

Limb Brace Device And System

5 TECHNICAL FIELD

The present disclosure relates broadly to a limb brace device and to a limb brace system, more particularly to a device for performance of a therapy, diagnosis and/or rehabilitation of muscles of a user.

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BACKGROUND

Spasticity is a well-known syndrome, most commonly arising after a subject/patient suffers from stroke, multiple sclerosis, spinal cord injury, certain traumatic brain injuries, and/or other central nervous system (CNS) lesions. Spasticity is defined as a motor disorder resulting from hyper excitability of the stretch reflex of a patient and is characterised by exaggerated tendon jerks and velocity-dependent increases in tonic stretch reflexes. When a muscle contracts in reflex due to spasticity, it may tend to remain in a shortened/contracted position. Over time, this restriction of range may cause length-related changes in the patient's muscle-tendon complex, with a loss of sarcomeres in series particularly, which may in turn lead to conditions involving a loss of joint range such as muscle contracture. In short, spasticity-caused immobilisation of muscles at shortened length, and thereby such biomechanical changes, may lead to stiffness, painful muscle spasms, hypertonia or even contractures.

Relief or treatment of the above conditions may be applied by moving the patient's affected joint through a range of motion (ROM) and a stretch-evoked torque on the joint may be varied based upon the patient's severity, stretch velocity and/or changing position over the full angular ROM. Besides the above, as muscle weakness is also a common consequence of stroke and may result in a decrease in physical activity, stretching to reduce muscle stiffness and performing strengthening exercises to condition the muscles

are also recognised as significant elements of rehabilitation to improve functional capacity.

It is recognised that rehabilitation may be key for a patient's recovery.

5 Stretching/ranging may help to prevent joint contractures and it has been recognised that intensive training may be relatively important to provide an effective outcome from rehabilitation. However, providing rehabilitation may be labour-intensive due to the amount of repetition required to have an effect and thus, treating spasticity has been recognised as a great challenge. Furthermore, it has been recognised that outcome

10 assessment of rehabilitation may be subjective if performed using conventional ways. In addition, it has been recognised that subjects/patients with spasticity, and/or weak muscles and who are required to undergo stretching and strengthening typically rely on one-on-one training with a therapist but such patients may not receive intensive training.

15 In the realm of robotics rehabilitation, there have been provided devices that emphasise on highly intensive and interactive rehabilitation that are paired with real-time performance feedback therapeutic games. However, it has been recognised that such devices may not stretch the tighter muscles of a subject/patient but rather, merely assist only in the patient's range of possible movement (about joint(s)).

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Further to the above-mentioned devices, Continuous Passive Motion (CPM) machines may possibly stretch stiff muscles. However, the inventors have recognised that such machines merely provide passive movement at a constant speed and do not react to an impaired reflex mechanism of a spastic subject/patient. Thus, for such CPM

25 machines, there is a problem of overstretching stiff muscles and this may cause extreme pain and harm to a subject/patient.

Even further to the above-mentioned devices, there have been provided a number of robotics rehabilitation devices for subjects/patients with spasticity to stretch tighter

30 muscles. For example, there have been provided devices for stretching that use an individual electric motor for a single degree of freedom to stretch a specific joint and muscle. However, it has been recognised by the inventors that these devices for spastic subjects/patients may be large in size, heavy, complicated to operate, lack portability

and/or lack affordability, which make such devices almost impossible to be implemented (or to have these devices installed) across a plurality of care centres. Such devices may also be impractical for home-based rehabilitation. The inventors have recognised that due to these limitations, the development of robotics rehabilitation devices specifically catered to the needs of a subject/patient with spasticity to stretch tighter muscles is not as widely available in the market. The inventors have also recognised that the same considerations above may apply for gym equipment in terms of their size. Further, the inventors have recognised that it may be difficult to maintain a subject's/patient's attention and motivation to perform strengthening exercises to condition muscles when gym equipment are used.

Further to the above, the inventors have also recognized that recent robotics rehabilitation market trends are moving towards providing visual feedback and allowing home-based rehabilitation with remote monitoring and assessment. However, the inventors have recognised that, for stretching therapy, there are limitations in designing visual feedback interactive game play to be incorporated with the rehabilitation devices. On the other hand, a device which merely offers machine-intelligent control stretching therapy without the above-mentioned game play may not be able to make the therapy fun and motivating for patients. The inventors have recognised that if the commercial sectors are to develop a device solely for stretching therapy, the device may have less marketable value as it may provide a specific (limited) treatment to a limited range of potential target users.

The inventors have recognised that there is a need for a solution (in the form of e.g. a device) for subjects/patients with spasticity to stretch tighter muscles to be available in the market and to offer a new therapy solution. The inventors have recognised that there is a need to develop an intelligent portable device which may provide stretching and strengthening training and may allow clinicians and patients to use as an effective therapeutic device e.g. at a home setting and/or at a clinic.

Hence, in light of the foregoing, there exists a need for a limb brace device and a limb brace system that seek to address at least one of the above problems or considerations.

SUMMARY

In accordance with an aspect of the present disclosure, there is provided a limb brace device, the device comprising one or more receiving portions to support one or more parts of a limb, such that at least one part of the limb is rotatable with respect to one or more limb joints; one or more driving motors; one or more gear engagement systems, each gear engagement system comprising at least one translator member capable of engaging or disengaging the respective gear engagement system to said one or more driving motors; one or more torque adjustable mechanisms coupled to the one or more receiving portions; wherein during engagement of at least one of the one or more gear engagement systems to the one or more driving motors, the engaged gear engagement system is capable of transmitting torque to the one or more receiving portions for movement with respect to the one or more limb joints; and further wherein during disengagement of the one or more gear engagement systems to the one or more driving motors, the one or more torque adjustable mechanisms is capable of affecting the one or more receiving portions for movement with respect to the one or more limb joints.

The limb brace device may further comprise the limb brace device being adapted to allow for at least five degrees of freedom for motion of the limb.

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The limb brace device may further comprise the at least one translator member being capable of causing linear displacement of a driven gear component to engage or disengage a driving gear component of said one or more driving motors.

25 During engagement of at least one of the one or more gear engagement systems to the one or more driving motors, the driven gear component may be capable of transmitting torque to a coupled component that is coupled to the driven gear.

The coupled component that is coupled to the driven gear may comprise another gear component or a rotatable shaft.

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The one or more receiving portions may comprise a digital segment, the digital segment comprising a base having a plurality of positioning holes and wherein the digital

segment is rotatable to lock in an interchangeable position using the positioning holes to accommodate a left limb or a right limb.

5 The one or more receiving portions may comprise a joint segment, the joint segment may comprise a mechanical stopper that is adjustable along a rotational path, the mechanical stopper being capable of preventing over-rotation of the joint segment.

10 The one or more receiving portions may comprise an upper segment, the upper segment may comprise at least one angular curve ring track and an upper segment lock system, the lock system being configured to lock the upper segment in position along the at least one angular curve ring track.

15 The one or more receiving portions may comprise at least one inflatable pad coupled to a heat pad.

The limb brace device may further comprise a releasable securing member for releasably securing the limb brace device to a surface.

20 The releasable securing member may comprise at least one vacuum leg.

The limb brace device may further comprise an interface module for coupling to a control module, the interface module being capable of receiving instructions from the control module.

25 The interface module may be capable of receiving instructions based on human-interface sensors and the one or more driving motors are controllable based on human-interface sensors signals from the human-interface sensors.

30 The limb brace device may further comprise an emergency switch coupled to the one or more driving motors, the emergency switch being capable of stopping operations of the one or more driving motors.

In accordance with another aspect of the present disclosure, there is provided a limb brace system, the system comprising a limb brace device as described with the first aspect

above and/or as described above; a control module coupled to the limb brace device; and a display coupled to the control module.

5 The control module may be capable of providing power to the one or more driving motors of the limb brace device.

The control module may be capable of processing human-interface sensors signals and controlling the one or more driving motors of the limb brace device based on the human-interface sensors signals.

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The limb brace system may further comprise the control module being capable of instructing a display of at least one limb movement program on the display.

15 The control module may be capable of receiving data from the limb brace device and transmitting the data to an external server.

The control module may be capable of receiving instructions from the external server and controlling the one or more driving motors of the limb brace device based on the received instructions.

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BRIEF DESCRIPTION OF THE DRAWINGS

25 Exemplary embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

FIG. 1A is a schematic drawing illustrating a limb brace system in an exemplary embodiment.

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FIG. 1B is a block diagram illustrating the limb brace system of FIG. 1A.

FIG. 2A is a drawing illustrating shoulder rotation in an exemplary embodiment.

FIG. 2B is a drawing illustrating elbow flexion and extension in an exemplary embodiment.

FIG. 2C is a drawing illustrating forearm pronation and supination in an exemplary
5 embodiment.

FIG. 2D is a drawing illustrating wrist flexion and extension in an exemplary embodiment.

10 FIG. 2E is a drawing illustrating finger flexion and extension in an exemplary embodiment.

FIG. 3 is a schematic drawing of a limb brace device in an exemplary embodiment.

15 FIG. 4A is a schematic drawing of a gear engagement system in an exemplary embodiment.

FIG. 4B is an enlarged view of a driven gear of the gear engagement system when
viewed from direction A.

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FIG. 5A is a schematic drawing illustrating an upper arm segment of a limb brace
device in an exemplary embodiment.

FIG. 5B is a first close-up view of the upper arm segment of FIG. 5A.

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FIG. 5C is a second close-up view of the upper arm segment of FIG. 5A.

FIG. 6 is a schematic drawing illustrating an elbow joint segment of a limb brace
device in an exemplary embodiment.

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FIG. 7A is a close-up view of an adjustable mechanical hard stopper component
of the elbow joint segment of FIG. 6.

FIG. 7B is a schematic drawing illustrating a locking plate in an exemplary embodiment.

5 FIG. 8 is a schematic drawing illustrating a forearm segment coupled to a hand-wrist segment of a limb brace device in an exemplary embodiment.

FIG. 9A is a schematic drawing illustrating a hand-wrist segment of a limb brace device in an exemplary embodiment.

10 FIG. 9B is a perspective view of the hand-wrist segment when viewed from direction C of FIG. 9A.

FIG. 9C is a front view of the hand-wrist segment when viewed from direction D of FIG. 9A.

15 FIG. 10 is a schematic drawing illustrating a pair of legs of a limb brace device in an exemplary embodiment.

FIG. 11A is a schematic drawing illustrating a removable padding of a limb brace device in an exemplary embodiment.

FIG. 11B is a schematic drawing illustrating positions of one or more hand valve air fittings on a limb brace device in an exemplary embodiment.

25 FIG. 11C is a schematic drawing illustrating a hand valve air fitting in an exemplary embodiment.

FIG. 12 is a schematic drawing illustrating an exemplary home-based rehabilitation architecture.

30 FIG. 13A is a schematic flowchart illustrating a proposed treatment protocol for a subject/patient with spastic muscles and who is able to perform voluntary movements in an exemplary embodiment.

FIG. 13B is a schematic flowchart illustrating a proposed treatment protocol for a subject/patient with flaccid muscles and who is not able to perform voluntary movements in an exemplary embodiment.

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FIG. 14 is a schematic drawing of a computer system suitable for implementing an exemplary embodiment.

FIG. 15A is a schematic drawing illustrating a second gear engagement system in association with a forearm segment and a hand-wrist segment of a limb brace device in an exemplary embodiment.

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FIG. 15B is a schematic side view drawing of the gear engagement system of FIG. 15A.

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FIG. 16A is a schematic drawing illustrating a one motor, i.e. the small/second servomotor 810. system in association with an upper arm segment and an elbow joint segment of a limb brace device in an exemplary embodiment.

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FIG. 16B is a schematic exploded view of a driving motor coupled to a driving gear of the first gear engagement system of FIG. 16A.

FIG. 16C is a schematic side view drawing of another example of an upper segment coupled to an elbow joint segment of a limb brace device in an exemplary embodiment.

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DETAILED DESCRIPTION

Exemplary embodiments described below may provide a device, system and/or technique for robotic rehabilitation that may include providing a diagnosis possibility, machine-intelligent active/passive stretching, voluntary strength training with visual feedback and/or outcome evaluation.

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FIG. 1A is a schematic drawing illustrating a limb brace system in an exemplary embodiment. In the exemplary embodiment, the limb brace system 100 comprises a limb brace device 102 that is coupled to one or more human-interface sensors such as a plurality of surface electromyography (sEMG) sensors 104, to a control module/box 106 and to a monitor 110. The limb brace device 102 may also be coupled to a portable emergency switch 108. For example, the switch 108 may function as a kill switch.

In the exemplary embodiment, the control box 106 may comprise a database and a processing module coupled to the database (both not shown). The processing module may be configured to receive and write/store information onto the database. The processing module may also be configured to retrieve information from the database for transmission.

In the exemplary embodiment, the limb brace system 100 may be engaged/used by a human subject/patient 112. The engagement may comprise, for example, placing an impaired limb e.g. an upper limb 114 onto the limb brace device 102.

