서, 수집된 보행패턴 및 분석결과를 보행장애자별로 저장하는 보행장애자별 데이터베이스화 단계;
보행장애자별 데이터베이스화 단계로부터 저장된 보행패턴들로부터, FES제어신호, 고관절부 및 무릎관절부를 구동시키는 액튜에이터 제어신호를 생성하여 출력하는 시스템 제어단계;를 포함하는 로보틱 보행 훈련 시스템의 구동방법에 있어서,
보행패턴 수집단계는,
보행훈련대상의 개인 정보가 입력되면, 보행장애자의 보행으로부터 보행패턴을 수집되는 보행패턴 수집단계;
보행패턴 수집단계에서 수집된 데이터에서, 관절각도, 보행시점을 포함하는 보행 이벤트(gait event), 보행주기, 보행속도를 검출하는 보행 파라미터검출단계;
보행 파라미터검출단계에서 검출된, 보행주기를 포함하는 보행 파라미터로부터, 보행훈련시 사용될 훈련용 보행패턴을 생성하는 훈련용 보행패턴 생성단계;
를 포함하여 이루어진 것을 특징으로 하는 로보틱 보행 훈련 시스템의 구동방법.

[청구항 23] 제22항에 있어서,
보행장애자별 데이터베이스화 단계는,
기 저장된 보행패턴 중 설정된 초기 보행패턴을 읽어들이는 초기 보행패턴설정단계;
초기 보행패턴설정단계에서 읽어들인 초기 보행패턴과, 상기 훈련용 보행패턴 생성단계에서 생성한 훈련용 보행패턴과 기 저장된 보행장애자 데이터베이스을 이용하여, 훈련용 보행패턴을 재 조정하는 개인 적응 훈련 패턴 생성단계;
개인 적응 훈련 패턴 생성단계에서 생성된 훈련용 보행패턴의 정보를 갱신, 저장하는 데이타베이스 업데이트 단계;
를 포함하여 이루어진 것을 특징으로 하는 로보틱 보행 훈련 시스템의 구동방법.

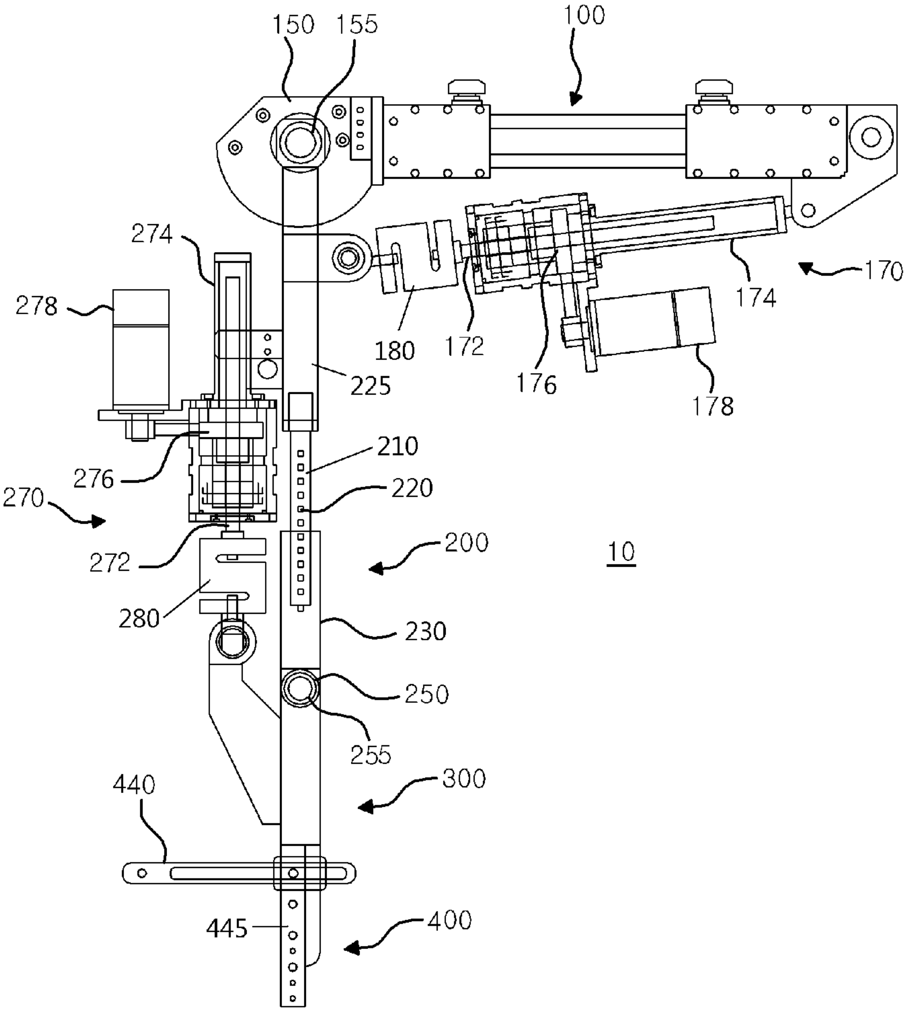
[청구항 24] 제23항에 있어서,

시스템 제어단계는,
설정된 훈련레벨 강도에 따라, FES 센서의 자극위치, 자극 속도를 설정하는 FES 센서 설정단계;
보행장애자가 탑승되지 않은 보행 훈련 장치로, 설정된 보행훈련 패턴으로 보행훈련 시뮬레이션이 행하여지고 장비구동상황을 점검하여 이상여부를 판단하는 보행훈련 시뮬레이션단계;
를 포함하여 이루어진 것을 특징으로 하는 로보틱 보행 훈련 시스템의 구동방법.

[Fig. 1]


Individual Gait Pattern Input
Hip
25
20
10
30
35
Individual Gait Pattern Input
Knee
Functional Electrical Stimulation
10
55
50
60
415
415

[Fig. 2]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278
170
174
180
172
176
178
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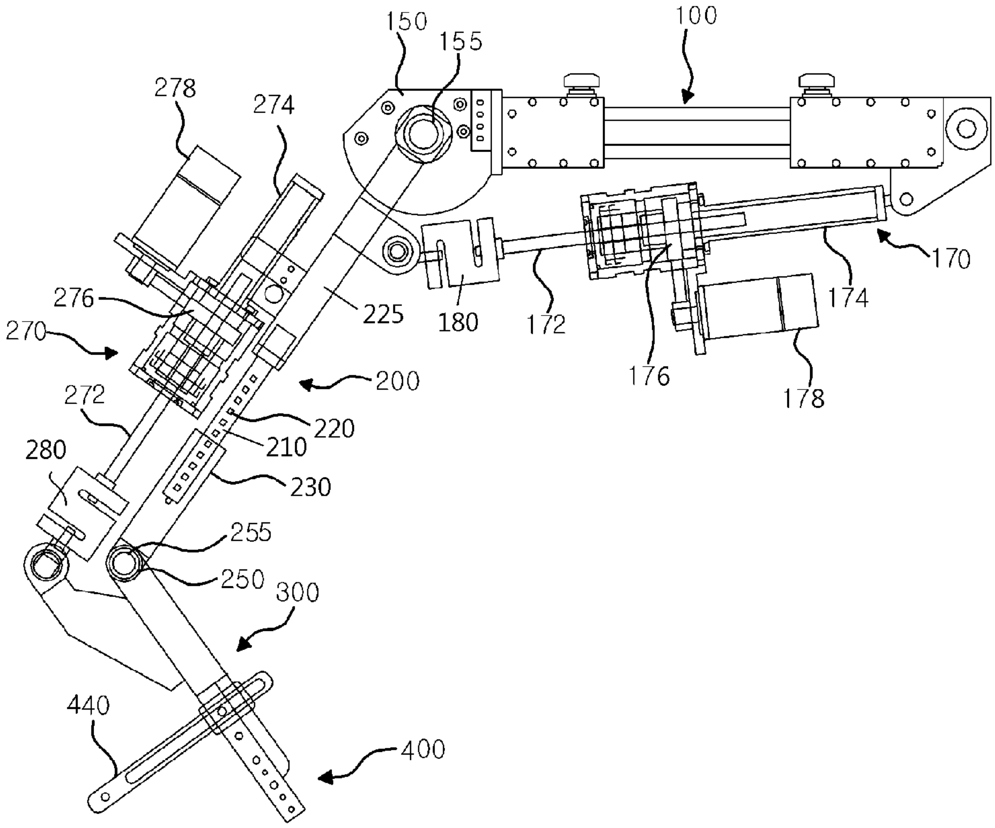
276
270
272
200
10
280
230
250
255
300
440
445
400