In the exemplary embodiment, the limb brace device 102 may be configured to move the impaired upper limb 114 in e.g. five Degrees of Freedom (DOFs) comprising shoulder rotation from a neutral position to an external position in about 90 degrees (as shown in FIG. 2A), elbow flexion and extension through about 180 degrees (as shown in FIG. 2B), forearm pronation and supination through rotation of about 80 degrees clockwise or counter-clockwise about an axis passing into the paper (as shown in FIG. 2C), wrist flexion and extension towards or away from an elbow pit in about 80 degrees or about 70 degrees respectively (as shown in FIG. 2D) and finger flexion and extension towards or away from a palm in about 90 degrees or about 30 degrees respectively (as shown in FIG. 2E).

In the exemplary embodiment, the limb brace device 102 may be configured to operate in one or more different modes. In the exemplary embodiment, the one or more different modes may comprise a passive mode, an active stretching/exercising mode and a strengthening mode.

It will be appreciated that the possible modes of operation are not limited to these described modes and can include any other modes that encompass control of one or more motors, determination and usage of a user's input such as EMG signals or muscle torque generated by the user, disengagement of one or more or all motors etc.

In the exemplary embodiment, in the passive mode, the limb brace device 102 may be configured to move a joint of the impaired upper limb 114 with the assistance of one or more electric servomotors (not shown) of the limb brace device 102 throughout the respective individual possible Range of Motions (ROMs), for example one joint at a time or multiple joints at a time, either to perform isolated stretching of stiff muscles or to maintain flaccid muscles in an active state under a predefined/predetermined protocol with precise control comprising applying torques, movement through positions and EMG signals measurement. In the exemplary embodiment, the joints may be moved as illustrated in FIGs. 2A to 2E.

In the exemplary embodiment, in the active exercising mode, the limb brace device 102 may be configured to allow active stretching of the impaired upper limb 114 to be performed. The process of performing active stretching may comprise attaching the plurality of sEMG sensors 104 to, for example, the impaired upper limb 114 of the human subject/patient 112, detecting EMG signals from the muscles of the impaired upper limb 114 of the human subject/patient 112 via the plurality of sEMG sensors 104, and activating the limb brace device 102 to perform one or more stretching exercises based on the detected signals. The plurality of sEMG sensors 104 may be placed at anatomical locations of a limb that the subject/patient 112 desires to exercise. For example, the human subject/patient 112 imagines a joint that he/she intends to move which generates EMG signals. The generated EMG signals are detected by the plurality of sEMG sensors 104 attached on the impaired upper limb 114 of the human subject/patient 112. The detected EMG signals are then processed to actuate/power the one or more servomotors of the limb brace device 102 to assist in movement of the intended/desired joint (or cause joint rotation desired by the human subject/patient 112). For example, if EMG signals are detected from a bicep of the human subject/patient 112 and sent by the plurality of sEMG sensors 104 to the control box 106, the control box 106 (of the limb brace system 100)

coupled to the limb brace system 102 is configured to generate electrical signals (based on the detected EMG signals) and to send the electrical signals to a motor of a gear engagement system (not shown in FIG. 1A; see e.g. FIGs. 4A, 4B, 15A, 15B, 16A and 16B) of the limb brace device 102 for movement of an elbow joint. The movement of the elbow joint may be performed via the engaging of one or more gears of the driving motor to perform elbow flexion and extension (as shown in FIG. 2B).

In the exemplary embodiment, in the strengthening mode, the limb brace device 102 may be configured to allow strengthening training to be performed. For strengthening training, the human subject/patient 112 should preferably have an ability to make a voluntary effort for a joint or multi-joint movements. In the strengthening mode of the exemplary embodiment, the electric servomotors (of the limb brace device 102) are not used for strength training and one or more torque adjustable mechanisms, such as a mechanical rotary damper (not shown) with torque adjustability, may be used instead. That is, one or more torque adjustable mechanisms may be coupled to one or more receiving portions of the limb brace device 102 and during disengagement of the electric servomotors, the one or more torque adjustable mechanisms is capable of affecting the one or more receiving portions (such as through a variance of resistance) for movement with respect to the one or more limb joints.

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In the exemplary embodiment, during strengthening training, the human subject/patient 112 may undergo rehabilitation by imitating or following a pre-determined set of specially designed visual feedback exercises through self-initiated, self-directed, functional and intense movements (which, for example, may be displayed on the display 110, of the limb brace system 100, coupled to the limb brace device 102). In the exemplary embodiment, under the strengthening mode, various muscles of the impaired upper limb 114 may work simultaneously to train for activities of daily living and achieve repetitive goal-oriented movements. Furthermore, the human subject/patient 112 may immediately receive feedback on his/her performance and this may increase motivation to engage in training for a longer period of time.

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In the exemplary embodiment, feedback information for the subject/patient 112 may be obtained from the processed EMG signal strength from an exercise/stretching

session and the feedback information may be displayed as graphical information via a Graphical User Interface (GUI) on the display 110. The feedback information to the subject/patient 112 may provide better user engagement and provide motivation to the subject/patient 112. Further, it is possible to use one or more motion sensors to provide
5 a limb position in a 3D workspace. Information from the motion sensors may be processed to manoeuvre or show movement directions in a constructed game for a visual feedback exercise. Such information can provide real time visual feedback to the subject/patient 112 regarding his/her movements. Such motion sensors are also not limited to use for game playing and it is possible to additionally use the motion sensors for patient
10 movement analysis.

With the exemplary embodiment, the human subject/patient 112 may practise movements at home independently (using the limb brace system 100) without the presence of a therapist. Therefore, using the exemplary embodiment, the limb brace
15 system 100 may allow the human subject/patient 112 to exploit his/her full potential for recovery.

In cases of emergency, the human subject/patient 112 may engage/press/actuate the portable emergency switch 108 of the limb brace system 100, for example, using a
20 non-impaired limb (e.g. arm) to e.g. stop actuation of the motors of the limb brace device 102 and this may make rehabilitation safe.

Moreover, using the exemplary embodiment, additionally, a healthcare professional may monitor the human subject's/patient's 112 progress with a remote
25 monitoring system (e.g. see FIG. 12).

FIG. 1B is a block diagram illustrating the limb brace system of FIG. 1A. Like numerals are used. The patient 112 is shown coupled to the limb brace device 102. The limb brace device 102 is coupled to the control box 106 e.g. via an interface module of
30 the limb brace device 102. The control box 106 may instruct a display of an exercise program or a limb movement on the display 110.

In the exemplary embodiment, the control box 106 provides power to the limb brace device 102 to power one or more motors of the limb brace device 102. The control box 106 also comprises one or more driver modules to drive the motors of the limb brace device 102. The control box 106 may also process signals from the human-interface sensors 104 and control the limb brace device 102 based on the processed signals. For example, in an active mode, EMG signals of muscles may be processed by the control box 106 and the control box 106 may trigger the limb brace device to activate a selected gear engagement system and motor to provide the respective limb part movement (including rotation) desired by the patient.

In exemplary embodiments where EMG signals are obtained, the control box 106 may comprise coding written to analyse the signals and to prevent unusual combination movement patterns. For example, an odd movement that may trigger prevention of actuation of the motors of the limb brace device may comprise signals processed for the following movement: shoulder internal rotation with elbow flexion with forearm supination with wrist extension with finger joint flexion.

In the exemplary embodiment, driving parameters such as rotational position, rotational velocity and speed, torque, number of cycles and sequences etc. may be provided and varied by the control box 106 to the limb brace device and the one or more motors of the limb brace device 102. Such parameters may affect e.g. stretch velocity of the segments of the limb brace device 102.

Alternatively, it is possible for the parameters to be stored and retrievable from one or more electronic modules e.g. embedded with the one or more motors and/or the one or more gear engagement systems of the limb brace device. The limb brace device may comprise a controller module to retrieve the parameters through connectors as digital information for precise control of the motors and the gear engagement systems.

Further, the control box 106 is configured to receive data from the limb brace device 102. Such data may comprise torque feedback, position feedback (of the segments of the limb brace device), range of motion achieved by a patient, muscle strength based on torque and processed EMG signals etc. Such data may be useful for

evaluation purposes and diagnosis. Such data may also be used for the visual feedback on the display 110.

5 In addition, the control box 106 is configured to receive instructions from an external server. Such instructions may be prescriptions provided by, for example, a clinician. The control box 106 may then control the one or more motors of the limb brace device based on the instructions.

FIG. 3 is a schematic drawing of a limb brace device in an exemplary embodiment.
10 The limb brace device 300 is substantially similar to the limb brace device 102 described with reference to FIG. 1A.

In the exemplary embodiment, a limb brace device comprises an upper segment coupled to a joint segment. The upper segment comprises an upper receiving portion to
15 accommodate an upper part of a limb. In the exemplary embodiment, the joint segment is coupled to a lower segment which is in turn coupled to a digital segment. The lower segment comprises a lower receiving portion to accommodate a lower part of a limb. The digital segment comprises a digital receiving portion to accommodate the digits of a user (e.g. fingers or toes of a limb).

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For illustration purposes, the limb described hereafter is an upper limb or an arm of a user/subject/patient.

In the exemplary embodiment, the limb brace device 300 comprises an upper arm
25 segment as the upper segment and the upper arm segment comprises an upper arm rest 302 as the upper receiving portion. The upper arm segment is coupled to an elbow joint segment functioning as the joint segment. The limb brace device 300 further comprises a forearm segment as the lower segment and the forearm segment comprises a forearm rest 304 as the lower receiving portion. The forearm segment is coupled to a hand-wrist
30 segment functioning as the digital segment. The hand-wrist segment comprises a palm rest 306 and a fingers rest 308 as the digital receiving portion. The various components of the limb brace device 300 are described in further detail with reference to later figures.

In use, an impaired upper limb may rest onto or be supported at up to four different sections of the limb brace device 300, namely, the upper arm rest 302, the forearm rest 304, the palm rest 306 (for a hand of the impaired upper limb to rest) and/or the fingers rest 308.

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In the exemplary embodiment, analysed data (such as those shown in Table 1 as an example) are used as an input for the designs of the upper arm rest 302, the forearm rest 304, the palm rest 306 and/or the fingers rest 308 for the impaired upper limb of different subjects/patients to fit snugly and comfortably into the respective resting sections.

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Table 1. Anthropometric Data of Asian Subjects

Description	5%ile	50%ile	95%ile	SD
Stature (cm)	139.5	161.5	183.5	14.1
Weight (kg)	37.3	57.8	85.2	18.7
Shoulder-elbow length (cm)	27.1	34.2	46.8	6.4
Elbow-fingertip length (cm)	37.9	43.9	52.3	4.7
Hand length (cm)	14.3	17	23.7	3.1
Hand breadth (cm)	5.9	7.9	10.1	1.3
Forearm length	23.3	27.4	29	1.9
CG of hand from wrist crease (cm)	5.6	7.7	12	2.4
CG of forearm-hand from fulcrum (cm)	14.5	23.4	35.4	9.3
Hand weight (kg)	0.22	0.38	0.59	0.15
Forearm-hand weight (kg)	0.82	1.33	2.04	0.49
Torque for hand (Nm)	0.13	0.27	0.64	0.2
Torque for forearm-hand (Nm)	1.27	3.04	6.21	2.13

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FIG. 4A is a schematic drawing of a gear engagement system in an exemplary embodiment. FIG. 4B is an enlarged view of a driven gear of the gear engagement system

when viewed from direction A. The gear engagement system comprises a coupling to or decoupling from (i.e. engagement or disengagement to) a driving motor. The coupling to or decoupling from the driving motor may be achieved by linear translation of a gear to engage with a driver gear driven by the driving motor. The description provided for FIGs. 4A and 4B is a broad illustration of the concept. Further exemplary illustration may be obtained from e.g. FIGs. 15A, 15B, 16A and 16B.

The gear engagement system 400 may be operatively coupled to a limb brace device (e.g. limb brace device 300 described with reference to FIG. 3). In the exemplary embodiment, the gear engagement system 400 is configured to drive a specific shaft of the gear engagement system 400 when the gear engagement system 400 is activated.

In the exemplary embodiment, the gear engagement system 400 may be capable of driving five DOFs (compare FIGs. 2A to 2E) with two driving motors (e.g. servomotor 604, servomotor 810 described later) instead of using five motors to drive five DOFs.

In the exemplary embodiment, a translator member such as a miniature motor 402 is mounted onto (or coupled to) a driven shaft 404. The translator member functions to translate a driven gear 408 along the driven shaft 404.

In the exemplary embodiment, the miniature motor 402 rotates together with the driven shaft 404 when the driven shaft 404 rotates. In the exemplary embodiment, the driven shaft 404 comprises a key way (not shown) to place a key 406. The key way may be in the form of an elongate groove disposed along a length of the driven shaft 404. The key 406 may be in the form of a rod that may correspondingly mate with the key way and may be disposed on the driven shaft 404. The driven gear 408 is disposed coupled to the key 406. For example, the driven gear 408 may comprise a groove 409 to mate with the key 406.

The key 406 is configured to prevent the driven gear 408 from freely rotating about the driven shaft 404 i.e. the driven gear 408 rotates together with the driven shaft 404. In the exemplary embodiment, the miniature motor 402 is coupled to an external threaded rotation shaft 410 which may be operatively engaged with an internal threaded hole 411

of the driven gear 408. The miniature motor 402 is capable of rotating the external threaded rotation shaft 410 in a clockwise or counter-clockwise direction.

When the external threaded rotation shaft 410 is rotated clockwise (CW) (when
5 viewed from direction A) by the miniature motor 402, the driven gear 408 slides backward along the driven shaft 404 (i.e. translates away from the miniature motor 402), and when the external threaded rotation shaft 410 is rotated counterclockwise (CCW) (when viewed from direction A) by the miniature motor 402, the driven gear 408 slides forward along the driven shaft 404 (i.e. translates towards the miniature motor 402). The aforementioned
10 forward and backward linear sliding movement of the driven gear 408 is possible due to the key 406 being capable of preventing the driven gear 408 from rotating (about the driven shaft 404).

In the exemplary embodiment, the miniature motor 402 may rotate the external
15 threaded rotation shaft 410 until the driven gear 408 is operatively engaged with a driver gear 412. The engagement is schematically shown at numeral 413. The engagement may be by e.g. gear teeth locking. Thereafter, the driven gear 408, the miniature motor 402, the external threaded rotation shaft 410, the key 406 and the driven shaft 404 may rotate together when a driver shaft 414 rotates the driver gear 412. That is, the driver shaft 414
20 can impart torque and/or rotation to the driven shaft 404 via the driven gear 408. The driven gear 408 may be coupled or decoupled from the driver gear 412 by the translator member (e.g. miniature motor 402). That is, the translator member is capable of engaging or disengaging the gear engagement system to a driving motor (not shown) that is rotating the driver shaft 414. An engaged gear engagement system is capable of transmitting
25 torque to one or more receiving portions (e.g. forearm rest 302 of FIG.3) for movement (including rotation) with respect to the one or more limb joints.

In the exemplary embodiment, the miniature motor 402 may be actuated or controlled by wired or wireless connections or a combination of both types. In the
30 exemplary embodiment, wired connections may be possible because the driven shaft 404 may not need/require the capability to perform a 360-degree continuous rotation.

The inventors have recognised that when the limb brace device 300 is operatively coupled to one or more gear engagement systems 400, the limb brace device 300 may be capable of providing five DOFs (comprising movement of the shoulder, elbow, forearm, hand and fingers) with two motors. The one or more torque adjustable mechanisms is
5 capable of affecting the one or more receiving portions for movement with respect to the one or more limb joints.

In the exemplary embodiment, one or more gear engagement systems 400 may engage/be coupled to one motor to provide one or more DOFs. The exemplary
10 embodiment may provide the option to move a specific joint in different permissible directions where required. The exemplary embodiment may also provide the option to set driving parameters such as position, speed, torque, number of cycle and sequence etc. to a driving motor (e.g. servomotor 604, servomotor 810 described later).

In the exemplary embodiment, the gear engagement system 400 may therefore
15 provide coupling and/or decoupling a motor by linear movement to respective shafts to transmit torque. Linear movement may be made using the miniature motor 402. It is understood that alternative translator members/methods may be used such as a pneumatic cylinder, mechanical adjustment and any other suitable method that can
20 provide linear movement or may provide an equivalent function.

FIG. 5A is a schematic drawing illustrating an upper arm segment of a limb brace device in an exemplary embodiment. The limb brace device is similar to the limb brace device 300 described with reference to FIG. 3. Like numerals for identical parts are used
25 in this drawing. FIG. 5B is a first close-up view of the upper arm segment of FIG. 5A. FIG. 5C is a second close-up view of the upper arm segment of FIG. 5A.

In the exemplary embodiment, the upper arm segment 500 may be configured to facilitate shoulder rotation (see e.g. FIG. 2A). The upper arm segment 500 comprises the
30 upper arm rest 302 and a plurality of angular curve ring tracks e.g. 220-degree curve ring tracks e.g. 502 that are mounted onto an upper arm based curve holder 504. The plurality of 220-degree curve ring tracks e.g. 502 are guided by a plurality of v-groove bearings 506. In some exemplary embodiments, the upper arm segment 500 may comprise two

220-degree curve ring tracks that are guided by eight v-groove bearings. In the exemplary embodiment, the upper arm based curve holder 504 may comprise a catered grove 508 for a timing belt (not shown). In the exemplary embodiment, the timing belt may be assembled onto the upper arm based curve holder 504 with a timing belt clamp (not shown) from one end to another end by looping along a driven pulley 510. The timing belt tension may be adjusted by a tensioner 512 which may be allocated/provided at both the left and right side of the upper arm segment 500 (when viewed from direction B).

In the exemplary embodiment, the upper arm segment 500 further comprises a pulley shaft 514. In the exemplary embodiment, the front end of the pulley shaft 514 (when viewed from direction B) is arranged to be coupled to a gear engagement system (not shown; compare e.g. gear engagement system 400 of FIG. 4), which is capable of facilitating e.g. motor assisted stretching exercises. The back end of the pulley shaft 514 is arranged to be coupled to a torque adjustable mechanism 516, which is capable of facilitating e.g. strengthening exercises.

In the exemplary embodiment, the upper arm rest 302 may rotate around the axis along the direction B or the axis parallel and passing through the centre of the limb brace device. Such rotation may facilitate shoulder rotation (see e.g. FIG. 2A).

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In the exemplary embodiment, the upper arm segment 500 further comprises a base plate 518. A plurality of v-groove bearings holder brackets may be mounted on to (or coupled to) the base plate 518. A plurality of electro-mechanical vacuum legs e.g. 520 may also be mounted to (or be coupled to) the base plate 518. In the exemplary embodiment, two electro-mechanical vacuum legs e.g. 520 are mounted to (or coupled to) the base plate 520. The electro-mechanical vacuum legs e.g. 520 function to anchor the limb brace device to a surface e.g. a table top.

In the exemplary embodiment, the upper arm segment 500 further comprises a base box 522 coupled to the base plate 518. The base box 522 may be provided to e.g. keep/store wires. The base box 522 may also store mechanical parts of the upper arm segment 500. In other exemplary embodiments, a motor (not shown) that is associated with the electro-mechanical vacuum legs e.g. 520 may also be stored in the base box

522. In yet other exemplary embodiments, the base box 522 may be configured to store the components of the control box 106 (FIGs. 1A, 1B) such that the limb brace device becomes a stand-alone device and incorporates the function of the control box 106 (FIGs. 1A, 1B). In the exemplary embodiment, the base box 522 may be mounted to (or coupled to) the base plate 518 with one or more top covers e.g. 524 (e.g. two top covers).

In the exemplary embodiment, the upper arm segment 500 may be configured to additionally facilitate elbow stretching (see e.g. FIG. 2B). In order to perform elbow stretching in different shoulder rotation positions (at e.g. 0 degree, 45 degrees and 90 degrees; see FIG. 2A), the upper arm segment 500 may be provided with a plurality of mechanical lock systems e.g. 526. In the exemplary embodiment, the plurality of mechanical lock systems e.g. 526 may be located at e.g. left and right sides of the upper arm segment 500 (i.e. one on each side when viewed from direction B). The plurality of mechanical lock systems e.g. 526 may each be provided with a knob 528 which is arranged to be pulled upwards or away from the upper arm segment 500 to be released from a locked position. In the exemplary embodiment, releasing the knob 528 triggers a plurality of spring loaded locating pins to be ejected which may then allow the upper arm segment 500 to be adjusted (via rotation along the angular curve ring tracks e.g. 502) such that an impaired limb of a subject/patient may be in a preferred shoulder rotation position to perform elbow stretching. In the exemplary embodiment, the locating pins may then self-allocate themselves into locating holes e.g. 530 on the upper arm based curve holder 504 to maintain the adjusted position of the upper arm segment 500. In the exemplary embodiment, pulling down the knob 528 and pressing the knob 528 towards the upper arm segment 500 may lock the knob 528.

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FIG. 6 is a schematic drawing illustrating an elbow joint segment of a limb brace device in an exemplary embodiment. The limb brace device is similar to the limb brace device 300 described with reference to FIG. 3. Like numerals for identical parts are used in this drawing.

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In the exemplary embodiment, the entire elbow assembly/segment 600 may be mounted onto (or coupled to) a bracket 602 attached to an upper arm rest 302 of an upper arm segment.

In the exemplary embodiment, the elbow joint segment 600 comprises a big servomotor (not shown; exemplarily illustrated in FIG. 16A). The big/first servomotor is capable of facilitating elbow flexion and extension (see FIG. 2B) and shoulder rotation (see FIG. 2A). In the exemplary embodiment, to facilitate these, the elbow joint segment 600 further comprises a left elbow rotation bar 606 arranged to be driven (e.g. rotated/moved) by the big servomotor. The elbow joint segment 600 further comprises a right elbow rotation bar 608 that is also arranged to be driven (e.g. rotated/moved) by the big servomotor.

In the exemplary embodiment, the big servomotor, and the left and right elbow rotation bars 606, 608 may be fully enclosed with/by covers 610. Further, a gap for the left and right elbow rotation bars 606, 608 may be covered with a gap cover ring 612.

In the exemplary embodiment, the big servomotor, and the left and right elbow rotation bars 606, 608 may be operatively coupled to an adjustable mechanical hard stopper component 614.

In use, a gear engagement system (not shown; compare e.g. gear engagement system 400 of FIG. 4A) may be coupled to or be engaged with the big servomotor of the elbow joint segment 600. Elbow flexion and extension (see e.g. FIG. 2B) may be done/performed with the assistance of the big servomotor for (motor assisted) stretching exercises. If the big servomotor is disengaged, a torque adjustable mechanism may assist/facilitate strengthening training.

In the exemplary embodiment, the elbow joint segment 600 may rotate in a plane of the paper or a plane containing the axis parallel and passing through the centre of the limb brace device, schematically indicated at numeral 616. Such rotation may facilitate elbow flexion and extension (see FIG. 2B).

FIG. 7A is a close-up view of an adjustable mechanical hard stopper component of the elbow joint segment of FIG. 6.

In the below description, the adjustable mechanical hard stopper component 700 is described as being suitable for use with the right elbow rotation bar 608 of FIG. 6. However, it is understood that a substantially similar adjustable mechanical hard stopper component may be provided such that it is suitable for use with a left elbow rotation bar (e.g. left elbow rotation bar 606 of FIG. 6).

In the exemplary embodiment, the adjustable mechanical hard stopper component 700 comprises (or is integrated with) a first contact sensor 702 and an elbow flexion hard stopper 704.

In the exemplary embodiment, the elbow flexion hard stopper 704 is arranged to prevent over flexion of the elbow when a subject/patient uses a limb brace device (compare limb brace device of FIG. 3). That is, the elbow flexion hard stopper 704 is adjustable along a rotational path of the elbow joint segment (see 616 of FIG. 6) and is capable of preventing over-rotation of the joint segment.

In the exemplary embodiment, the elbow flexion hard stopper 704 is coupled/attached to a first rotatable bracket 706. Further, the elbow flexion hard stopper 704 comprises a spring-loaded system.

The position of the elbow flexion hard stopper 704 may be adjusted (e.g. for the purposes of preventing over flexion) by first pulling the elbow flexion hard stopper 704 outwards (i.e. away from the adjustable mechanical hard stopper component 700), rotating the first rotatable bracket 706 to move the elbow flexion hard stopper 704 towards e.g. a first preferred locking hole 708, then releasing the elbow flexion hard stopper 704 to allocate/position the elbow flexion hard stopper 704 into the first preferred locking hole 708. In the exemplary embodiment, the locking holes e.g. 708 are provided on the bracket 604 of FIG.6.

In the exemplary embodiment, the first contact sensor 702 together with a first printed circuit board (PCB) 710 may be mounted onto the first rotatable bracket 706. The first contact sensor 702 and the first PCB 710 may be arranged such that, in the event that a right elbow of a subject/patient is over flexed, the right elbow rotation bar 608 may

press onto (or come into contact with) the first contact sensor 702 to cause the power to the big servomotor 604 to be cut off. For example, the first contact sensor 702 may transmit a signal to a control box (compare control box 106 of FIG. 1A) indicating that there is over-flexion and the control box may transmit an instruction to switch off the big servomotor 604 or to terminate power supply to the big servomotor 604. In the event that the first contact sensor 702 is not functioning (i.e. the power to the big servomotor 604 is not cut off even if the right elbow rotation bar 608 comes into contact with the first contact sensor 702), the elbow flexion hard stopper 704 acts as a mechanical stopper to prevent over flexion by preventing further rotation of the first rotatable bracket 706. Such rotation is counterclockwise with respect to the drawing of FIG. 7A.

In the exemplary embodiment, the adjustable mechanical hard stopper component 700 further comprises an elbow extension hard stopper 712.

In the exemplary embodiment, the elbow extension hard stopper 712 is arranged to prevent over extension of the elbow when a subject/patient uses a limb brace device. That is, the elbow extension hard stopper 712 is adjustable along a rotational path of the elbow joint segment (see counter-direction of 616 of FIG. 6) and is capable of preventing over-rotation of the joint segment.