[Fig. 3]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270
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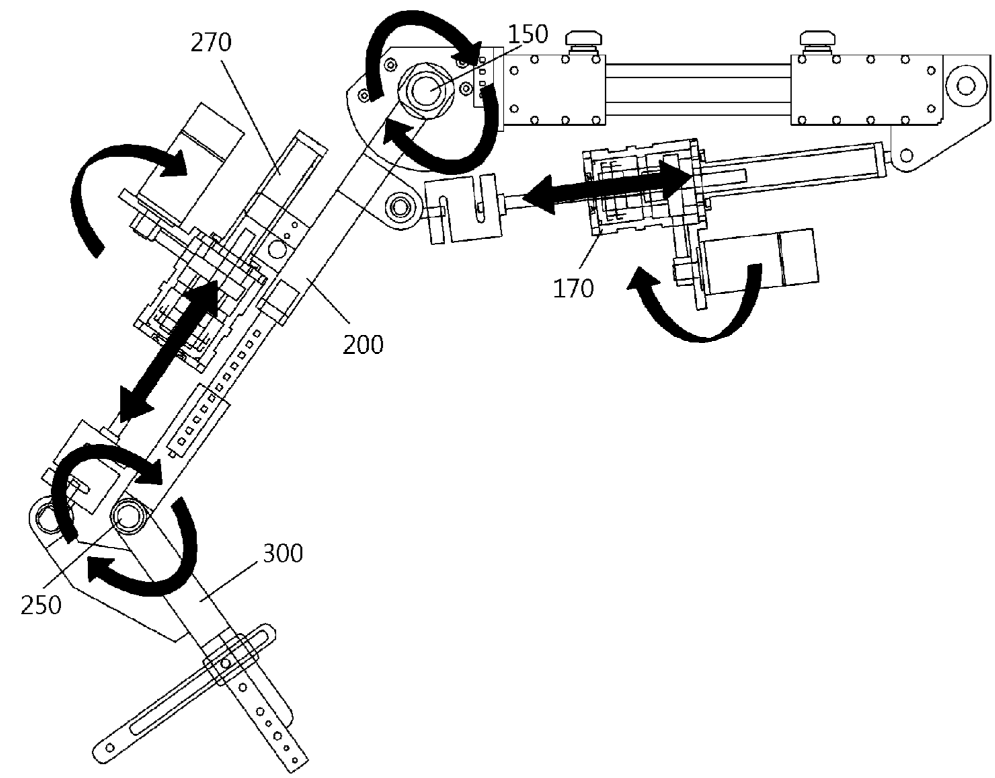
200
176
178
272
220
210
280
230
255
250
300
440
400

[Fig. 4]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150
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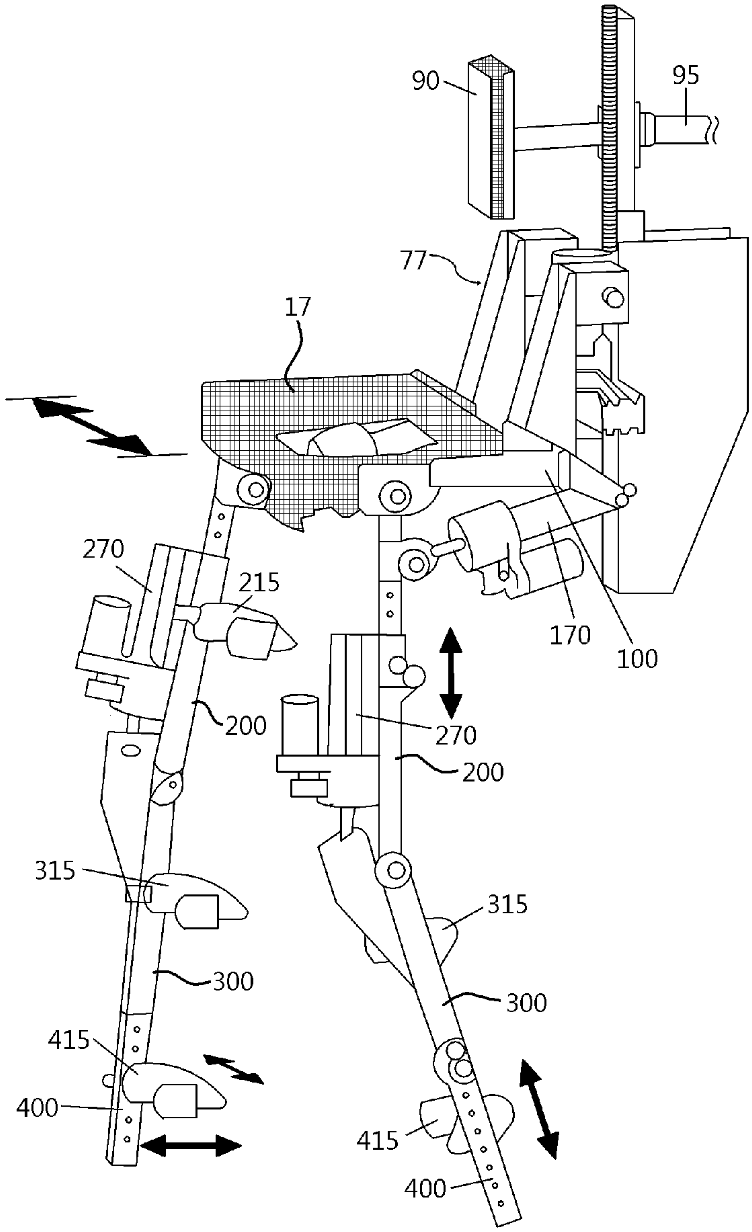
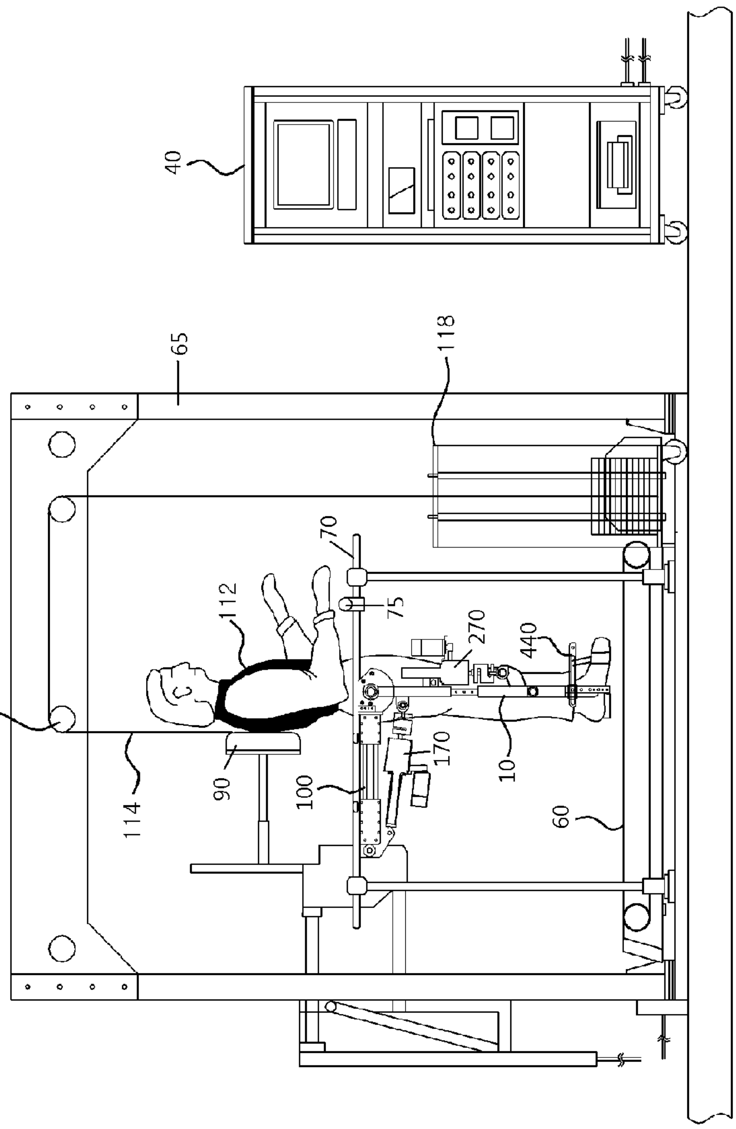
300
250

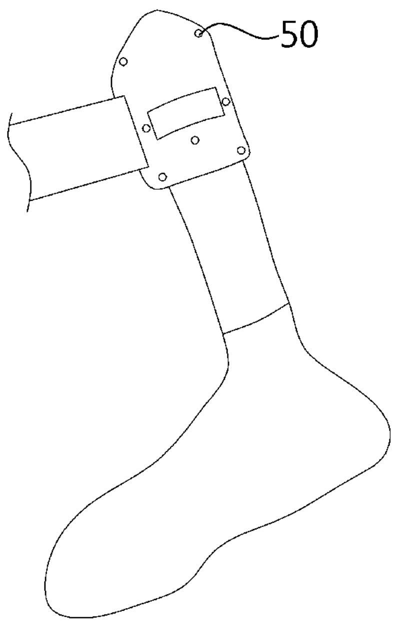
[Fig. 5]


90
95
77
17
270
215
200
170
100
270
200
315
315
300
300
415
400
415
400

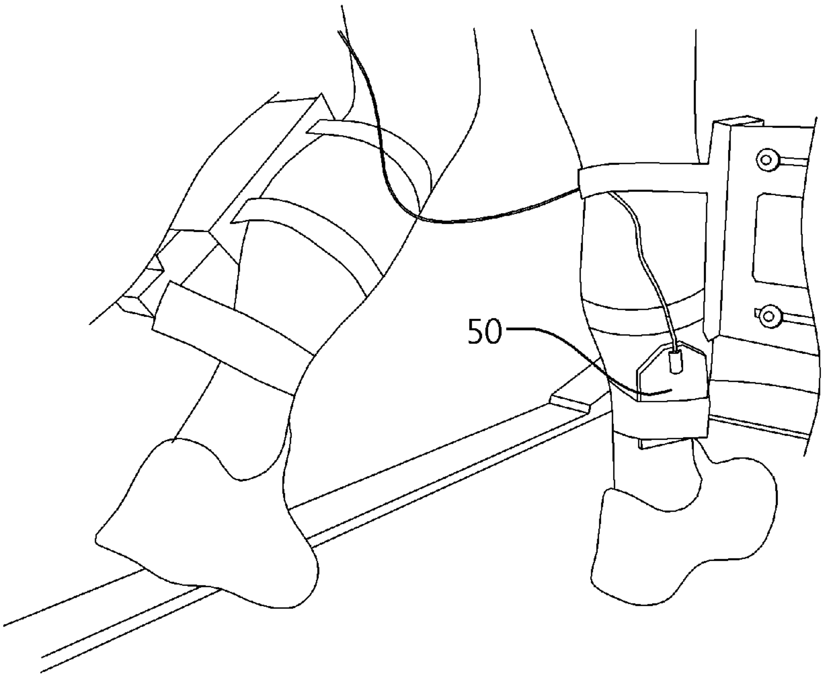
[Fig. 6]