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In the exemplary embodiment, the elbow extension hard stopper 712 may be designed to be substantially similar to the elbow flexion hard stopper 704 as described. Further, a second rotatable bracket 714, a second contact sensor 716, a second PCB 718 and a second set of locking holes e.g. 720 are provided and these are substantially similar to the first rotatable bracket 706, the first contact sensor 702, the first PCB 710 and the first preferred locking hole 708 respectively. The elbow extension hard stopper 712 is for preventing over-rotation of the right elbow rotation bar 608 in the clockwise direction with respect to the drawing of FIG. 7A.

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FIG. 7B is a schematic drawing illustrating a locking plate in an exemplary embodiment. The locking plate 722 may be provided behind, or in front of, the locking holes e.g. 708, 720.

In the exemplary embodiment, the locking plate 722 comprises a first plurality of smaller-diameter locking holes 724 and a first plurality of larger-diameter locking holes 726. That is, the holes 724, 726 may be provided in the form of a trench 725 having
5 narrowing and widening intervals along the perimeter of the trench 725. The first plurality of smaller-diameter locking holes 724 and the first plurality of larger-diameter locking holes 726 may be capable of allowing an elbow flexion hard stopper (compare elbow flexion hard stopper 704 of FIG. 7A) to be fixed at a preferred position along a pre-determined path (with the plurality of smaller-diameter locking holes 724 and the first
10 plurality of larger-diameter locking holes 726) on the locking plate 722.

In the exemplary embodiment, the locking plate 722 further comprises a second plurality of smaller-diameter locking holes 728 and a second plurality of larger-diameter locking holes 730. That is, the holes 728, 730 may be provided in the form of a trench 729
15 having narrowing and widening intervals along the perimeter of the trench 729. The second plurality of smaller-diameter locking holes 728 and the second plurality of larger-diameter locking holes 730 may be capable of allowing an elbow extension hard stopper (compare elbow extension hard stopper 712 of FIG. 7A) to be fixed at a preferred position along a pre-determined path (with the second plurality of smaller-diameter locking holes
20 728 and the second plurality of larger-diameter locking holes 730) on the locking plate 722.

When in use, if a hard stopper (e.g. a elbow flexion hard stopper, an elbow extension hard stopper) comprises a two-step diameter shaft i.e. having a smaller
25 diameter at an end of the shaft followed by a larger diameter further from the end of the shaft, when the hard stopper is pulled outwards and away from an adjustable mechanical hard stopper component (compare adjustable mechanical hard stopper component 700 of FIG. 7A), an end of the hard stopper with a smaller diameter may be in contact with the front side/surface of the locking plate 722 and allows the elbow flexion hard stopper to be
30 movable to a preferred position along a pre-determined path available to the hard stopper e.g. along the trench e.g. 725, 729. The hard stopper may be fixed in the preferred position by allowing the end of the hard stopper with a larger diameter to be fitted/fixed into one of the accessible plurality of larger-diameter locking holes (the first plurality of larger-

diameter locking holes 726 or the second plurality of larger-diameter locking holes 730) that is nearest to or at the preferred position. That is, the hard stopper is moved inwards or towards the adjustable mechanical hard stopper component. The hard stopper is stopped from moving into adjacent smaller-diameter holes e.g. 724, 728 due to the larger
5 diameter of the shaft being contacted by the boundaries of the smaller-diameter holes e.g. 724, 728.

FIG. 16A is a schematic drawing illustrating a first gear engagement system in association with an upper arm segment and an elbow joint segment of a limb brace device
10 in an exemplary embodiment. The limb brace device is similar to the limb brace device described with reference to FIG. 3. The upper arm segment is similar to the upper arm segment 500 described with reference to FIGs. 5A to 5C and the elbow joint segment is similar to the elbow joint segment 600 with reference to FIGs. 6, 7A and 7B. Like numerals for identical parts are used in this drawing.

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FIG. 16B is a schematic exploded view of a driving motor coupled to a driving gear of the first gear engagement system of FIG. 16A.

FIG. 16C is a schematic side view drawing of another example of an upper
20 segment coupled to an elbow joint segment of a limb brace device in an exemplary embodiment.

The numerals 500 and 600 show schematically the locations of the upper arm segment and the elbow joint segment where they would be.

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The gear engagement system may provide torque to drive shoulder rotation from neutral to external (see FIG. 2A), and elbow flexion and extension (see FIG. 2B), with one first driving motor, i.e. the big/first servomotor 1602. The big/first servomotor 1602 may rotate a driver shaft 1603. There are provided two translator members 1604, 1606. The
30 translator member 1604 is provided to assist in shoulder rotation for the upper arm segment 500, and the translator member 1606 is provided to assist in elbow flexion and extension for the elbow joint segment 600. In the exemplary embodiment, the two translator members 1604, 1606 are in the form of miniature motors.

There is provided a driven gear 1612 mounted onto/coupled to a driver hollow shaft 1614 such that a rotation of the driven gear 1612 may rotate the driver hollow shaft 1614. The driver hollow shaft 1614 comprises a hollow through hole, through which the driver shaft 1603 is disposed within. The hollow through hole of the driver hollow shaft 1614 has a larger diameter than the external diameter of the driver shaft 1603 and therefore, the driver hollow shaft 1614 is not in contact with the driver shaft 1603.

In the exemplary embodiment, a timing belt with a pulley 1616 is mounted onto the driver hollow shaft 1614 such that a rotation of the driven gear 1612 effects movement of the timing belt with a pulley 1616. The timing belt with a pulley 1616 is coupled to a pulley shaft 514. The pulley shaft 514 is in turn coupled to the driven pulley 510 that may rotate the upper arm based curve holder 504.

When the miniature motor 1604 is activated, a driven gear 1608 is translated linearly towards a driver gear 1610 to engage the driven gear 1608 with the driver gear 1610. The shaft for the miniature motor 1604 is shown schematically at numeral 1605. The miniature motor 1604 is mounted the shaft 1605 and the shaft 1605 is in turn mounted on a bracket 1607. The engagement of the driven gear 1608 with the driver gear 1610 may create the shoulder rotation from neutral to external motion for stretching exercise. That is, the translation of the driven gear 1608 also engages the driven gear 1608 with the driven gear 1612. The engagement of driven gear 1608 with the driver gear 1610 imparts a torque from the big/first servomotor 1602 to the driven gear 1612. The rotation of the driven gear 1612 rotates the driver hollow shaft 1614. Rotational torque is thus transmitted to the pulley shaft 514 that in turns provides rotation for the upper arm segment for the shoulder rotation motion.

In the exemplary embodiment, for the elbow flexion and extension motion, there is provided a driven gear 1618 disposed on one end of the driver shaft 1603. The driven gear 1618 is coupled to another driven gear 1620 mounted on a driven shaft 1622. At an opposite end of the driven shaft 1622 with respect to the driven gear 1620, another driven gear 1624 is disposed. It is appreciated that when the driver shaft 1603 is rotating due to

the big/first servomotor 1602, the driven gear 1624 is also rotating. Thus, the gear 1624 functions as a second driver gear 1624.

At the translator member 1606, there is provided a driven gear 1626 mounted on
 5 a driven shaft 1628 (compare e.g. gear 408 and shaft 404 of FIG. 4A). At an opposite end of the driven shaft 1628 with respect to the driven gear 1626, another driven gear 1630 is disposed. The driven gear 1630 is coupled to another driven gear 1632 that is in turn mounted on a drive shaft 1634. At the ends of the drive shaft, two driven pulleys 1636, 1638 are disposed. Timing belts 1640, 1642 are respectively coupled to the driven pulleys
 10 1636, 1638. The timing belts 1640, 1642 are also coupled to driven pulleys 1644, 1646 respectively such that rotation of the drive shaft 1634 may impart movement of the timing belts 1640, 1642 that in turn impart rotation of the driven pulleys 1644, 1646. The driven pulleys 1644, 1646 are coupled to the left and right elbow rotation bars 606, 608 of FIG. 6 respectively.

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In the exemplary embodiment, to create the elbow flexion and extension motion, the miniature motor 1606 is activated to translate the driven gear 1626 towards the second driver gear 1624. The driven gear 1626 may engage the second driver gear 1624. Thus, the servomotor 1602 may impart torque via rotation of the second driver gear 1624 which
 20 is in turn imparted to the driven gear 1626. The driven gear 1626 may transmit the torque to the driven gear 1630 through the driven shaft 1628. The driven gear 1630 in turn drives the driven gear 1632 to rotate the drive shaft 1634 together with the driven pulleys 1636, 1638. The rotational torque is then transmitted through the timing belts 1640, 1642 to the driven pulleys 1644, 1646 to in turn rotate the left and right elbow rotation bars 606, 608
 25 of FIG. 6 for the intended motion for the elbow flexion and extension motion.

It will be appreciated that to create the forward and backward movement for the driven gears 1608 and 1626 i.e. towards or away from the driver gear 1610 and the second driver gear 1624, the mechanism is not limited to using miniature motors. The
 30 translator members 1604, 1606 may be in the form of any suitable mechanism that can create the linear motion for the driven gears 1608 and 1626.

In the exemplary embodiment, the miniature motors 1604, 1606 may be activated by a patient's EMG signal of the upper limb through s-EMG sensors (compare sensors 104).

5 In addition, it is appreciated that the layout of the gear engagement system is not limited to the specific illustration of FIGs. 16A and 16B. The layout is shown exemplarily to illustrate achievable shoulder and elbow rotation. The layout may be modified depending on applications.

10 In the exemplary embodiment, the driven gears 1608 and 1626 may be disengaged from the driver gear 1610 and the second driver gear 1624 using the translator members 1604, 1606. The disengagement allows for strengthening training where the patient may make self-initiated movement without assistance from the big/first servomotor 1602.

15 There are provided one or more torque adjustable mechanisms, e.g. rotary dampers. These are shown at numerals 516 and 1648. The torque adjustable mechanisms 516 is applicable to the upper arm segment 500 and the torque adjustable mechanisms 1648 is applicable to the elbow joint segment 600. Each torque adjustable
20 mechanism may be used to adjust resistance to rotation of each respective segment of the limb brace device. With reference to FIGs. 16A and 16B, knobs 1650, 1652 are provided to control the rotational torque to increase or decrease. For example, a user may adjust the rotational torque by turning CW and CCW for the knobs 1650, 1652. For example, the knob 1650 allows control or adjustment of the rotational torque for the upper
25 arm segment 500 and the knob 1652 allows control or adjustment of the rotational torque for the elbow joint segment 600. Each torque adjustable mechanism may allow control of the torque for the shoulder rotation from neutral to external (of the upper arm segment 500), and for the elbow flexion and extension (of the elbow joint segment 600) for the patient to undergo strengthening exercise.

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It will be appreciated that the illustrated system is not limited to performing active stretching and strengthening exercises, the system may also be used for a flaccid impaired limb to perform a passive range of motion exercise, or under the passive mode.

FIG. 8 is a schematic drawing illustrating a forearm segment coupled to a hand-wrist segment of a limb brace device in an exemplary embodiment. The limb brace device is similar to the limb brace device described with reference to FIG. 3. Like numerals for
 5 identical parts are used in this drawing.

In the exemplary embodiment, the design concept for the forearm segment may be similar to the design concept for the upper arm segment of the limb brace device 300 (also compare upper arm segment 500 of FIG. 5). As described in FIG. 5, the upper arm
 10 segment 500 may be configured to facilitate shoulder rotation (see FIG. 2A).

In the exemplary embodiment, the forearm segment comprises the forearm rest 304, and a plurality of angular curve ring tracks e.g. 220-degree curve ring tracks e.g. 802 coupled to a forearm based curve holder 804 and a plurality of v-groove bearings 806.
 15 The forearm segment 800 also comprises a gear engagement system (not shown; compare e.g. gear engagement system 400 of FIG. 4A for a broad concept of the gear engagement system) and a torque adjustable mechanism 808. The forearm segment 800 further comprises a small/second servomotor 810 that may be coupled to the gear engagement system, which may allow the forearm segment 800 to be capable of
 20 facilitating forearm pronation and supination (see FIG. 2C), wrist flexion and extension (see FIG. 2D), and finger flexion and extension (see FIG. 2E).

A more specific example of a possible gear engagement system that may be used for the forearm segment is described with reference to FIGs. 15A and 15B below.
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In the exemplary embodiment, for forearm pronation and supination (see FIG. 2C), the forearm rest 304 may rotate around the axis along the direction E or the axis parallel and passing through the centre of the limb brace device.

In the exemplary embodiment, the forearm rest 304 may be attached to elbow rotation bars (compare left and right elbow rotation bars 606, 608 of FIG. 6) with a pivot pin inserted into each of a plurality of allocated pivot pin holes e.g. 812.
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In the exemplary embodiment, the forearm segment 800 may further comprise a wire box 814. Wires may be carried by a carrier rack in the wire box 814. This may prevent exposing tangling wires.