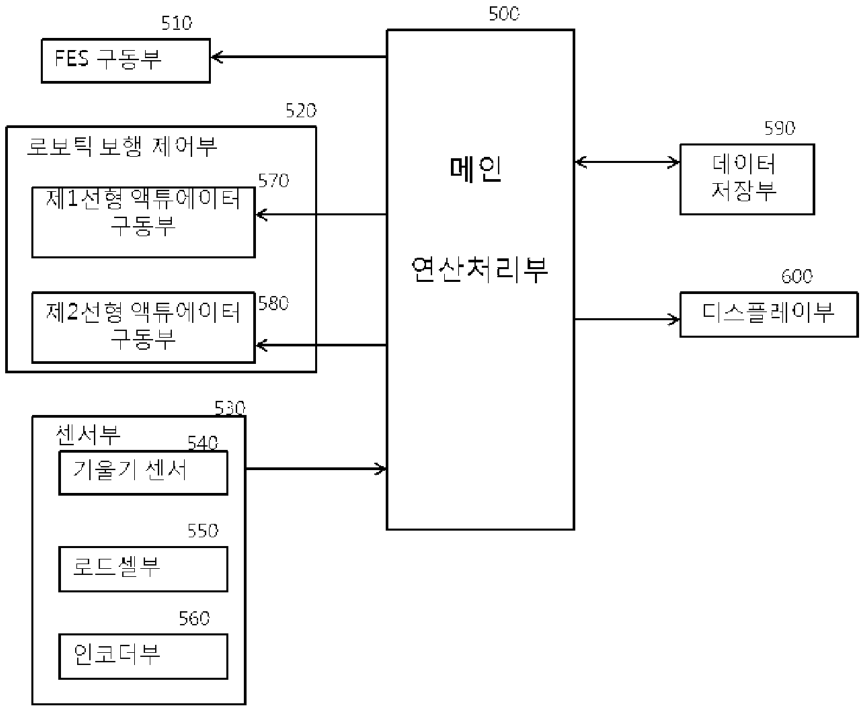
[Fig. 7]



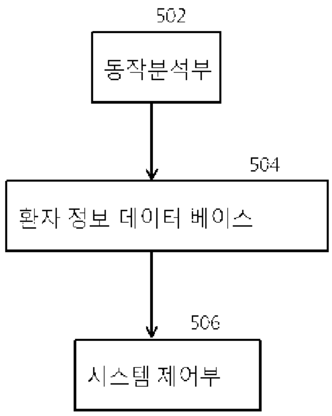
[Fig. 8]



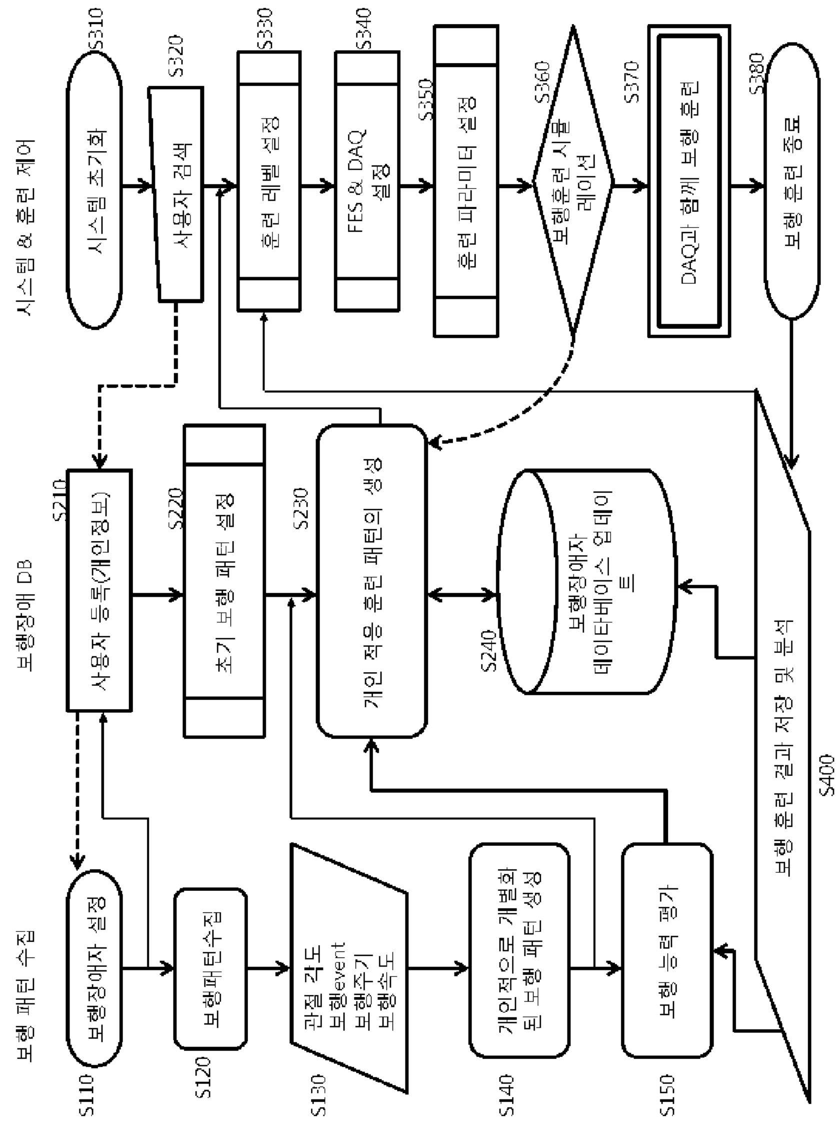
[Fig. 9]



[Fig. 10]



[Fig. 11]


시스템 & 훈련 제어
보행장애 DB
보행 패턴 수집
S310
시스템 초기화
S320
사용자 검색
S330
훈련 레벨 설정
S340
FES & DAQ 설정
S350
훈련 파라미터 설정
S360
보행훈련 시뮬레이션
S370
DAQ과 함께 보행 훈련
S380
보행 훈련 종료
S210
사용자 등록(개인정보)
S220
초기 보행 패턴 설정
S230
개인 적응 훈련 패턴의 생성
S240
보행장애자 데이타베이스 업데이트
S400
보행 훈련 결과 저장 및 분석
S110
보행장애자 설정
S120
보행패턴수집
S130
관절 각도
보행event
보행주기
보행속도
S140
개인적으로 개별화된 보행 패턴 생성
S150
보행 능력 평가

Espacenet

Bibliographic data: WO2012138203 (A2) — 2012-10-11

ACTIVE ROBOTIC GAIT-TRAINING SYSTEM AND METHOD

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Classification:
- **international:** ***A61H1/02; A61H3/00; A61N1/36; B25J13/08***
- **cooperative:** **A61H1/0255 (EP, US); A61H1/0262 (KR); A61N1/36003 (KR); A61N1/36014 (KR); A61N1/3603 (KR); A61N1/36031 (EP, US); A63B21/00178 (EP, KR, US); A63B21/00181 (EP, KR, US); A63B21/4009 (EP, KR, US); A63B21/4011 (EP, KR, US); A63B22/0235 (KR); A63B69/0064 (EP, KR, US); A63B71/0009 (EP, KR, US);** A61H1/0262 (EP, US); A61H2201/10 (EP, KR, US); A61H2201/163 (EP, KR, US); A61H2201/1642 (EP, KR, US); A61H2201/5069 (EP, KR, US); A61N1/36003 (EP, US); A63B2022/0094 (EP, KR, US); A63B22/0235 (EP, US); A63B2213/004 (EP, KR, US); A63B2220/16 (EP, KR, US)

Application number: WO2012KR02678 20120409 Global Dossier

Priority number(s): KR20110032679 20110408

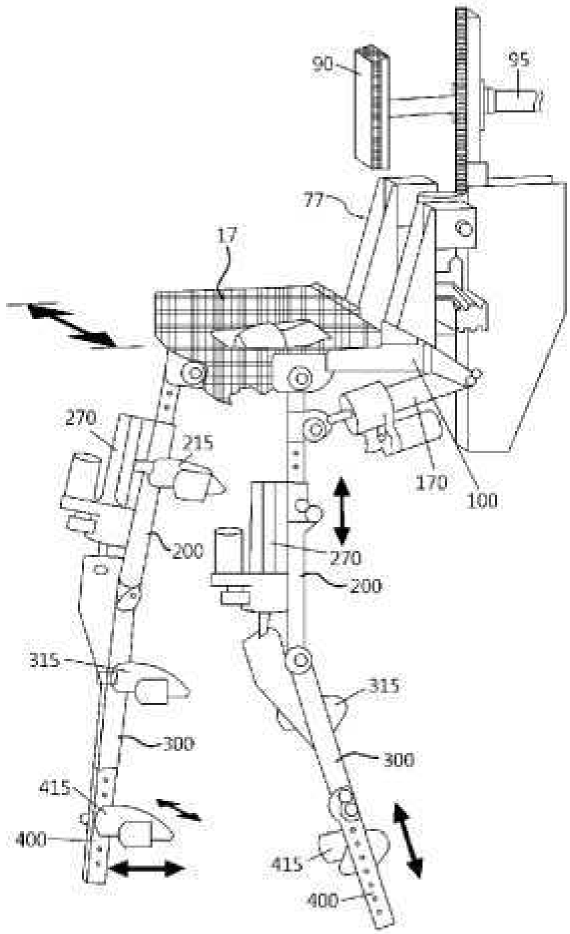
Also published as: WO2012138203 (A3) JP2014509919 (A) JP6175050 (B2) KR101384988 (B1) KR20120115168 (A) more