5 In the exemplary embodiment, the forearm segment 800 is coupled to a hand-wrist segment 900 (see FIGs. 9A-9C) via a bracket 816 of the forearm segment 800, which is in turn mounted onto a linear motion (LM) slider. In the exemplary embodiment, the LM slider may allow sliding of the bracket 816 forwards and backwards along the LM slider, i.e. along the axis along the direction E or the axis parallel and passing through the centre
10 of the limb brace device. Therefore, the exemplary embodiment may allow the distance between the forearm segment 800 and hand-wrist segment 900 to be extended or reduced to accommodate to different forearm lengths of different subjects/patients. In the exemplary embodiment, this mechanism may not be viewed externally i.e. the bracket 818 and the LM slider may be enclosed by a cover 818.

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In the exemplary embodiment, the gear engagement system may be engaged/coupled to the small servomotor 810. In use, forearm pronation and supination (see FIG. 2C) may be facilitated with the assistance of the small servomotor 810 for stretching exercises. If the small servomotor 810 is disengaged, the torque adjustable
20 mechanism 808 may assist/facilitate strengthening training.

FIG. 9A is a schematic drawing illustrating a hand-wrist segment of a limb brace device in an exemplary embodiment. The limb brace device is similar to the limb brace device described with reference to FIG. 3. Like numerals for identical parts are used in
25 this drawing. FIG. 9B is a back view of the hand-wrist segment when viewed from direction C of FIG. 9A. FIG. 9C is a front view of the hand-wrist segment when viewed from direction D of FIG. 9A.

In the exemplary embodiment, the hand-wrist segment 900 may be designed for
30 (or may be configured to) facilitate dual action wrist and finger joint rotation (see FIGs. 2D and 2E respectively).

In the exemplary embodiment, the hand-wrist segment 900 comprises a centre pivot pin 902 coupled to the palm rest 306 which allows the palm rest 306 to be rotated about an axis F perpendicular to the axis along the direction E. The hand-wrist segment 900 further comprises a first plunger 904 and a locking hole 906, i.e. a positioning hole.

5 In the exemplary embodiment, interchanging between left hand and right hand usage is possible. To effect the interchanging, the first plunger 904 is pulled upwards to unlock and allow rotation of the palm rest 306 for usage by the other hand. The first plunger 904 is then released when the first plunger 904 is in the vicinity of the locking hole 906 to lock the first plunger 904 into the locking hole 906 and thereby lock the palm rest 306 in the
10 interchanged position.

In the exemplary embodiment, the hand-wrist segment 900 further comprises one or more contact sensors e.g. 908. In the exemplary embodiment, the tip of the plunger 904 may press onto one of the contact sensors e.g. 908 and a signal may be transmitted
15 by the contact sensor e.g. 908 to a processing module of a controller box (compare control box 106 of FIG. 1A). In the exemplary embodiment, the processing module of the controller box may be configured to store/overwrite the received information (as data) onto a database in the controller box. The received information may, for example, be which hand the device is used for (for example, the left hand). In the exemplary embodiment,
20 this may be a failsafe design concept.

In the exemplary embodiment, the hand-wrist segment 900 further comprises the fingers rest 308 that is coupled to a finger rotation bar 910. In the exemplary embodiment, the original/initial position of the fingers rest 308 may be 20 degrees away from the centre
25 axis (see axis X) for both left and right hand usage. When configuring the hand-wrist segment 900 to be ready for use by the opposite hand (i.e. interchanging between left and right hand usage), the finger rotation bar 910 may first be placed 20 degrees away from the centre axis accordingly. Thereafter, the fingers rest 308 may be rotated through/about a pivot pin 912 after unlocking by pulling a second plunger 914 upwards.
30 The second plunger 914 may be locked into a locking hole 916, i.e. a positioning hole, by releasing it to in turn lock the fingers rest 308 in the interchanged position.

In use, a subject/patient may utilise the hand-wrist segment 900 for dual action hand-wrist exercises. For dual action hand-wrist exercises, a gear engagement system (not shown; compare e.g. gear engagement system 400 of FIG. 4A) may engage a driver gear 918. Reference may also be made to the description of FIGs. 15A and 15B. A driven gear 920 may be secured to a rotary shaft 922 which may be the pivot point for wrist flexion and extension (see FIG. 2D). A hand base plate 924 may be fixed/coupled to the rotary shaft 922.

In the exemplary embodiment, the hand-wrist segment 900 is in a “ready status” for right hand usage. The rotary shaft 922 is able to rotate about the axis F based on a torque transmitted via the driver gear 918. When the rotary shaft 922 rotates counter-clock wise (CCW), the hand base plate 924 may follow the rotary shaft 922 to be rotated in the CCW direction. In the exemplary embodiment, when the hand base plate 924 is rotated, the contact sensor 908, the palm rest 306, the fingers rest 308, the driven gear 926, a plurality of shaft holder brackets 928, 930, a plurality of gears 932, 934, an L bracket 936, a rotary shaft 938, and a linear motion (LM) slider 940 which are mounted /operatively coupled to the base plate 924 may move along together with the hand base plate 924. The rotation of the palm rest 308 may facilitate wrist flexion and extension (see FIG. 2D).

In the exemplary embodiment, a fixed gear 942 may be fixed to a bracket 944 and may not be freely rotatable. The fixed gear 942 rotates together with the rotary shaft 922. The fixed gear 942 is coupled to the driven gear 926. The driven gear 926 may rotate in a CCW direction along with (or based on) the rotation of the fixed gear 942 when the rotary shaft 922 is rotating in a CCW direction. The CCW rotation of the driven gear 926 is transmitted through the shaft 938 (via a coupling of the driven gear 926 to the shaft 938) to rotate the gear 932 in a similar CCW direction. In the exemplary embodiment, the gear 932 may engage with the gear 934 by the L bracket 936 being coupled to both the gears 932, 934. Via the engagement, the gear 934 may rotate in a CCW direction when the gear 932 is rotating in a CCW direction.

In the exemplary embodiment, the hand-wrist segment 900 further comprises a pivot shaft 946 that is fixed/coupled to the gear 934. The pivot shaft 946 may rotate with

the gear 934 e.g. in a CCW direction and this may facilitate finger flexion and extension exercises (see FIG. 2E) when the gear 934 is rotating in a CCW direction.

In the exemplary embodiment, wrist flexion and extension (see FIG. 2D) and finger flexion and extension (see FIG. 2E) may take place simultaneously when the rotary shaft 922 rotates. During use, if the fingers of subjects/patients are in a bent condition, strapping the fingers with, but not limited to, Velcro straps, may help to straighten the fingers. The dual hand action may correlate to activities of daily living (ADL) such as grasping and opening of grips.

In the exemplary embodiment, the bracket 936 on which the gear 934 is mounted is in turn mounted to the LM slider 940. The gear 932 is assembled to the shaft 938 with a key (not shown; compare key 406 of FIG. 4A). In the exemplary embodiment, the LM slider 940 may move forwards and backwards along the axis along the direction E or the axis parallel and passing through the centre of the limb brace device. A knob 948 may be loosened to allow the LM slider 940 to move and the knob 948 may be tightened to lock the LM slider 940 in position. When the LM slider 940 moves, the gears 932, 934, the bracket 936, the pivot shaft 946, the finger rotation bar 910, the pivot pin 912, the second plunger 914, the locking hole 916, the knob 948, and the fingers rest 308 may move together. Thus, movement of the LM slider 940 may allow the hand-wrist segment 900 to be adjusted to accommodate various hand lengths of subjects/patients.

In the exemplary embodiment, the mechanism of the hand-wrist segment 900 may not be viewed externally i.e. components of the hand-wrist segment 900 shown beneath the hand base plate 924 in FIG. 9C may be enclosed by a cover 950.

FIG. 15A is a schematic drawing illustrating a second gear engagement system in association with a forearm segment and a hand-wrist segment of a limb brace device in an exemplary embodiment. FIG. 15B is a schematic side view drawing of the second gear engagement system of FIG. 15A. The limb brace device is similar to the limb brace device described with reference to FIG. 3. The forearm segment is similar to the forearm segment 800 described with reference to FIG. 8 and the hand-wrist segment is similar to the hand-

wrist segment 900 with reference to FIGs. 9A to 9C. Like numerals for identical parts are used in this drawing.

The second gear engagement system may provide torque to drive forearm
5 pronation and supination (see FIG. 2C), wrist flexion and extension (see FIG. 2D), and
fingers flexion and extension (see FIG. 2E) with one second driving motor, i.e. the
small/second servomotor 810. There are provided two translator members 1502, 1504.
The translator member 1502 is provided to assist in forearm pronation and supination for
the forearm segment 800, and translator member 1504 is provided to assist in wrist flexion
10 and extension and fingers flexion and extension for the hand-wrist segment 900. In the
exemplary embodiment, the two translator members 1502, 1504 are in the form of
miniature motors.

When the miniature motor 1502 is activated, a driven gear 1506 is translated
15 linearly towards a driver gear 1508 to engage the driven gear 1506 with the driver gear
1506. The engagement may create the forearm pronation and supination motion for
stretching exercise. That is, the servomotor 810 may impart torque via rotation of the
driver gear 1508 which is in turn imparted to the driven gear 1506 to rotate the shaft 1510.
The rotation of the shaft 1510 provides the rotation for the forearm segment 800 for the
20 forearm pronation and supination motion.

In the exemplary embodiment, to create the wrist flexion and extension motion,
and the fingers flexion and extension motion for stretching exercise, the miniature motor
1504 is activated to translate a driven gear 1512 towards the driver gear 1508. The driven
25 gear 1512 may engage the driver gear 1508. The servomotor 810 may impart torque via
rotation of the driver gear 1508 which is in turn imparted to the driven gear 1512. The
driven gear 1512 may transmit the torque to the driver gear 918 for the wrist flexion and
extension motion, and the fingers flexion and extension motion. The description has been
provided with reference to FIG. 9C.

30

It will be appreciated that to create the forward and backward movement for the
driven gears 1506 and 1512 i.e. towards or away from the driver gear 1508, the
mechanism is not limited to using miniature motors. The translator members 1502, 1504

may be in the form of any suitable mechanism that can create the linear motion for the driven gears 1506 and 1512.

5 In addition, it is appreciated that the layout of the second gear engagement system is not limited to the specific illustration of FIGs. 15A and 15B. For example, the miniature motors 1502, 1504 may be activated by a patient's EMG signal of the upper limb through s-EMG sensors (compare sensors 104).

10 In the exemplary embodiment, when the driven gears 1506 and 1512 are engaged to the driver gear 1508 at the same time, a combination of forearm, wrist and fingers stretching may be provided at the same time, based on the rotation and torque provided by the small/second servomotor 810. Such a combination of stretching is mimicked to a typical therapy under therapeutics practice.

15 In the exemplary embodiment, the driven gears 1506 and 1512 may be disengaged from the driver gear 1508 using the translator members 1502, 1504. The disengagement allows for strengthening training where the patient may make self-initiated movement without assistance from the small/second servomotor 810.

20 There are provided one or more torque adjustable mechanisms, e.g. rotary dampers. Each/the torque adjustable mechanism may be used to adjust resistance to rotation of each segment of the limb brace device. With reference to FIGs. 15A and 15B, knobs 1514, 1516 are provided to control the rotational torque to increase or decrease. For example, a user may adjust the rotational torque by turning CW and CCW for the
25 knobs 1514, 1516. For example, the knob 1514 allows control or adjustment of the rotational torque for the forearm segment 800 and the knob 1516 allows control or adjustment of the rotational torque for the hand-wrist segment 900. Each/the torque adjustable mechanism may allow control of the torque for the forearm pronation and supination (of the forearm segment 800), for the wrist flexion and extension, and fingers
30 flexion and extension (both of the hand-wrist segment 900) for the patient to undergo strengthening exercise.

It will be appreciated that the illustrated system is not limited to performing active stretching and strengthening exercises, the system may also be used for a flaccid impaired limb to perform a passive range of motion exercise, or under the passive mode.

5 FIG. 10 is a schematic drawing illustrating a pair of legs of a limb brace device in an exemplary embodiment. The limb brace device is similar to the limb brace device described with reference to FIG. 3. Like numerals for identical parts are used in this drawing.

10 In the exemplary embodiment, the pair of legs 1000 may be a pair of electro-mechanical vacuum legs to provide vacuum suction. The pair of legs 1000 may be provided to secure the limb brace device on a surface on which the device is placed (for example, a table top). Thus, the pair of legs 1000 function as a releasable securing member for releasably securing the limb brace device to a surface.

15 In the exemplary embodiment, the pair of legs 1000 has each leg comprising a handle e.g. 1002 and a rubber pad e.g. 1004. The handle e.g. 1002 may be in an upright position to allow air to flow between the rubber pad e.g. 1004 and the surface. When the handle e.g. 1002 is pushed downwards e.g. in the direction G (or its opposite direction),
20 the rubber pad e.g. 1004 may create a vacuum with the surface 1006 to secure the limb brace device to the surface and prevent the device from moving.

 In the exemplary embodiment, the handle e.g. 1002 is linked with / coupled to a lead screw e.g. 1006 which is in turn coupled to a motor (not shown). For example, the
25 motor (not shown) may be stored in a base box (compare base box 522 of FIG. 5A). The lead screw e.g. 1006 may be in the form of an elongated cylindrical shaft that is capable of performing forward/backward movement e.g. in the direction G (or its opposite direction) with a pneumatic cylinder. When the motor is activated, the lead screw e.g. 1006 is capable of pushing down the handle e.g. 1002 e.g. in the direction G. The
30 exemplary embodiment may allow the limb brace device to be firmly secured on the surface 1006 on which the device is placed (e.g. a table) without requiring any clamping mechanisms.

In other exemplary embodiments, the lead screw e.g. 1006 may be coupled to one of the driving motors of the limb brace device. For example, the lead screw e.g. 1006 may be coupled to the big/first servomotor of the upper arm segment and/or the elbow joint segment. The driving motor may be configured to drive the lead screw e.g. 1006 via
5 addition of one or more gears or one or more gear engagement systems.

FIG. 11A is a schematic drawing illustrating a removable padding of a limb brace device in an exemplary embodiment. The limb brace device is similar to the limb brace device described with reference to FIG. 3. Like numerals for identical parts are used in
10 this drawing.

In the exemplary embodiment, the removable padding 1100 comprises three layers, namely, a heating pad 1102, a cushion 1104 and an air inflatable pad 1106. In the exemplary embodiment, the three layers are attached to one another with, for example
15 but is not limited to, Velcro strips/straps or the like mating material. Each layer 1102, 1104, 1106 is removable based on requirements.

In use, the removable padding 1100 is to be placed on the upper arm rest 302 and/or the forearm rest 304 of the limb brace device. An impaired upper limb (compare
20 impaired upper limb 114 of FIG. 1A) may be placed on the removable padding 1100 and secured with one or more Velcro straps, for example, one at the upper arm and another at the forearm respectively (i.e. a total of two Velcro straps). Any alternative mating or securing devices may also be used.

In the exemplary embodiment, the heating pad 1102 is capable of providing heat
25 to the impaired limb. Providing heat may increase the flexibility of stiff muscles, promote better stretch ability and/or reduce pain. In the exemplary embodiment, the temperature of the heating pad 1102 may be adjusted based on, for example, the requirements set by a healthcare professional. The heating pad 1102 may comprise heating elements
30 internally which are controllable by a control box (compare control box 106 of FIG. 1A).

In the exemplary embodiment, the cushion 1104 is capable of providing comfort to a subject/patient using the limb brace device (compare human subject/patient 112 of FIG. 1A).

5 In the exemplary embodiment, the air inflatable pad 1106 may be capable of allowing air to be pumped into the pad 1106. In the exemplary embodiment, the air inflatable pad 1106 may thus allow for the limb brace device to accommodate various arm sizes of different subjects/patients. The air inflatable pad 1106 may comprise air intake conduits internally which are usable for inflation or deflation controllable by e.g. a control
10 box (compare control box 106 of FIG. 1A) or by an air pump.

FIG. 11B is a schematic drawing illustrating positions of one or more hand valve air fittings on a limb brace device in an exemplary embodiment.

15 In the exemplary embodiment, three hand valve air fittings may be provided on the limb brace device, namely, a forearm hand valve air fitting 1108 for underneath of the forearm, an upperarm hand valve air fitting 1110 for underneath of an upper arm and a side-elbow fulcrum hand valve air fitting 1112 for the left and right sides of an elbow fulcrum.

20

FIG. 11C is a schematic drawing illustrating a hand valve air fitting in an exemplary embodiment.

In the exemplary embodiment, each hand valve air fitting (e.g. hand valve air fitting
25 1108, 1110, 1112) comprises an air inlet 1114, a valve 1116 and an air outlet 1118. The air outlet 1118 is connected to e.g. an air conduit of the air inflatable pad 1106. In the exemplary embodiment, air may be pumped into the air inflatable pad 1106 from/via the air inlet 1114 while the valve 1116 is open. The pumping of the air may be by any number of different ways such as by usage of a manual air pump or by automatic usage
30 of a pneumatic air pump etc. When a desired amount of air is filled in the air inflatable pad 1106 through/via the air outlet 1118, the valve 1116 may be closed to prevent air from leaking.

The exemplary embodiment may allow the impaired upper limb to be snugly fitted without needing any complicated adjustment mechanisms for performing rehabilitation.

FIG. 12 is a schematic drawing illustrating an exemplary home-based rehabilitation architecture.

In the example, the home-based rehabilitation architecture 1200 comprises a limb brace system. The limb brace system is similar to the limb brace system 100 described with reference to FIG. 1A. Like numerals for identical parts are used in this drawing.

The limb brace system 100 may be located at a home 1202 or at a hospital 1204. The human subject/patient 112 using the limb brace system 100 may transmit statistics/data (e.g. game playing scores) using wireless connections (or by wired connections) from the limb brace device 102 (e.g. using the control box 106) via a suitable transceiver device 1206 to enable access to e.g. the Internet or other network systems such as Local Area Network (LAN) or Wide Area Network (WAN) or a personal network etc. The network can comprise e.g. a server, a router, a network personal computer, a peer device or other common network node. In the example, the transmitted statistics/data (e.g. data on the human subject's/patient's 112 activities) is transmitted to the web server 1208 for reviewing the subject's/patient's progress over time.

The home-based rehabilitation architecture 1200 further comprises a database 1210 (e.g. MySQL Database). The database 1210 may be configured to store, for example, patient identity credentials, real time data and data on a subject's/patient's 112 day-to-day performance. The database 1210 may also be configured to store the statistics/data received from the limb brace system 100 via the Web Server 1208.

The home-based rehabilitation architecture 1200 further comprises data visualisation on a website 1212 (that can be viewed via one or more computer units 1214A-C) that is running on the web server 1208. The website 1212 may display real-time data in time-series graphs, and reports summaries on the level of exercise intensity, range of motion, repetition and functional reach etc. of a subject/patient 112.

One or more healthcare professionals 1216A-B may monitor and assess a subject's/patient's 112 progress and provide prescription (e.g. stretching parameters to the control box 106) via the website 1212. If there is no activity data received from the human subject/patient 112 that is in accordance with a prescription, email notification
 5 alerts may be sent to respective healthcare professionals 1216A-B automatically to alert the healthcare professionals 1216A-B.

In the example, authentication of a user via e.g. login mechanisms may be implemented for identity management and security purposes.
 10

In another example, a home-based rehabilitation architecture may have the following characteristics.

The types and range of motion permitted by the limb brace device 100 are, for
 15 example, elbow flexion (up to 120°) / extension (up to 0°), wrist flexion / extension (up to 60° each), forearm pronation / supination (up to 90° each) and shoulder rotation (up to 90° each). Customised settings are possible for the permissible range of motion. The standard velocity for each motion is 10°/s but customised settings are also be possible. The manual rotation torque range is also customisable. The dimension (length x width x
 20 height) of the limb brace device 100 is, for example, 54 cm x 26.2 cm x 30 cm, and the limb brace device 100 may weigh 10 kg.

The control box 106 may comprise an Intel® Core™ i7 processor, and the display 110 is a 13.9" touch screen monitor. The system rating is 115/230 VAC, the frequency is
 25 50-60 Hz and the DC output is 24V/ 14.6A. The control box 106 has two USB ports.

In the example, the software used in the home-based rehabilitation architecture may have the following aspects.

30 Visual studio 2012, NI- Measurement Studio and EPOS Studio are three different types of software that may be used to create a user interface (UI). The user interface is built on Visual C#(C-Sharp) and has integrated both EPOS and Measurement Studio.

That is, Visual C#, Windows Form is used to develop the user interface which is interfaced with NI-Measurement Studio and it can be integrated with EPOS Studio using C#.

Epos Studio is a software provided by Maxon Motor. EPOS Studio may be used
5 to learn the function of a Maxon Motor.

Measurement Studio is an end-to-end system design solution with customisable Windows Presentation Foundation (WPF), Windows, and Web Forms user interface (UI) controls such as graphs, charts, and gauges; advanced data analysis functions; and
10 code-generating tools for hardware communication. It is used in this example to display e.g. the EMG signal graphs in Windows Form.

In the example, coding may be written in C# language.

15 In the example, PHP server side language may be used to communicate with MySQL and is suited for web development as it may be embedded into a HTML code (e.g. for static web page content).

In the example, an Ubuntu operating system may be used as a software platform
20 to run ranging from a computer to the server.

Keeping costs down is beneficial. In the example, Ubuntu, MySQL, PHP and HTML are open source software platforms and may be chosen for development in this regard. In the example, only a small cost may be incurred for obtaining a public IP address
25 and a virtual server hosting once the web interface is ready.

FIG. 13A is a schematic flowchart illustrating a proposed treatment protocol for a subject/patient with spastic muscles and who is able to perform voluntary movements
1300 in an exemplary embodiment. At step 1302, a subject/patient with spastic muscles
30 and who is able to perform voluntary movements is identified. At step 1304, the condition of the subject/patient is diagnosed. At step 1306, active or passive isolated stretching treatment is performed. At step 1308, the subject/patient is assessed on whether the subject/patient has the ability to make their own multi-joint movements. If the

subject/patient is assessed to not have the ability to make their own multi-joint movements, the protocol proceeds to step 1310 where outcome assessment is performed. If the subject/patient is assessed to have the ability to make their own multi-joint movements, the protocol proceeds to step 1312 where multi-joint movement strengthening treatment with visual feedback is performed. At step 1314, outcome assessment is performed.

FIG. 13B is a schematic flowchart illustrating a proposed treatment protocol for a subject/patient with flaccid muscles and who is not able to perform voluntary movements 1316 in an exemplary embodiment. At step 1318, a subject/patient with flaccid muscles and who is not able to perform voluntary movements is identified. At step 1320, the condition of the subject/patient is diagnosed. At step 1322, passive isolated movement treatment is performed. Movement may include rotation with respect to a joint. For example, for a flaccid impaired limb, the movement treatment may comprise repetitive movement in the passive mode through a pre-determined range of motion. At step 1324, outcome assessment is performed.

In one exemplary embodiment, there may be provided a device for performance of a therapy, diagnosis and/or rehabilitation of muscles of a user, comprising of: fittings adapted for supporting an/the upper limb such that the upper limb is rotatable with respect to one or more joints; one or more motors; one or more gear engagement systems; one or more torque adjustable mechanisms; wherein the device is adapted for stretching of the limb via the movement and rotation of one or more joints of a limb through the use of one or more motors to provide torque to one or more of the said gear engagement systems to allow for at least five degrees of freedom for the range of motion, and adapted for strengthening training by disengaging the motors from the gear engagement systems, and coupling to the one or more torque adjustable mechanisms.

In some exemplary embodiments, the mechanisms for providing torque/resistance may be tensioned by one or more torque adjustable mechanisms. For example, for an exemplary embodiment using a rotary damper as a torque adjustable mechanism, a resistance of the rotary damper may be set at a minimum and the torque adjustable mechanism is not in use. When the motors are disengaged from the gear engagement

systems, the rotary damper may be adjusted to increase the resistance e.g. by tuning a knob to increase the torque.

5 In one exemplary embodiment, there may be provided a mechanical design for combination therapy (e.g. stretching and strengthening) arm/limb brace comprising upper arm, elbow, forearm and hand-wrist segments. There may also be provided a gear engagement system designed to operate five DOFs with two motors. There may further be provided an adjustable mechanical hard stopper integrated with a contact sensor, a mechanical design for dual action hand-wrist exercises, electro-mechanical vacuum legs,
10 and a removable padding which is capable of being heated and inflated.

With the described exemplary embodiments, there may be provided an active-assisted portable arm brace. The described exemplary embodiments may also provide an active-assisted arm brace with biofeedback for stroke patients with spasticity.

15

The described exemplary embodiments may provide a device for diagnosing, exercising and evaluating human upper limbs. In particular, the described exemplary embodiments may provide a robotic device that allows rehabilitation including comprehensive diagnosis of the upper limbs, precise stretching of the upper limb with
20 intelligent control, strengthening training of the upper limb through self-initiated and self-directed voluntary exercise with visual feedback, and for evaluating outcomes of rehabilitation. A robotic apparatus/device may be designed to diagnose, treat with both passive stretching and active strengthening functional movements with visual feedback, and evaluate multi-joint and multi-DOF biomechanical and neuromuscular changes in
25 patients with limb impairments.

The inventors have recognised that in recent times, home-based rehabilitation is a promising trend to ease challenges (e.g. being posed to the healthcare industry) and for speedier subjects'/patients' recovery. The inventors have also recognised that home-based rehabilitation may promote/enable "ageing in place" for seniors and disabled
30 individuals. To make home-based rehabilitation possible, the inventors have recognised that there are significant elements that a rehabilitation device/system may preferably be equipped with such as allowing remote monitoring and assessment, being portable, being

compact in size, being relatively light in weight, having intelligent control, being sufficiently simple to operate and being safe for use by the subject/patient themselves. It has been recognised by the inventors that many of the existing devices for stretching are using an individual electric motor for a single degree of freedom which makes them impractical for home-based rehabilitation. The described exemplary embodiments may satisfy a need to develop an intelligent portable device which can provide stretching and strengthening training and may allow both clinicians and subjects/patients to use as an effective therapeutic device, whether at home or at a clinic.