Abstract of WO2012138203 (A2)

The present invention relates to an active robotic gait-training system and method, which involve measuring the tilt of a lower leg to estimate a gait cycle and enable a hip joint and a knee joint to operate by means of an actuator in accordance with the gait cycle, and which enable an ankle joint to operate by functional electrical stimulation

(FES), thus enabling more active gait training for a person with dysbasia in accordance with the remaining walking ability of the person with dysbasia. According to the present invention, a robot-assisted gait-training system, including a thigh support unit, a hip joint support unit and a lower leg support unit, comprises: a toe-fixing ring which is arranged at the lower end of the lower leg support unit and to which a string, which is connected to a foot strap for covering a foot (tiptoe) part, is fixed; a tilt sensor attached to the lower end of the lower leg support unit or to one side of the foot strap; a control unit which generates an FES control signal, a hip joint angle control signal, and a knee joint angle control signal from the tilt signal received from the tilt sensor; a first linear actuator which receives the hip joint angle control signal from the control unit, and rotates the thigh support unit at a hip joint unit, which is a coupling unit between the thigh support unit and the hip joint support unit, in accordance with the hip joint angle control signal; and a second linear actuator which receives the knee joint angle control signal from the control unit, and rotates the lower leg support unit at a knee joint unit, which is a coupling unit between the lower leg support unit and the thigh support unit, in accordance with the knee joint angle control signal.

[Fig. 5]



Description: WO2012138203 (A2) — 2012-10-11

ACTIVE ROBOTIC GAIT-TRAINING SYSTEM AND METHOD

Description not available for WO2012138203 (A2)
Description of corresponding document: US2014094345 (A1)

A high quality text as facsimile in your desired language may be available amongst the following family members:

JP2014509919 (A) KR20120115168 (A) US2014094345 (A1)

TECHNICAL FIELD

[0001] The present invention relates to an active robotic gait training system and method. In more details, the active robotic gait training system and method can do more active gait training based on remaining gait ability of patients with gait disorder by estimating the gait cycle through the measurement of slope of the lower legs, operating the hip joint and the knee joint by an actuator depending on the gait cycle and operating the ankle joint by functional electric stimulation (FES).

BACKGROUND ART

[0002] Gait is one of unique physical features of human beings and it is the most common exercise as well as the basic activity that humans perform every day.

[0003] In general, the gait cycle of normal people has the stance phase and the swing phase. Stance phase is the period when the foot is in contact with the ground and it consists of the initial contact step, the foot flat step, the mid stance step, the heel-off step and the toe off step. The swing phase is the period when the foot is off the ground and it consists of the toe off step, the mid swing step and the initial contact step. In normal gait, the stance phase accounts for approximately 60% of the gait cycle and the swing phase accounts for 40% of the gait cycle.

[0004] The gait training is a very important unit for patients with gait disorders who lose the gait ability in order to improve the level of independence and the quality of a good life.

[0005] Comprehensive assistance of many experts in multiple fields is required for the rehabilitation training to recover the gait ability of patients with gait disorders. In particular, repeated and systematic gait training is required to improve the sense of balance of patients and increase the tolerance of patients.

[0006] About 90% of patients with gait disorders are caused by the acquired gait disorders and 50% of acquired disabilities are caused by various diseases. Among them, the stroke accounts for the highest percentage. In the initial period after the occurrence of the stroke, it has been reported that 51% of patients cannot walk at all and 12% of patients can walk with assistance and 37% of patients can walk independently. After the rehabilitation treatment, 64% of patients are recovered to allow them to walk independently, but 36% of patients cannot walk or can walk dependently. Even if the gait function is recovered, abnormal gait patterns may be shown due to the disorders of various motor functions.

[0007] In particular, because the extent of possible walking varies depending on patients with gait disorders, the gait training using the patient's own remaining senses could produce a higher effect rather than the uniform gait training.

[0008] In order to do this, the accurate judgment on how much patients with gait disorders can currently walk is needed and the gait training based on this judgment is required.

[0009] In conventional cases, the gait level of patients with gait disorders was determined by the palpation of a therapist and by using the sensory stimulation.

[0010] In the middle of 1980s, the gait training on a treadmill through body weight support was proposed and it was reported that the treatment was clinically effective through this training.

[0011] However, the conventional cases had disadvantages in which a couple of therapists held the movement of limbs and trunk of patients with gait disorders and induced the gait while patients with gait disorders performed the training on treadmill.

[0012] Also, the passive gait training robot which passively moved the leg joint by the robot joint, was proposed for the elderly and the disabled. However, it was not accurately consistent with the gait path which a patient intended and the fundamental gait training for rehabilitation which satisfied the normal gait pattern could not be made.

[0013] Therefore, the gait training system is required in which active gait training is available and the joint movement optimal for normal gait pattern is provided by using the remaining senses of patients with gait disorders.

[0014] The present invention proposes the active robotic gait training system and method which estimates the gait cycle by measuring the slope of the lower legs, operates the hip joint and knee joint based on the gait cycle by an actuator, operates the ankle joint by functional electric stimulation (FES) and enables more active gait training based on remaining gait ability of patients with gait disorders.

DISCLOSURE

Technical Problem

[0015] Accordingly, the present invention is directed to provide an active robotic gait training system and method that it can do more active gait training, by estimating the gait cycle through measurement of slope of the lower leg, operating the hip joint and the knee joint by the actuator depending on the gait cycle and operating the ankle joint by functional electric stimulation.

[0016] The present invention is also directed to provide an active robotic gait training system and method which enables patients with gait disorder to perform the active gait training without the aid activities of therapists and provides the joint movement optimal for normal gait pattern.

Technical Solution

[0017] In an embodiment according to the present invention, a robotic gait training system is comprised of a femoral support unit, a hip joint support unit, a lower leg support unit, a support fixing toe tip, a tilt sensor, a control unit and a FES unit. The femoral support unit is located on the thigh and has the same length and direction of the thigh. The hip joint support unit is located on the buttocks and one end of the hip joint support is installed on the upper part of the femoral support unit to rotate the femoral support unit. The lower leg support unit is located on the lower leg and is installed on the bottom of the femoral support unit to rotate the lower leg support unit. The support fixing toe tip is located on the lower part of the lower leg support unit and is fixed the strap connecting to the toe tip pad wrapping the toe tip (forefoot). The tilt sensor is installed on the lower part of lower leg support unit or on one side of the toe tip pad. The control unit generates FES control signal to do functional electric stimulation (FES) to plantarflexor or dorsiflexor of ankle joint by using the slope signal received from the tilt sensor. The FES unit is formed to do FES to plantarflexor or dorsiflexor of ankle joint based on FES control signal received from the control unit.

[0018] In another embodiment according to the present invention, a robotic gait training system is comprised of the femoral support unit, the hip joint support unit, the lower leg support unit, the support fixing toe tip, the tilt sensor, a control unit and a first linear actuator operation unit. The control unit generates the hip joint angle control signal by using the slope signal received from the tilt sensor. The first linear actuator operation unit receives the hip joint angle control signal from the control unit and operates the first linear actuator to rotate the femoral support unit based on the hip joint angle control signal in the hip joint unit that is the coupling unit between the femoral support unit and the hip joint support unit.

[0019] In another embodiment according to the present invention, a robotic gait training system is comprised of the femoral support unit, the hip joint support unit, the lower leg support unit, the support fixing toe tip, the tilt sensor, a control unit and a second linear actuator operation unit. The control unit generates the knee joint angle control signal by using the slope signal received from the tilt sensor. The second linear actuator operation unit receives the knee joint angle control signal from the control unit and operates the second linear actuator to rotate the lower leg support unit based on the knee joint angle control signal in the knee joint unit that is the coupling unit between the lower leg support unit and the femoral support unit.

[0020] The control unit estimates the gait cycle from the slope signal and generates the hip joint angle control signal based on the estimated gait cycle by using previously stored hip joint operation pattern, and the control unit estimates the gait cycle from the slope signal and generates the knee joint angle control signal based on the estimated gait cycle by using previously stored knee joint operation pattern.

[0021] One side of the first linear actuator is installed on one end of the hip joint support unit and the other side of the first linear actuator is installed on the upper part of femoral support unit and one side of the second linear actuator is installed on one end of the femoral support unit and the other side of the second linear actuator is installed on the upper part of the lower leg support unit.

[0022] The hip joint unit is equipped with the first encoder to measure the rotated angle of the femoral support unit and the knee joint unit is equipped with the second encoder to measure the rotated angle of the lower leg support unit.

[0023] The control unit estimates the gait cycle from the slope signal and receives the hip joint angle signal from the first encoder, and then generates the hip joint angle control signal based on the estimated gait cycle by using the previously stored hip joint operation pattern. Also, the control unit estimates the gait cycle from the slope signal and receives the knee joint angle signal from the second encoder, and then generates the knee joint angle control signal based on the estimated gait cycle by using the previously stored knee joint operation pattern.

[0024] The first load cell is installed between the first linear actuator and the femoral support unit and the second load cell is installed between the second linear actuator and the lower leg support unit.

[0025] The femoral support unit, the hip joint support unit and the lower leg support unit form the robot-assisted gait training device for one side leg and the robotic gait training system contains one pair of robot-assisted gait training device for left and right sides of legs and contains the treadmill that a person who put on one pair of the robot-assisted gait training device does the gait training.