The described exemplary embodiments may provide an intelligent rehabilitation robot/device capable of providing stretching and strengthening of muscles which may help to achieve effective stroke rehabilitation based on one or more of the following:– the robot/device has diagnostic capabilities for subjects/patients with various medical conditions including information on range of motion, muscle strength in terms of torque and electromyogram (EMG) (e.g. whether impairment and abnormal conditions are due to passive muscle properties or active control capabilities); based on diagnosis, the robot/device may stretch the hypertonic upper limb of the subjects/patients post-stroke under intelligent control to loosen up specific stiff joints so that the central nervous system (CNS) may potentially control the relevant muscles and limb movement more effectively; after the stiff joints are loosened up and with an increase in the range of motion, the subjects/patients may perform voluntary exercises to regain and improve their motor control capability; with improvements in the ROM and motor control, the subjects/patients may continue rehabilitation via strengthening exercises with the adjustable torque range based on their capability to condition the weak muscles; coupling strengthening exercises with e.g. interactive virtual feedback games related to functional tasks in robotics therapy environment; and the outcomes may be monitored and evaluated quantitatively at the level of individual joints, muscle activities and the whole upper limb, on site or remotely.

The described exemplary embodiments may enable a flaccid upper limb to perform repetitive limb movements with the assistance of an electric motor in order to maintain the ROM and active movement of the arm/limb.

The described exemplary embodiments may, therefore, satisfy a need for therapy of limbs with impairment through both isolated and multi-joint integrated rehabilitation approaches. That is, the therapy comprises diagnosing neuromuscular and biomedical impairments in limb functions, performing physical therapy including passive stretching,
5 muscle conditioning and voluntary movement exercises, and evaluating the outcome quantitatively (see e.g. FIG. 13).

The described exemplary embodiments may further satisfy a need for a limb and joint therapeutic device that is precise and accurate. Furthermore, the described
10 exemplary embodiments may satisfy a need for a device that can stretch the limb or joints under intelligent control that can react to an impaired reflex mechanism to allow a human subject/patient to move his/her limb safely and also strengthen the limb or muscles under varied torque adjustment settings.

15 The described exemplary embodiments may also satisfy a need for quantitative and objective measurements of the impairments in terms of, for example, ROM, EMG activities, torque, biomechanical and neuromuscular changes for diagnosis and outcome evaluations on site or remotely as a home-based rehabilitation device.

20 With the described exemplary embodiments, with portability, compactness, and clamp-free method of securing the limb brace device to a surface (e.g. table top), both clinicians and subjects/patients may use the limb brace device as a potentially effective therapeutic device, whether at home or at a clinic. Furthermore, the use of symmetry in the design of the limb brace device may satisfy/permit the usage of both a left and right
25 limb with a single device without any significant adjustments. In the described exemplary embodiments, the limb brace device may comprise a limb support (e.g. the upper arm rest, the forearm rest) and the limb support may secure a limb such that the limb is rotatable with respect to one or more joints.

30 In the described exemplary embodiments, the limb brace device may be provided with two motors to control five DOFs with motor shafts which has (or is coupled to) a plurality of gear engagement systems and the shafts may be rotated at a variable velocity. A controller (compare control box 106 of FIG. 1A) may be configured to control the velocity

of movements at each joint based on the joint resistance torques in different control modes. For example, in an intelligent stretching mode, the controller may control the stretching velocity of the two motors with a force feedback system. In the active exercising mode, specific joint rotation may be triggered by the respective EMG signals detected via
 5 the subject's/patient's muscle. In the passive mode, exercise may be controlled by the pre-programmed settings based on the diagnosis of the clinicians.

In an exemplary embodiment, the limb brace device may implement a force feedback system e.g. for enhancing machine-intelligence. In such an example, the
 10 servomotors used for the limb brace device comprise built in hall sensors which are for current sensing. The hall sensors are used to create a safety feature called electrical current feedback and may be used for force feedback. For example, if a patient's impaired stretch reflex mechanism of an impaired limb is triggered (for example due to yawning), the reflex mechanism may lead to an increase in the resistance causing a motor to draw
 15 more current. When the current exceeds a pre-set threshold current, the motor is configured to stop operations in order not to react against the impaired reflex and to avoid overstretching of the limb. In such an example, the sEMG sensors may monitor the muscle signals in order to determine whether the patient is back to a relaxed condition. When it is determined that the EMG signals of the patient has returned to a pre-set
 20 threshold EMG signal, the motor is configured to return to a home/initial position and therapy may be resumed. The current feedback can thus allow for monitoring and analysis of the patient's movements (for example, jerky movements, smooth movements, change in resistance depending on the position of the limb etc). The current feedback also allows for determination and setting of a mean stretch velocity, e.g. to maintain a velocity that is
 25 sufficient or low enough to avoid excessive activation of impaired stretch reflex mechanisms progressively along the patient's recovery journey.

It will be appreciated that the force feedback system may be incorporated into various modes such as the passive mode or the active stretching/exercising mode. It is
 30 recognised that as long as the motors are in use, it is possible to implement the force feedback system. The force feedback system may allow real-time detection and may prevent over-stretching.

The described exemplary embodiments may provide an ergonomic robotic arm designed comprehensively to stretch tighter muscles of the subject/patient with spasticity along with torque feedback, position feedback and stretch velocity control function to perform the subject's/patient's specific therapy protocols safely.

5

The described exemplary embodiments may accommodate varied stretch evoked torque based upon the subject's/patient's severity, stretch velocity and changing position over the ROM with capabilities to counteract the impaired stretch reflex mechanism together with a multi-channel EMG circuitry to capture EMG signals via the subject's/patient's muscles.

10

The described exemplary embodiments may provide a combination therapy concept which allows not only stretching but also strengthening training to condition the weak muscles. Strengthening training may comprise self-initiated and self-directed movements by the subject/patient coupled with visual feedback exercises where the subject/patient can receive feedback on their performance simultaneously.

15

The described exemplary embodiments may further provide remote monitoring and assessment which may make it possible for the subject's/patient's data to be transmitted wirelessly to allow a healthcare professional to monitor real-time data in e.g. time-series graphs, report summaries in terms of the level of exercise intensities, range of motion, repetition and functional reaches, and to review progress over time regardless of the location.

20

The described exemplary embodiments may provide a promising rehabilitation intervention not only for subjects/patients with spasticity but also for a wide range of subject/patient conditions to achieve better recovery faster. The described exemplary embodiments may thus be an efficient tool to assist therapists to help e.g. neurological subjects/patients regain mobility to their impaired arms/limbs.

25

30

The described exemplary embodiments may provide an ergonomic and flexible design and a system capable of accommodating to various anthropometries of a limb/arm and medical conditions of subjects/patients with spasticity.

The described exemplary embodiments may provide a device suitable for use for both a left and right limb/arm due to a dedicated symmetric design.

5 The described exemplary embodiments may provide an intelligent system with variable speed control, range of motion and Biofeedback EMG threshold which may allow treatment parameters to be customised to meet a subject's/patient's specific therapy protocols and to accommodate to progressive changes during therapy.

10 In some exemplary embodiments, additional mechanical locks and/or limit sensors for ROM settings may be incorporated to prevent accidental program changes and potential injuries.

 In some exemplary embodiments, there may be provided a combination therapy
15 concept to stretch tighter muscles and to condition weak muscles in five DOFs.

 In some exemplary embodiments, there may be provided an integrated design concept whereby two electric motors are used to operate five DOFs for stretching. Strength training is also possible to be performed with visual feedback and torque
20 adjustability without using a motor.

 The described exemplary embodiments may be provided/incorporated with three different modes (of operation), namely, active exercising mode, passive mode, and interactive therapy mode (or strengthening mode with visual feedback on a patient's self-
25 movements).

 The described exemplary embodiments may provide a way for a doctor and/or a therapist to give a diagnosis and to evaluate subject/patient conditions.

30 The described exemplary embodiments may provide portability, allow remote monitoring and assessment and may be suitable for home-based rehabilitation.

It has been recognised that subjects/patients who suffer from e.g. stroke, other neurological disorders, brain injury, arm injury, and spinal cord injury may involve upper limb disorders such as loss of muscle power, loss in range of motion, spasticity and lack of coordination in muscle activation. Such subjects/patients may require an occupational therapy treatment.

The described exemplary embodiments may provide a device and/or technique to stretch e.g. the elbow, forearm, wrist and fingers joints of a spastic subject/patient accurately with a capacity/capability to control the stretch velocity in order for the subject/patient to have faster recovery through intensive training.

The described exemplary embodiments may also provide a device and/or technique to condition weak muscles through visual feedback strength training for faster recovery, increase motivation and/or to have/create a fun therapy environment.

The described exemplary embodiments may further provide a device and/or technique to expedite the subject's/patients' recovery to be independent and possibly their return back to work force, and to reduce burden on the family and care givers.

The described exemplary embodiments may provide a device and/or technique that may save valuable therapists' time and minimise physical strain on the therapists.

The described exemplary embodiments may provide a way to measure impairment and offer new therapy protocols.

The described exemplary embodiments may provide a device and/or technique to support subject/patient care service and facilities to prepare for a rapidly ageing population and an anticipated increase in the number of stroke victims.

The described exemplary embodiments may further provide a device and/or technique to ease the healthcare challenges associated with home-based rehabilitation which is a promising trend for potentially better healthcare outcomes.

The described exemplary embodiments may provide a therapy solution that may be called/referred to as a combination therapy for stretching and strengthening by one single device. By incorporating into a stretching therapy device the capability to also carry out strengthening therapy, it may be possible for the device to be incorporated with a visual feedback game playing activity. The described exemplary embodiments may have significant elements of rehabilitation technology and development may be aligned with the recent trend of moving towards home-based rehabilitation.

In the described exemplary embodiments, a gear engagement system may be provided.

Although there are many types of stretching available, statics stretching and isolated stretching may be emphasised for development which may be effective for subjects/patients with tighter muscles and especially for subjects/patients with spasticity. Further, intensive training may assist subjects/patients to recover faster. To generate a combination therapy solution, in some exemplary embodiments, there may be provided stretching to stretch tighter muscles one joint at a time in the development.

In the described exemplary embodiments, the number of electric motors used/provided to operate five DOFs may be significantly reduced from five to two. Furthermore, strengthening training may be integrated to the same device and this may make it possible to incorporate visual feedback game playing exercises.

In the described exemplary embodiments, the economic value may lie within the device and this may promote its marketability. The described exemplary embodiments may provide a potentially promising approach with technical merits and advantages that may benefit not only the subjects/patients with spasticity but also the neurological disorder subjects/patients, healthcare professions, family and their care givers.

Different exemplary embodiments can be implemented in the context of data structure, program modules, program and computer instructions executed in a computer implemented environment. A general purpose computing environment is briefly disclosed herein. One or

more exemplary embodiments may be embodied in one or more computer systems, such as is schematically illustrated in FIG. 14.

One or more exemplary embodiments may be implemented as software, such as a computer program being executed within a computer system 1400, and instructing the computer system 1400 to conduct a method of an exemplary embodiment.

The computer system 1400 comprises a computer unit 1402, input modules such as a keyboard 1404 and a pointing device 1406 and a plurality of output devices such as a display 1408, and printer 1410. A user can interact with the computer unit 1402 using the above devices. The pointing device can be implemented with a mouse, track ball, pen device or any similar device. One or more other input devices (not shown) such as a joystick, game pad, satellite dish, scanner, touch sensitive screen or the like can also be connected to the computer unit 1402. The display 1408 may include a cathode ray tube (CRT), liquid crystal display (LCD), field emission display (FED), plasma display or any other device that produces an image that is viewable by the user.

The computer unit 1402 can be connected to a computer network 1412 via a suitable transceiver device 1414, to enable access to e.g. the Internet or other network systems such as Local Area Network (LAN) or Wide Area Network (WAN) or a personal network. The network 1412 can comprise a server, a router, a network personal computer, a peer device or other common network node, a wireless telephone or wireless personal digital assistant. Networking environments may be found in offices, enterprise-wide computer networks and home computer systems etc. The transceiver device 1414 can be a modem/router unit located within or external to the computer unit 1402, and may be any type of modem/router such as a cable modem or a satellite modem.

It will be appreciated that network connections shown are exemplary and other ways of establishing a communications link between computers can be used. The existence of any of various protocols, such as TCP/IP, Frame Relay, Ethernet, FTP, HTTP and the like, is presumed, and the computer unit 1402 can be operated in a client-server configuration to permit a user to retrieve web pages from a web-based server. Furthermore, any of various web browsers can be used to display and manipulate data on web pages.

The computer unit 1402 in the example comprises a processor 1418, a Random Access Memory (RAM) 1420 and a Read Only Memory (ROM) 1422. The ROM 1422 can be a system memory storing basic input/ output system (BIOS) information. The RAM 1420 can
5 store one or more program modules such as operating systems, application programs and program data.

The computer unit 1402 further comprises a number of Input/Output (I/O) interface units, for example I/O interface unit 1424 to the display 1408, and I/O interface unit 1426 to
10 the keyboard 1404. The components of the computer unit 1402 typically communicate and interface/couple connectedly via an interconnected system bus 1428 and in a manner known to the person skilled in the relevant art. The bus 1428 can be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures.