[0026] The robotic gait training system contains the harness, the frame to install the pulley that the rope installed on the harness goes through, and the counterweight installed on one end of the rope passing through the pulley.

[0027] The femoral strap to couple the femoral support unit and the thigh is installed on the femoral support unit and it contains the lower leg strap to couple the upper part of lower leg support unit and the lower leg and contains the ankle strap to couple the lower part of lower leg support unit and the ankle.

[0028] In another embodiment according to the present invention, a operation method of the robotic gait training system is comprised of: the step collecting the gait pattern, which collects the gait pattern of patients with gait disorders and analyzes the motions; the step making database by patients with gait disorders, which stores the collected gait pattern and the results of analysis from the step collecting the gait pattern; the system control step, which generates FES control signal and generates the signal to control the actuator operating the hip joint unit and the knee joint unit, using the gait pattern stored from the step making database by patients with gait disorders. The step collecting the gait pattern is further comprising: the step collecting the gait pattern by patients, which measures the gait of patients with gait disorders and collects the gait pattern; the step detecting the gait parameters, which detects the joint angle, the gait cycle, the gait speed and the gait event including gait timing; the step producing the gait pattern of the training, which generates the gait pattern for gait training, by using the gait parameters detected at the step detecting the gait parameters.

[0029] The step making database by patients with gait disorders has further comprising: the step setting the initial gait pattern, which reads the initial gait pattern selected among the previously stored gait patterns; the step generating the personal adaptive training pattern, which re-adjusts the gait pattern for training by using the initial gait pattern read in the step setting the initial gait pattern, the gait pattern for training generated in the step producing the gait pattern of the training and the previously stored database of patients with gait disorders; and the step updating the database, which stores and updates the information of the gait pattern re-adjusted in the step generating the personal adaptive training pattern.

[0030] The system control step has further comprising: the step setting the FES sensor, which sets the stimulation speed and the stimulation location of the FES sensor depending on the intensity level of the training set; the gait training simulation step, which determines whether it is normal by examining the situation of the system operation when the gait training simulation is carried out with the gait training pattern, when the patient are not getting on the robotic gait training system.

Advantageous Effects

[0031] According to the active robotic gait training system and method of the present invention, it can do the training customized to the patient's own pace, by estimating the gait cycle through measurement of slope of the lower leg, operating the hip joint and the knee joint by the actuator depending on the gait cycle and operating the ankle joint by functional electric stimulation (FES).

[0032] Thus, the gait training can be made according to the patient's own willingness, and more active gait training is available.

[0033] In addition, the present invention enables the active gait training of patients with gait disorders without the support activities of the therapists and the active robotic gait training providing the joint training optimal for normal gait pattern.

BRIEF DESCRIPTION OF DRAWINGS

[0034] FIG. 1 is a schematic diagram to briefly describe active robotic gait training system of the present invention.

[0035] FIG. 2 is a block diagram to describe the configuration of robot-assisted gait training device created by the present invention.

[0036] FIG. 3 is an example of the operating form of robot-assisted gait training device in FIG. 2.

[0037] FIG. 4 is a diagram showing the operating principle of a robot-assisted gait training device that is operated.

[0038] FIG. 5 is an explanation drawing to describe the robotic gait training system in which combines the robot-assisted gait training device of left leg and the robot-assisted gait training device of right leg.

[0039] FIG. 6 is an explanation drawing to describe the state of use of the active robotic gait training system of the present invention.

[0040] FIG. 7 is an example of FES unit integrated with a strap.

[0041] FIG. 8 shows an example of the FES unit installed using a strap in the present invention.

[0042] FIG. 9 is a block diagram for an overview of the configuration to control the active robotic gait training system of the present invention.

[0043] FIG. 10 is a block diagram for an overview of the configuration of the main arithmetic processing unit of FIG. 9.

[0044] FIG. 11 is an explanation drawing for an overview of operating method of active robotic gait training system of the present invention.

BEST MODE

[0045] Hereinafter, preferred embodiments of the present invention will be described below in more detail with reference to the accompanying drawings.

[0046] FIG. 1 is a schematic diagram to explain the overview of the active robotic gait training system of the present invention.

[0047] A trainee who is a patient of gait disorder wears the robot-assisted gait training device (10) on both legs and takes the training on the treadmill (60).

[0048] Robot-assisted gait training device (10) includes the hip joint unit (20), the knee joint unit (30), the ankle strap (415), the FES unit (50) and the tilt sensor (not shown).

[0049] The tilt sensor (not shown) detects the slope of lower leg region (or foot) once it is installed on robot-assisted gait training device (10).

[0050] The hip joint unit (20) is made to rotate the hip joint at a predetermined angle by operation of actuator (motor) and it is operated by receiving the signal to operate the hip joint actuator based on hip joint operation pattern (25) during the gait cycle previously set, from the control unit (not shown).

[0051] The knee joint unit (30) is made to rotate the knee joint at a predetermined angle by operation of actuator (motor) and it is operated by receiving the signal to operate the knee joint actuator based on knee joint operation pattern (35) during the gait cycle previously set, from the control unit (not shown).

[0052] The ankle strap (415) is one of means to install robot-assisted gait training device (10) on the leg and the bottom of robot-assisted gait training device (10) is fixed and installed on the ankle.

[0053] The FES unit (50) is one of means for applying the functional electric stimulation (FES) to the plantarflexor or dorsiflexor of ankle joint and it is operated by receiving the electrical stimulation signal based on the predetermined function electrical stimulation pattern (55) from the control unit (not shown). The predetermined functional electric stimulation pattern (55) may be made of the pulse train. The FES unit (50) can be placed on the part of the ankle or instep.

[0054] The FES unit (50) is operated at the time of pre-swing (toe off) on the ROM (range of motion) curve. The time of pre-swing (toe off) can be the point of 60% when the entire of 1 gait cycle is referred to as 100%. Namely, the pre-swing (toe off) can be the point that changes from the stance period to the swing period.

[0055] The control unit (not shown) determines current gait cycle based on the signal received from the tilt sensor (not shown) and operates hip joint unit (20), knee joint unit (30) and FES unit (50) based on determined gait cycle. The hip joint unit (20) is operated based on hip joint operating pattern (25) during predetermined gait cycle and the knee joint unit (30) is operated based on knee joint operating pattern (35) during predetermined gait cycle. FES unit (50) stimulates the muscle related to the ankle joint based on predetermined functional electric stimulation pattern (55).

[0056] In other words, the robot-assisted gait training device (10) controls the passive gait training of hip joint and knee joint of patients with gait disorders like patients with spinal cord injury or stroke, based on the characteristics of normal gait by using a linear actuator driven by a servo motor. It can induce the active gait training by applying functional electric stimulation (FES) to the plantarflexor/dorsiflexor of ankle joint based on gait cycle of the paralyzed patients detected by a tilt sensor. Hip joint operation pattern (25) shows the operation of an actuator operating the hip joint based on the characteristics of normal gait of patients with gait disorders. Knee joint operation pattern (35) shows the operation of an actuator operating the knee joint based on the characteristics of normal gait of patients with gait disorders. Predetermined functional electric stimulation pattern (55) shows the action which induces active gait training by applying functional electric stimulation (FES) to the plantarflexor/dorsiflexor of ankle joint based on characteristics of normal gait of patients with gait disorders.

[0057] FIG. 2 is a block diagram that describes the configuration of robot-assisted gait training device in the present invention. FIG. 3 is an example of the operating form of robot-assisted gait training device in FIG. 2.

[0058] The robot-assisted gait training device (10) consists of the hip support unit (100), the femoral support unit (200), the lower leg support unit (300), ankle support unit (400), hip joint unit (150) and knee joint unit (250).

[0059] The hip joint support unit (100) is installed on hip areas of the left and right sides of the body which is the buttock, and holds the femoral support unit (200) installed on hip joint unit (150) in order to be rotated by the first linear actuator (170). The hip joint unit (150) is installed on one end of hip joint support unit (100).

[0060] The hip joint unit (150) is installed between the hip support unit (100) and the femoral support unit (200). The hip joint support unit (150) is fixed and installed on the hip joint unit (150). The femoral support unit (200) is installed to be rotated on the hip joint unit (150). In other words, the hip joint unit (150) acts as a joint which enables hip joint support unit (100) and femoral support unit (200) to be rotated. The first rotation angle encoder (155) which measures the joint rotation angle can be installed on hip joint unit (150). The first rotation angle encoder (155) generates the signal to identify the gait characteristics by repeatedly measuring the joint rotation angle of patients with gait disorders. The control signal which operates hip joint unit (150) based on gait characteristics of patients with gait disorders can be generated by using this signal.

[0061] The first linear actuator (170) includes the piston (172), cylinder (174), gear unit (176) and servo motor (178) and it is the actuator making a linear motion. One side of the first linear actuator (170) is installed on one end of hip joint support unit (100) and the other side is installed on the upper part of femoral support unit (200) through the first load cell (180). The first load cell (180) can be omitted in a certain case.

[0062] Piston (172) is the threaded piston. One end of piston (172) is fixed on the femoral support unit (200) through the first load cell (180) and the other end is accommodated within the cylinder (174) fixed on the hip joint support unit (100).

[0063] The cylinder (174) accommodates piston (172) and one end is fixed on the hip joint support unit (100). The other end is fixed on the femoral support unit (200) through the first load cell (180) connected to the piston (172) accommodated in the cylinder (174).

[0064] The gear unit (176) is penetrated and coupled to be rotated on the threads of the piston (172).