15 It will be appreciated that other devices can also be connected to the system bus 1428. For example, a universal serial bus (USB) interface can be used for coupling a video or digital camera to the system bus 1428. An IEEE 1394 interface may be used to couple additional devices to the computer unit 1402. Other manufacturer interfaces are also possible such as
20 FireWire developed by Apple Computer and i.Link developed by Sony. Coupling of devices to the system bus 1428 can also be via a parallel port, a game port, a PCI board or any other interface used to couple an input device to a computer. It will also be appreciated that, while the components are not shown in the figure, sound/audio can be recorded and reproduced with a microphone and a speaker. A sound card may be used to couple a microphone and a
25 speaker to the system bus 1428. It will be appreciated that several peripheral devices can be coupled to the system bus 1428 via alternative interfaces simultaneously.

An application program can be supplied to the user of the computer system 1400 being encoded/stored on a data storage medium such as a CD-ROM or flash memory carrier. The
30 application program can be read using a corresponding data storage medium drive of a data storage device 1430. The data storage medium is not limited to being portable and can include instances of being embedded in the computer unit 1402. The data storage device 1430 can comprise a hard disk interface unit and/or a removable memory interface unit (both not shown)

in detail) respectively coupling a hard disk drive and/or a removable memory drive to the system bus 1428. This can enable reading/writing of data. Examples of removable memory drives include magnetic disk drives and optical disk drives. The drives and their associated computer-readable media, such as a floppy disk provide nonvolatile storage of computer readable instructions, data structures, program modules and other data for the computer unit 1402. It will be appreciated that the computer unit 1402 may include several of such drives. Furthermore, the computer unit 1402 may include drives for interfacing with other types of computer readable media.

The application program is read and controlled in its execution by the processor 1418. Intermediate storage of program data may be accomplished using RAM 1420. The method(s) of the exemplary embodiments can be implemented as computer readable instructions, computer executable components, or software modules. One or more software modules may alternatively be used. These can include an executable program, a data link library, a configuration file, a database, a graphical image, a binary data file, a text data file, an object file, a source code file, or the like. When one or more computer processors execute one or more of the software modules, the software modules interact to cause one or more computer systems to perform according to the teachings herein.

The operation of the computer unit 1402 can be controlled by a variety of different program modules. Examples of program modules are routines, programs, objects, components, data structures, libraries, etc. that perform particular tasks or implement particular abstract data types. The exemplary embodiments may also be practiced with other computer system configurations, including handheld devices, multiprocessor systems, microprocessor-based or programmable consumer electronics, network PCs, minicomputers, mainframe computers, personal digital assistants, mobile telephones and the like. Furthermore, the exemplary embodiments may also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a wireless or wired communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

The terms "coupled" or "connected" as used in this description are intended to cover both directly connected or connected through one or more intermediate means, unless otherwise stated.

5 The description herein may be, in certain portions, explicitly or implicitly described as algorithms and/or functional operations that operate on data within a computer memory or an electronic circuit. These algorithmic descriptions and/or functional operations are usually used by those skilled in the information/data processing arts for efficient description. An algorithm is generally relating to a self-consistent sequence of steps leading to a desired result. The
10 algorithmic steps can include physical manipulations of physical quantities, such as electrical, magnetic or optical signals capable of being stored, transmitted, transferred, combined, compared, and otherwise manipulated.

 Further, unless specifically stated otherwise, and would ordinarily be apparent from
15 the following, a person skilled in the art will appreciate that throughout the present specification, discussions utilizing terms such as "scanning", "calculating", "determining", "replacing", "generating", "initializing", "outputting", and the like, refer to action and processes of an instructing processor/computer system, or similar electronic circuit/device/component, that manipulates/processes and transforms data represented as physical quantities within the
20 described system into other data similarly represented as physical quantities within the system or other information storage, transmission or display devices etc.

 The description also discloses relevant device/apparatus for performing the steps of the described methods. Such apparatus may be specifically constructed for the purposes of
25 the methods, or may comprise a general purpose computer/processor or other device selectively activated or reconfigured by a computer program stored in a storage member. The algorithms and displays described herein are not inherently related to any particular computer or other apparatus. It is understood that general purpose devices/machines may be used in accordance with the teachings herein. Alternatively, the construction of a specialized
30 device/apparatus to perform the method steps may be desired.

 In addition, it is submitted that the description also implicitly covers a computer program, in that it would be clear that the steps of the methods described herein may be put

into effect by computer code. It will be appreciated that a large variety of programming languages and coding can be used to implement the teachings of the description herein. Moreover, the computer program if applicable is not limited to any particular control flow and can use different control flows without departing from the scope of the invention.

5

Furthermore, one or more of the steps of the computer program if applicable may be performed in parallel and/or sequentially. Such a computer program if applicable may be stored on any computer readable medium. The computer readable medium may include storage devices such as magnetic or optical disks, memory chips, or other storage devices
10 suitable for interfacing with a suitable reader/general purpose computer. In such instances, the computer readable storage medium is non-transitory. Such storage medium also covers all computer-readable media e.g. medium that stores data only for short periods of time and/or only in the presence of power, such as register memory, processor cache and Random Access Memory (RAM) and the like. The computer readable medium may even include a wired
15 medium such as exemplified in the Internet system, or wireless medium such as exemplified in bluetooth technology. The computer program when loaded and executed on a suitable reader effectively results in an apparatus that can implement the steps of the described methods.

20 The exemplary embodiments may also be implemented as hardware modules. A module is a functional hardware unit designed for use with other components or modules. For example, a module may be implemented using digital or discrete electronic components, or it can form a portion of an entire electronic circuit such as an Application Specific Integrated Circuit (ASIC). A person skilled in the art will understand that the exemplary embodiments can
25 also be implemented as a combination of hardware and software modules.

Additionally, when describing some embodiments, the disclosure may have disclosed a method and/or process as a particular sequence of steps. However, unless otherwise required, it will be appreciated the method or process should not be limited to the particular
30 sequence of steps disclosed. Other sequences of steps may be possible. The particular order of the steps disclosed herein should not be construed as undue limitations. Unless otherwise required, a method and/or process disclosed herein should not be limited to the steps being

carried out in the order written. The sequence of steps may be varied and still remain within the scope of the disclosure.

Further, in the description herein, the word “substantially” whenever used is understood to include, but not restricted to, “entirely” or “completely” and the like. In addition, terms such as “comprising”, “comprise”, and the like whenever used, are intended to be non-restricting descriptive language in that they broadly include elements/components recited after such terms, in addition to other components not explicitly recited. For an example, when “comprising” is used, reference to a “one” feature is also intended to be a reference to “at least one” of that feature. Terms such as “consisting”, “consist”, and the like, may, in the appropriate context, be considered as a subset of terms such as “comprising”, “comprise”, and the like. Therefore, in embodiments disclosed herein using the terms such as “comprising”, “comprise”, and the like, it will be appreciated that these embodiments provide teaching for corresponding embodiments using terms such as “consisting”, “consist”, and the like. Further, terms such as “about”, “approximately” and the like whenever used, typically means a reasonable variation, for example a variation of +/- 5% of the disclosed value, or a variance of 4% of the disclosed value, or a variance of 3% of the disclosed value, a variance of 2% of the disclosed value or a variance of 1% of the disclosed value.

Furthermore, in the description herein, certain values may be disclosed in a range. The values showing the end points of a range are intended to illustrate a preferred range. Whenever a range has been described, it is intended that the range covers and teaches all possible sub-ranges as well as individual numerical values within that range. That is, the end points of a range should not be interpreted as inflexible limitations. For example, a description of a range of 1% to 5% is intended to have specifically disclosed sub-ranges 1% to 2%, 1% to 3%, 1% to 4%, 2% to 3% etc., as well as individually, values within that range such as 1%, 2%, 3%, 4% and 5%. The intention of the above specific disclosure is applicable to any depth/breadth of a range.

In the exemplary embodiments, a torque adjustable mechanism may be in the form of a rotary damper. However, it will be appreciated that other forms for providing adjustable torque may also be used as long as a variable resistance may be provided to the movement (including rotation) of the various segments of the limb brace device.

In the exemplary embodiments, while the gear engagement systems may have been described as providing either isolated movement of a segment of the limb brace device or a combined movement of more than one segment of the limb brace device, it will be appreciated that the gear engagement systems are not limited as such. That is, depending on application, isolated or combined movement may be chosen with the gear engagement systems. For example, the hand-wrist segment may have isolated hand and isolated fingers movements e.g. through adding one or more additional gears or gear engagement systems.

In the description herein, gears have been described in the exemplary embodiments. It will be appreciated that such gears are not limited to the specific gears illustrated herein and may include any other forms of gear components.

It will be appreciated by a person skilled in the art that other variations and/or modifications may be made to the specific embodiments without departing from the scope of the invention as broadly described. For example, in the description herein, features of different exemplary embodiments may be mixed, combined, interchanged, incorporated, adopted, modified, included etc. or the like across different exemplary embodiments. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A limb brace device, the device comprising,
one or more receiving portions to support one or more parts of a limb, such that at least
5 one part of the limb is rotatable with respect to one or more limb joints;
one or more driving motors;
one or more gear engagement systems, each gear engagement system comprising at
least one translator member capable of engaging or disengaging the respective gear
engagement system to said one or more driving motors;
10 one or more torque adjustable mechanisms coupled to the one or more receiving
portions;
wherein during engagement of at least one of the one or more gear engagement
systems to the one or more driving motors, the engaged gear engagement system is capable
of transmitting torque to the one or more receiving portions for movement with respect to the
15 one or more limb joints; and
further wherein during disengagement of the one or more gear engagement systems
to the one or more driving motors, the one or more torque adjustable mechanisms is capable
of affecting the one or more receiving portions for movement with respect to the one or more
limb joints.
20
2. The limb brace device as claimed in claim 1, further comprising the limb brace
device being adapted to allow for at least five degrees of freedom for motion of the limb.
3. The limb brace device as claimed in claims 1 or 2, further comprising the at
25 least one translator member being capable of causing linear displacement of a driven gear
component to engage or disengage a driving gear component of said one or more driving
motors.
4. The limb brace device as claimed in claim 3, further comprising during
30 engagement of at least one of the one or more gear engagement systems to the one or more
driving motors, the driven gear component being capable of transmitting torque to a coupled
component that is coupled to the driven gear.

5. The limb brace device as claimed in claim 4, wherein the coupled component that is coupled to the driven gear comprises another gear component or a rotatable shaft.

6. The limb brace device as claimed in any one of claims 1 to 5, wherein the one or more receiving portions comprises a digital segment, the digital segment comprising a base having a plurality of positioning holes and wherein the digital segment is rotatable to lock in an interchangeable position using the positioning holes to accommodate a left limb or a right limb.

7. The limb brace device as claimed in any one of claims 1 to 6, wherein the one or more receiving portions comprises a joint segment, the joint segment comprising a mechanical stopper that is adjustable along a rotational path, the mechanical stopper being capable of preventing over-rotation of the joint segment.

8. The limb brace device as claimed in any one of claims 1 to 7, wherein the one or more receiving portions comprises an upper segment, the upper segment comprising at least one angular curve ring track and an upper segment lock system, the lock system being configured to lock the upper segment in position along the at least one angular curve ring track.

9. The limb brace device as claimed in any one of claims 1 to 8, wherein the one or more receiving portions comprises at least one inflatable pad coupled to a heat pad.

10. The limb brace device as claimed in any one of claims 1 to 9, further comprising a releasable securing member for releasably securing the limb brace device to a surface.

11. The limb brace device as claimed in claim 10, wherein the releasable securing member comprises at least one vacuum leg.

12. The limb brace device as claimed in any one of claims 1 to 11, further comprising an interface module for coupling to a control module, the interface module being capable of receiving instructions from the control module.

13. The limb brace device as claimed in claim 12, wherein the interface module is capable of receiving instructions based on human-interface sensors and the one or more driving motors are controllable based on human-interface sensors signals from the human-interface sensors.

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14. The limb brace device as claimed in any one of claims 1 to 12, further comprising an emergency switch coupled to the one or more driving motors, the emergency switch being capable of stopping operations of the one or more driving motors.

10

15. A limb brace system, the system comprising,
a limb brace device as claimed in any one of claims 1 to 14;
a control module coupled to the limb brace device; and
a display coupled to the control module.

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16. The limb brace system as claimed in claim 15, further comprising the control module being capable of providing power to the one or more driving motors of the limb brace device.

20

17. The limb brace system as claimed in claims 15 or 16, further comprising the control module being capable of processing human-interface sensors signals and controlling the one or more driving motors of the limb brace device based on the human-interface sensors signals.

25

18. The limb brace system as claimed in any one of claims 15 to 17, further comprising the control module being capable of instructing a display of at least one limb movement program on the display.

30

19. The limb brace system as claimed in any one of claims 15 to 17, further comprising the control module being capable of receiving data from the limb brace device and transmitting the data to an external server.

20. The limb brace system as claimed in claim 19, further comprising the control module being capable of receiving instructions from the external server and controlling the one or more driving motors of the limb brace device based on the received instructions.