[0065] Piston (172), cylinder (174) and gear unit (176) can be referred to as ball screw and ball screw is the means to change the rotation of the servo motor (178) into the linear motion.

[0066] The servo motor (178) makes the piston (172) move as the round exercise to the in/outside of cylinder (174) by rotating the gear unit (176).

[0067] The first load cell (180) measures the force (load) applied to lift the femoral support unit (200) in hip joint unit (150). In other words, it measures the force applied on the hip joint by the first linear actuator (170).

[0068] The femoral support unit (200) is installed on the location of the femoral region in the left and right sides of body. One end of the femoral support unit (200) is installed to rotate on the hip joint unit (150) and the other end is fixed on the knee joint unit (250). The femoral support unit (200) is rotated by the first linear actuator (170) and the actions to lift up and down the femoral region are made. Also, the femoral support unit (200) gives the support to rotate the lower leg support unit (300) by the second linear actuator (270) and the lower leg support unit (300) installed the knee joint unit (250). The femoral support unit (200) is fixed on the femoral region of body by the strap.

[0069] Since the femoral support unit (200) supports the femoral region and the length of the thigh may vary depending on people, the femoral extension unit (210) located between upper femoral support unit (225) and lower femoral support unit which the femoral support unit (200) is divided into is further provided.

[0070] The femoral extension unit (210) is the bar shape in which one end of the femoral extension unit (210) is fixed on the upper femoral support unit (225) and it comprises a plurality of holes (220). The other end of the femoral extension unit (210) is inserted into the lower femoral support unit (230), and hole of the outside of lower femoral support unit (230) is coupled to the screw with holes (220) of the other end of the femoral extension unit (210). The length can be changed by the femoral extension unit (210).

[0071] The knee joint unit (250) is installed between the femoral support unit (200) and lower leg support unit (300). The femoral support unit (200) is fixed and installed on the knee joint unit (250) and the lower leg support unit (300) is installed to be rotated on the knee joint unit (250).

[0072] In the knee joint unit (250), the second rotation angle encoder (250) which measures the joint rotation angle can be installed. The second rotation angle encoder (250) generates the signal to identify the gait characteristics by repeatedly measuring the joint rotation angle of patients with gait disorders. The control signal operating the knee joint unit (250) based on the gait characteristics of patients with gait disorders can be generated by using this signal (output signal of the second rotation angle encoder (250)).

[0073] The second linear actuator (270) includes the piston (272), cylinder (274), gear unit (276) and servo motor (278) and it is the actuator making a linear motion. One side of the second linear actuator (270) is installed on the femoral support unit (200) and the other side is installed on the upper side of lower leg support unit (300) through the second load cell (280). The second load cell (280) can be omitted.

[0074] Piston (272) is the threaded piston. One end of piston (272) is fixed on the lower leg support unit (300) through the second load cell (280) and the other end of piston (272) is accommodated within the cylinder (274) fixed on the femoral support unit (200).

[0075] The cylinder (274) accommodates the piston (272) and one end of the cylinder (274) is fixed on the femoral support unit (200). The other end of the cylinder (274) is fixed on the lower leg support unit (300) through the second load cell (280) connected to the piston (272) accommodated in the cylinder (274).

[0076] The gear unit (276) is penetrated and coupled to be rotated on the threads of the piston (272).

[0077] Piston (272), cylinder (274) and gear unit (276) can be referred to as ball screw and ball screw is the means to change the rotation of the servo motor (278) into the linear motion.

[0078] The servo motor (278) makes the piston (272) move as the round exercise to the in/outside of cylinder (274) by rotating the gear unit (276).

[0079] The second load cell (280) measures the force (load) applied to lift the lower leg support unit (300) in hip joint unit (150). In other words, the second load cell (280) measures the force applied by the second linear actuator (270).

[0080] The lower leg support unit (300) is installed on the location of the lower leg region in the left and right sides of body. One end of the lower leg support unit (300) is installed to rotate on the knee joint unit (250) and the other end of the lower leg support unit (300) is connected to the ankle support unit (400). The lower leg support unit (300) is rotated by the second linear actuator (270) and the actions to lift up and down the legs are made. The lower leg support unit (300) corresponds to the calf of body and it is fixed with the lower leg support unit (300) and the calf by a strap.

[0081] One end of the ankle support unit (400) is connected to the lower leg support unit (300) and the support fixing toe tip (440) is installed on the one end of the ankle support unit (400). The ankle support unit (400) is equipped with an ankle strap and the ankle support unit (400) can be fixed to the ankle.

[0082] The strap connecting to the toe tip pad (forefoot strap) (not shown) wrapping the toe tip (forefoot) fixes to the hole of the support fixing toe tip (440) and the toe tip (forefoot) part is fixed.

[0083] FES stimulation part (not shown) can be installed on the foot through the support fixing toe tip (440).

[0084] The ankle extension unit (445) is the bar shape in which one end of the ankle extension unit (445) is fixed on the ankle support unit (400) and it comprises a plurality of holes (220). The hole of the outside of ankle support unit (400) is coupled to the screw, and the length of ankle support unit (400) can be changed. The ankle extension unit (445) can be omitted in a certain case.

[0085] FIG. 4 is a diagram showing the operating principle of a robot-assisted gait training device that is operated.

[0086] If the first linear actuator (170) moves towards the hip joint unit (150) or the first load cell (180), the hip joint unit (150) moves clockwise and the femoral support unit (200) moves upward. In other words, the femoral support unit (200) moves in the direction of lifting up the thigh. If the first linear actuator (170) moves in the opposite direction, as the result, the femoral support unit (200) moves downward. In other words, the femoral support unit (200) moves in the direction of lifting down the thigh.

[0087] If the second linear actuator (270) moves towards the hip joint unit (150), the knee joint unit (250) moves clockwise, and the lower leg support unit (300) moves upward. In other words, the lower leg support unit (300) moves in the direction of lifting up the lower leg (calf). If the second linear actuator (270) moves towards the ankle unit (400), as the result, the lower leg support unit (300) moves downward. In other words, the lower leg support unit (300) moves in the direction of lifting down the lower leg.

[0088] FIG. 5 is an explanation drawing to describe the robotic gait training system in which have with robot-assisted gait training device of left leg and robot-assisted gait training device of right leg.

[0089] In the robot-assisted gait training device (10) of the left and right legs, one end (it is opposite to the hip joint unit (150)) of the hip joint support unit (100) is installed and fixed on the integrated fixation end (77). The back support unit (90) is installed on one side of the integrated fixation end (77) to support the back when wearing this robotic gait training system. In addition, the integrated fixation end (77) is connected to the frame of robotic gait training system through the frame joint unit (95). The frame is a frame to install the harness.

[0090] The robot-assisted gait training device (10) of left and right sides of legs is equipped with the femoral strap (215), lower leg strap (315) and ankle strap (415), and these combine the leg with the robot-assisted gait training device (10).

[0091] The buttock guide (17) is located on the upper side of robot-assisted gait training device (10) and is positioned on both right side and left side of the hip. The buttock guide (17) plays a role as a cushion to mitigate the pain caused by pressing the skin by robot-assisted gait training device (10).

[0092] In other words, the hybrid robot-assisted gait training device in the present invention is a gait training device that reinforces the muscular strength so as to make the patient with gait disorders move the joints of the legs and does the gait training. It includes the hip joint support unit (100), the femoral support unit (200) and the lower leg support unit (300) connecting to the waist & hip area, the thigh and calf of the human body, respectively. It also includes the hip joint unit (150) and the knee joint unit (250) coupled to rotate each support unit. Hip support unit (100) corresponding to the waist and hip areas of the human body can be simply responsible for bearing the weight of the femoral support unit (200) and the lower leg support unit (300). Also, hip support unit (100) can bear the weight of the upper body by coupling the upper body and it by a strap. The femoral support unit (200) fixes the femur (thigh) by coupling by a strap on the thigh of the human body. The lower leg support unit (300) corresponding to the calf of human body can be fixed with human body by coupling the calf and it with a strap.

[0093] FIG. 6 is an explanation drawing to describe the state of use of the active robotic gait training system of the present invention.

[0094] Once patients with gait disorders are equipped with harness (112) and the robot-assisted gait training device (10) on the left and right sides of legs, they are taking the gait training on the treadmill (60).

[0095] A rope (114) installed on the harness (112) to support the weight of patients with gait disorders is installed on the frame (65). It is connected to the counterweight (118) to support the weight through a pulley (116) installed on the upper side of patients with gait disorders. In other words, it consists of the harness (112), the pulley (116) and the counterweight (118), to bear the weight of patients with gait disorders. A pulley (116) supports the weight of patient with gait disorders through a rope (114) connected to the harness (112) which the patient wears. A counterweight (118) controls the vertical movement of patients with gait disorders through the rope (114).

[0096] The arm holder (70) which patients with gait disorders can hold with hands during the gait training is located on the left and right sides. Since the stop switch (75) is equipped on the arm holder (70), the training can be stopped by a trainee during the training upon the occurrence of emergency.

[0097] The control unit (40) determines the status and gait cycle of pedestrian from the signal received from a tilt sensor and a load cell. It operates the hip joint unit (20), the knee joint unit (30) and FES unit (50) according to the determined gait cycle.

[0098] Also, the patients with gait disorders can take the gait training while they are looking at the display of results of training on the display unit of the control unit (40), and the effect of biofeedback is brought.

[0099] FIG. 7 is an example of FES unit integrated with a strap in the present invention. FIG. 8 shows an example of the FES unit installed using a strap in the present invention.

[0100] FES unit (50) is located at the bottom of the lower leg support unit (300) and applies a functional electric stimulation (FES) to the ankle part of the human body by the control unit (40).

[0101] The electric stimulation unit (50) can take shape of a strap or a sock, and apply FES (Functional Electric Stimulation) stimulus to the ankle part of the human body by contacting the strap or the sock.

[0102] The gait training device (10) is equipped with the first rotational angle encoder (155) which measures the joint rotational angle on the hip joint unit (150), and the second rotational angle encoder (250) which measures the joint rotational angle on the knee joint unit (250) in the present invention. The joint rotational angle detected in the rotational angle encoders (155, 255) is sent to the control unit (40). The control unit (40) makes the database of the gait characteristics of each patient with gait disorders by using the repetitive rotational angle data, and controls the amount and speed of rotation of the servo motors (178, 278) based on the each gait characteristic, and as the results, controls the linear actuator (170, 270).

[0103] In addition, the gait training device (10) has the load cell measuring the load applied to the hip joint unit (150) and the load cell measuring the load applied to the knee joint unit (250), in the present invention. The load cell transmits the weight applied to the joint unit (150, 250) to the control unit. The control unit (40) controls the counterweight (118) so as to take the appropriate tension, depending on the gait characteristics of patients with gait disorders. Thus, it controls the tension applied to the harness (112) coupled to the rope (114) and the pulley (116), and each patient with gait disorders can do the optimized gait training according to personal gait characteristics.

[0104] In addition, the second support unit (25) is equipped with the tilt sensor to measure the slope with reference to earth axis and the electric stimulation unit (40) applies the functional electric stimulation to the plantarflexor/the dorsiflexor of ankle joint for each gait cycle of the patients with gait disorders measured by the tilt sensor, and then the patients can do active gait training. Electrical stimulation unit (40) can detect the moment of the gait measured by the tilt sensor and produce the functional electric stimulation. It also can produce the functional electric stimulation for each gait cycle in accordance with the gait training optimized from the database for the gait characteristics of each patient with gait disorders accumulated in the control unit (40).

[0105] FIG. 9 is a block diagram for an overview of the configuration to control the active robotic gait training system of the present invention. It includes the main arithmetic processing unit (500), the FES operating unit (510), the robotic gait control unit (520), the sensor unit (530), the data storage unit (590) and the display unit (600).

[0106] The main arithmetic processing unit (500) receives the output signal of the sensor unit (530) and receives the gait cycle pattern previously stored from the data storage unit (590). It generates the FES control signal, the first linear actuator control signal and the second linear actuator control signal. It sends the signal to the FES operation unit (510), the first linear actuator operation unit (570) and the second linear actuator operation unit (580) of robotic gait control unit (520). Also, the output signal received from the sensor unit (530) is stored in the data storage unit (590). The main arithmetic processing unit (500) analyzes the result of gait training of patients with gait disorders and shows the output on the display unit (600).

[0107] The FES operation unit (510) gives the output of FES stimulation signal according to FES control signal of the main arithmetic processing unit (500).

[0108] The robotic gait control unit (520) includes the first linear actuator operation unit (570) and the second linear actuator operation unit (580).

[0109] The first linear actuator operation unit (570) operates the first linear actuator (

170) by the first linear actuator control signal received from the main arithmetic processing unit (500). The first linear actuator (170) is rotated to lift up or down the femoral support unit (200).

[0110] The second linear actuator operation unit (580) operates the second linear actuator (270) by the second linear actuator control signal received from the main arithmetic processing unit (500). The second linear actuator (270) is rotated to lift up or down the lower leg support unit (300).

[0111] The sensor unit (530) includes a tilt sensor (540), a load cell unit (550) and the encoder unit (560), and it sends the detected signal to the main arithmetic processing unit (500).

[0112] The tilt sensor (540) is installed on the lower leg support unit of the robot-assisted gait training device (10) and on the toe tip pad wrapping the forefoot (toe tip).

[0113] The load cell unit (550) includes the first load cell (180) and the second load cell (280). The first load cell (180) measures the force (load) applied to the hip joint unit (150) in order to lift up the femoral support unit (200). The second load cell (280) measures the force (load) applied to the knee joint unit (250) in order to lift up the lower leg support unit (300).

[0114] The encoder (560) includes the first rotation angle encoder (155) and the second rotation angle encoder (255). The first rotation angle encoder (155) measures the rotation angle of the hip joint and the main arithmetic processing unit (500) generates the first linear actuator control signal by using it. The second rotation angle encoder (255) measures the rotation angle of the knee joint and the main arithmetic processing unit (500) generates the second linear actuator control signal by using it. In other words, the main arithmetic processing unit (500) produces the signal to identify the gait characteristics by repeatedly measuring the joint rotation angle of patients with gait disorders through the encoder unit (560). Then, the main arithmetic processing unit (500) process the signal, and produces the control signal which operates the hip joint unit (150) and the knee joint unit (250) based on the gait characteristics of patient with gait disorders.

[0115] The data storage unit (590) stores the signal received from the main arithmetic processing unit (500), and the display unit (600) displays the signal received from the main arithmetic processing unit (500).

[0116] FIG. 10 is a block diagram for an overview of the configuration of the main arithmetic processing unit of FIG. 9, and it includes the motion analysis unit (502), the patient information database (504) and the system control unit (506).

[0117] The motion analysis unit (502) collects the gait pattern of patients, especially patients with gait disorders and analyzes the motions.

[0118] Patient information database (504) stores the gait patterns and the analysis results received from the motion analysis unit (502) by patients.

[0119] The system control unit (506) reads the gait patterns from the patient information database (504), generates the FES control signals, the first linear actuator control signal and the second linear actuator control signal, and then transmits them to the FES operation unit (510), the first linear actuator operation unit (570) of the robotic gait control unit (520) and the second linear actuator operation unit (580) of the robotic gait control unit (520).

[0120] FIG. 11 is an explanation drawing for an overview of operating method of the active robotic gait training system of the present invention.

[0121] As the step (S 110) inputting the basic information of the patient with gait disorders, it sets the patient as the subject for gait training, and enters the basic information (personal information) of patients with gait disorders.

[0122] As the step (S 120) collecting the gait pattern, it measures the gait of patients with gait disorders and collects the gait pattern.

[0123] As the step (S 130) detecting the gait parameters, it detects the gait parameters related to the gait training, that is, it detects the joint angle, gait event, gait cycle and gait speed. The gait event includes the gait timing.

[0124] As the step (S 140) producing the gait pattern of the training, it generates the gait pattern for gait training, by using the parameters detected at the step detecting the gait parameters. The gait pattern is the personally individualized gait pattern for gait training.

[0125] As the step (S 150) evaluating the gait ability, it evaluates the gait ability by using the previously stored data.

[0126] The step (S 110) inputting the basic information of the patient with gait disorders or the step (S 150) evaluating the gait ability, can be the step of the gait pattern acquisition that analyzes the motions and collects the gait pattern.

[0127] The followings describe the steps to make database with detection or setting data by patients with gait disorders.

[0128] As the step (S 210) loading the user registration information, it reads the basic information (personal information) of users of the gait training system who are patients with gait disorders.

[0129] As the step (S 220) setting the initial gait pattern, it sets the initial gait pattern being used in the gait training system.

[0130] As the step (S 230) generating the personal adaptive training pattern, it generates the personal adaptive training pattern, by using the step (S 210) loading the user registration information, the step (S 140) producing the gait pattern of the training, and the previously stored database for patients with gait disorders.

[0131] As the step (S 240) updating the database, it stores and updates the generated personal adaptive training pattern information.

[0132] The step (S 210) loading the user registration information or the step (S 240) updating the database, can be the step making database by patients with gait disorders.

[0133] The followings describe the control based the system and the training.

[0134] As the system initialization step (S 310), it initializes the system.

[0135] As the user search step (S 320), it searches and recognizes the user.

[0136] As the step (S 330) setting training level, it sets the training level (namely the training intensity level) of the training using training pattern.

[0137] For example, if it is set with 6 steps, the joint angle control of left and right knee joint units and left and right hip joint units of the gait training device (10), are divided into 6 steps based on the difference between normal gait and the patient gait.

[0138] As the step (S 340) setting the FES sensor, it sets the stimulation speed and the stimulation location of the FES sensor, and sets the speed of data acquisition (DAQ).

[0139] As the step (S 350) setting the training parameter, it sets the training parameter in the gait training device (10).

[0140] As the gait training simulation step (S 360), it checks out the equipment operation situation by performing the gait training simulation with the gait training pattern being set only with the gait training device (10). Then, if a problem is found, it returns to the step (S 230) generating the personal adaptive training pattern, and the training pattern is re-generated.

[0141] As the gait training step (S 370), it performs the gait training and performs the data acquisition at the same time.

[0142] As the step (S 400) analyzing the result of gait training, when the gait training is completed (S 380), it stores and analyzes the result of gait training.

[0143] The data stored at the step (S 400) analyzing the result of gait training, will be used henceforward in the step (S 120) collecting the gait pattern and the step making database by patients with gait disorders.

[0144] In here, although the preferred embodiments of the present invention have been described, it will be understood by those skilled in the art that the present invention should not be limited to the described preferred embodiments, but various changes and modifications can be made within the sprit and scope of the present invention as defined by the appended claims.

INDUSTRIAL APPLICABILITY

[0145] The present invention relates to the active robotic gait training system in which is allowed more active gait training based on remaining gait ability of patients with gait disorders. It can be used for the gait training of patients with gait disorders in the rehabilitation hospitals.

Espacenet

Claims: WO2012138203 (A2) — 2012-10-11

ACTIVE ROBOTIC GAIT-TRAINING SYSTEM AND METHOD

Claims not available for WO2012138203 (A2)
Claims of corresponding document: US2014094345 (A1)

A high quality text as facsimile in your desired language may be available amongst the following family members:

JP2014509919 (A) KR20120115168 (A) US2014094345 (A1)

- Original claims
- Claims tree

1. 1. A robotic gait training system, wherein the femoral support unit is located on the thigh and has the same length and direction of the thigh; the hip joint support unit is located on the buttocks and one end of the hip joint support unit is installed on the upper part of the femoral support unit to rotate the femoral support unit; the lower leg support unit is located on the lower leg and is installed on the bottom of the femoral support unit to rotate the lower leg support unit; further comprising:
a support fixing toe tip, located on the lower part of the lower leg support unit and fixed the strap connecting to the toe tip pad wrapping the toe tip (forefoot);
a tilt sensor, installed on the lower part of lower leg support unit or on one side of the toe tip pad;
a control unit, generated FES control signal to do functional electric stimulation (FES) to plantarflexor or dorsiflexor of ankle joint by using the slope signal received from the tilt sensor; and,
a FES unit, formed to do FES to plantarflexor or dorsiflexor of ankle joint based on FES control signal received from the control unit.

2. 2. A robotic gait training system, wherein the femoral support unit is located on the thigh and has the same length and direction of the thigh; the hip joint support unit is located on the buttocks and one end of the hip joint support unit is installed on the upper part of the femoral support unit to rotate the femoral support unit; the lower leg support unit is located on the lower leg and is installed on the bottom of the femoral support unit to rotate the lower leg support unit; further comprising:
a support fixing toe tip, located on the lower part of the lower leg support unit and fixed the strap connecting to the toe tip pad wrapping the toe tip (forefoot);
a tilt sensor installed on the lower part of lower leg support unit or on one side of the toe tip pad;
a control unit, generated the hip joint angle control signal by using the slope signal received from the tilt sensor; and,
a first linear actuator operation unit, received the hip joint angle control signal from the

control unit and operates the first linear actuator to rotate the femoral support unit based on the hip joint angle control signal in the hip joint unit that is the coupling unit between the femoral support unit and the hip joint support unit.

3. 3. A robotic gait training system, wherein the femoral support unit is located on the thigh and has the same length and direction of the thigh; the hip joint support unit is located on the buttocks and one end of the hip joint support unit is installed on the upper part of the femoral support unit to rotate the femoral support unit; the lower leg support unit is located on the lower leg and is installed on the bottom of the femoral support unit to rotate the lower leg support unit; further comprising:
a support fixing toe tip, located on the lower part of the lower leg support unit and fixed the strap connecting to the toe tip pad wrapping the toe tip (forefoot);
a tilt sensor installed on the lower part of lower leg support unit or on one side of the toe tip pad;
a control unit, generated the knee joint angle control signal by using the slope signal received from the tilt sensor; and,
a second linear actuator operation unit, received the knee joint angle control signal from the control unit and operates the second linear actuator to rotate the lower leg support unit based on the knee joint angle control signal in the knee joint unit that is the coupling unit between the lower leg support unit and the femoral support unit.

4. 4. The robotic gait training system as claimed in claim 2, wherein the control unit generates the FES control signal to do functional electric stimulation (FES) to plantarflexor or dorsiflexor of ankle joint by using the slope signal received from the tilt sensor, further comprising:
a FES unit, formed to do FES to plantarflexor or dorsiflexor of ankle joint based on the FES control signal received from the control unit.

5. 5. The robotic gait training system as claimed in claim 1, wherein the control unit generates the hip joint angle control signal and the knee joint angle control signal by using the slope signal received from the tilt sensor, further comprising:
a first linear actuator operation unit, received the hip joint angle control signal from the control unit and operates the first linear actuator to rotate the femoral support unit based on the hip joint angle control signal in the hip joint unit that is the coupling unit between the femoral support unit and the hip joint support unit; and,
a second linear actuator operation unit, received the knee joint angle control signal from the control unit and operates the second linear actuator to rotate the lower leg support unit based on the knee joint angle control signal in the knee joint unit that is the coupling unit between the lower leg support unit and the femoral support unit.

6. 6. The robotic gait training system as claimed in claim 5, wherein the control unit estimates the gait cycle from the slope signal and generates the hip joint angle control signal based on the estimated gait cycle by using previously stored hip joint operation pattern.

7. 7. The robotic gait training system as claimed in claim 5, wherein the control unit estimates the gait cycle from the slope signal and generates the knee joint angle control signal based on the estimated gait cycle by using previously stored knee joint operation pattern.

8. 8. The robotic gait training system as claimed in claim 2, wherein the control unit generates the knee joint angle control signal by using the slope signal received from the tilt sensor, further comprising:
a second linear actuator operation unit, received the knee joint angle control signal from the control unit and operates the second linear actuator to rotate the lower leg support unit based on the knee joint angle control signal in the knee joint unit that is the coupling unit between the lower leg support unit and the femoral support unit.

9. 9. The robotic gait training system as claimed in claim 2, wherein one side of the first linear actuator is installed on one end of the hip joint support unit and the other side of the first linear actuator is installed on the upper part of femoral support unit.

10. 10. The robotic gait training system as claimed in claim 3, wherein one side of the second linear actuator is installed on one end of the femoral support unit and the other side of the second linear actuator is installed on the upper part of the lower leg support unit.

11. 11. The robotic gait training system as claimed in claim 2, wherein the hip joint unit is equipped with the first encoder to measure the rotated angle of the femoral support unit.

12. 12. The robotic gait training system as claimed in claim 3, wherein the knee joint unit is equipped with the second encoder to measure the rotated angle of the lower leg support unit.

13. 13. The robotic gait training system as claimed in claim 11, wherein the control unit estimates the gait cycle from the slope signal and receives the hip joint angle signal from the first encoder, and then generates the hip joint angle control signal based on the estimated gait cycle by using the previously stored hip joint operation pattern.

14. 14. The robotic gait training system as claimed in claim 12, wherein the control unit estimates the gait cycle from the slope signal and receives the knee joint angle signal from the second encoder, and then generates the knee joint angle control signal based on the estimated gait cycle by using the previously stored knee joint operation pattern.

15. 15. The robotic gait training system as claimed in claim 9, wherein the load cell is installed between the first linear actuator and the femoral support unit.

16. 16. The robotic gait training system as claimed in claim 10, wherein the load cell is installed between the second linear actuator and the lower leg support unit.

17. 17. The robotic gait training system as claimed in claim 5, wherein the encoder is installed in hip joint and knee joint unit, respectively.

18. 18. The robotic gait training system as claimed in claim 5, wherein the first load cell is installed between the first linear actuator and the femoral support unit and the second load cell is installed between the second linear actuator and the lower leg support unit.

19. 19. The robotic gait training system as claimed in claim 5, wherein the femoral support unit, the hip joint support unit and the lower leg support unit form the robot-assisted gait training device for one side leg and the robotic gait training system contains one pair of robot-assisted gait training device for left and right sides of legs and contains the treadmill that a person who put on one pair of the robot-assisted gait training device does the gait training.

20. 20. The robotic gait training system as claimed in claim 19, wherein contains the harness, the frame to install the pulley that the rope installed on the harness goes through, and the counterweight installed on one end of the rope passing through the pulley.

21. 21. The robotic gait training system as claimed in claim 5, wherein the femoral strap to couple the femoral support unit and the thigh is installed on the femoral support unit and it contains the lower leg strap to couple the upper part of lower leg support unit and the lower leg and contains the ankle strap to couple the lower part of lower leg support unit and the ankle.

22. 22. A operation method of the robotic gait training system, wherein the step collecting the gait pattern, which collects the gait pattern of patients with gait disorders and analyzes the motions; the step making database by patients with gait disorders, which stores the collected gait pattern and the results of analysis from the step collecting the gait pattern; the system control step, which generates FES control signal and generates the signal to control the actuator operating the hip joint unit and the knee joint unit, using the gait pattern stored from the step making database by patients with gait disorders; the step collecting the gait pattern is further comprising:
the step collecting the gait pattern by patients, which measures the gait of patients with gait disorders and collects the gait pattern;
the step detecting the gait parameters, which detects the joint angle, the gait cycle, the gait speed and the gait event including gait timing;
the step producing the gait pattern of the training, which generates the gait pattern for gait training, by using the gait parameters detected at the step detecting the gait parameters.

23. 23. The operation method of the robotic gait training system as claimed in claim 22, wherein the step making database by patients with gait disorders has further comprising:
the step setting the initial gait pattern, which reads the initial gait pattern selected among the previously stored gait patterns;
the step generating the personal adaptive training pattern, which re-adjusts the gait pattern for training by using the initial gait pattern read in the step setting the initial gait pattern, the gait pattern for training generated in the step producing the gait pattern of the training and the previously stored database of patients with gait disorders; and,
the step updating the database, which stores and updates the information of the gait pattern re-adjusted in the step generating the personal adaptive training pattern.

24. 24. The operation method of the robotic gait training system as claimed in claim 23, wherein the system control step has further comprising:
the step setting the FES sensor, which sets the stimulation speed and the stimulation location of the FES sensor depending on the intensity level of the training set;
the gait training simulation step, which determines whether it is normal by examining the situation of the system operation when the gait training simulation is carried out with the gait training pattern, when the patient are not getting on the robotic gait training system.

25. 25. The robotic gait training system as claimed in claim 3, wherein the control unit generates the FES control signal to do functional electric stimulation (FES) to plantarflexor or dorsiflexor of ankle joint by using the slope signal received from the tilt sensor, further comprising:
a FES unit, formed to do FES to plantarflexor or dorsiflexor of ankle joint based on the FES control signal received from the control unit.