



Portable Movement Facilitation Device and Method of Operating the Device

5 Background and Field of the Invention

This invention relates to a portable movement facilitation device for facilitating movement of a limb and a method of operating the device.

10 Stroke is a major problem worldwide and it is common for a stroke patient to suffer from upper limb paralysis, thus reducing the functions of the upper limb. With suitable rehabilitation and therapy, it has been found that it is possible to improve or even regain the proper functioning of the upper limb.

15 As a result, robotic devices to assist with limb movement have been proposed to aid the rehabilitation. However, such robotic devices are often bulky and expensive.

It is an object of the present invention to provide a portable movement
20 facilitation device and a method of operating the device which provides the public with a useful choice and/or addresses at least one of the disadvantages of the prior art.

Summary of the Invention



In a first specific expression of the invention, there is provided a portable movement facilitation device for facilitating movement of a limb, comprising a holding mechanism for securing to at least one digit of the limb; at least one flex string attached to the holding mechanism, the at least one flex string and the holding mechanism being configured to rely on the at least one digit's skeletal structure as a primary mechanical structure for movement of the at least one digit; and an actuating device operable to actuate the at least one flex string to facilitate the movement of the at least one digit between an unflex position and a flex position.

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Flex string is used in this specification to mean a lightweight and thin strand of cord which is flexible to follow and accommodate the movement of the digit and has the required tensile strength for causing movement of the digits of a limb without breaking. Examples of suitable flex strings are fishing line which is made of nylon or monofilament; or cords made with polyester.

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By using flex strings such as fishing lines, this results in an unpredictable effect since this reduces the overall size and weight of the device as well as the cost of manufacturing the device. At the same time, the fishing lines exhibit good breaking strength and thus, making them suitable for such an application. As described in the preferred embodiment, the portable movement facilitation device does not have an integral primary mechanical structural support but instead relies on the digit's skeletal structure as the primary mechanical structure which further reduces the overall size and weight of the device.

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Preferably, the actuating device comprises an active actuator operable to actuate the at least one flex string. The active actuator may be operable to actuate the at least one flex string to move the at least one digit from the flex to the unflex position. In the alternative or in addition, the active actuator may be operable to actuate the at least one flex string to move the at least one digit from the unflex to the flex position.

Advantageously, the actuating device may comprise a passive actuator configured to create a biasing force when the at least one digit is moved to the unflex position; and wherein the biasing force is arranged to urge the at least one digit from the unflex to the flex position. In the alternative, the passive actuator may be configured to create a biasing force when the at least one digit is moved to the flex position; and wherein the biasing force is arranged to urge the at least one digit from the flex position to the unflex position. The passive actuator may be combined with the active actuator discussed above.

The portable movement facilitation device may further comprise guide rings adapted to be worn by the at least one digit, the guide rings being arranged to guide the at least one flex string. The use of guide rings provide a simple and economic way of guiding the flex string and to guide the digit between flex and unflex positions.

The portable movement facilitation device may further comprise a flex sensor for detecting flexing of the at least one digit. The passive actuator may include at least one resilient member arranged adjacent to the back of the at least one

digit.

The active actuator may include at least one motor operable to pull the at least one flex string to move the digit to the unflex position or flex position. The active
5 actuator may include a bobbin for stowing the at least one flex string, and wherein the at least one motor is operable to rotate the bobbin to dispense or retract the at least one flex string. The use of the bobbin to stow and/or dispense the flex string reduces the risk of tangling of the flex string.

10 Preferably, the active actuator includes an encoder for encoding amount of displacement of the at least one flex string.

The at least one flex string may be selected from the group consisting of: fishing line, nylon string, and polyester string.

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The portable movement facilitation device may further comprise an abrasion protector to be worn by the limb. The portable movement facilitation device may further comprise an IR distance sensor for detecting distance of an object relative to the IR distance sensor. The detected distance may be used to
20 determine when to clench the digits to pick up an object.

The portable movement facilitation device may further comprise a bio sensor for performing electromyography measurements on the limb. The bio sensor may include an accelerometer for measuring movements of the limb. The portable
25 movement facilitation device may further comprise a controller operable to

control the actuation of the actuating device based on a reading from the accelerometer.

The portable movement facilitation device may further comprise a controller
5 operable to control the actuation of the active actuator based on the electromyography measurements.

The limb may be a hand, and the at least one digit is a finger or thumb.

10 The holding mechanism may comprise a plurality of finger tip holders, with each holder configured to be secured to a respective digit; and a plurality of flex strings with each flex string attached to respective ones of the plurality of fingertip holders.

15 The portable movement facilitation device may further comprise a glove for carrying the holding mechanism, the at least one flex string and the actuating device.

The portable movement facilitation device may be used to maintain and/or
20 improve condition of a person's limb and digits, in particular for rehabilitation.

In a second specific expression of the invention, there is provided a method of operating a portable movement facilitation device as discussed above, which includes a bio sensor for performing electromyography measurements on the
25 limb, the method comprising the steps of:

receiving an electromyography measurement;
comparing the electromyography measurement with a threshold and if the measurement exceeds the threshold, controlling the actuating device to actuate the at least one flex string to flex the at least one digit.

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The bio sensor may further comprise an accelerometer, and the method may further comprise the step of: receiving a reading from the accelerometer; comparing the reading with an accelerometer threshold and if the measurement exceeds the threshold, controlling the actuating device to actuate the at least one flex string to flex the at least one digit.

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The device may further comprise a flex sensor for detecting flexing of the at least one digit, and the method may further comprise the steps of: receiving a reading from the flex sensor; and determining whether maximum clenching or maximum flexion has been achieved by the at least one digit.

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The method may further comprise the step of stopping the actuation of the actuating device when the maximum clenching or maximum flexion is reached.

20 Brief Description of the Drawings

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings in which,

Figure 1 is a side view of a hand wearing a portable movement facilitation device according to a preferred embodiment of the invention;

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Figure 2 is a rear palm view of the hand and the portable movement facilitation device of Figure 1;

Figure 3 is a palm view of the hand and the portable movement facilitation device of Figure 1;

5 Figure 4 includes Figure 4a which is a block diagram of a GUI module of the portable movement facilitation device of Figure 1, and Figure 4b which is a block diagram of various components of the portable movement facilitation device of Figure 1 and which includes a main processor configured to communicate with the GUI module of Figure 4a;

10 Figure 5 shows the portable movement facilitation device of Figure 1 with most of the components housed in a glove;

Figure 6 shows the portable movement facilitation device of Figure 5 further including biosensor modules;

Figure 7 is a block diagram of one of the biosensor modules of Figure 6;

15 Figure 8 is a flow chart illustrating a rehabilitation routine for a user of the portable movement facilitation device of Figure 6;

Figure 9 is a flow chart illustrating steps to be performed when waiting for conditions to be fulfilled which is used in the flow chart of Figure 8;

20 Figure 10 is a flow chart illustrating steps to be performed when carrying out clenching of fingers routine which is used in the flow chart of Figure 8;

Figure 11 is a flow chart illustrating steps to be performed when carrying out flexing of fingers routine which is used in the flow chart of Figure 8;

Figure 12 is an enlarged perspective view of the internal structure of a bobbin of a motor which is shown in Figures 2 and 4b;

Figure 13 is a side view of the portable movement facilitation device of Figure 1 shown separately from the hand; and

Figure 14 shows how the bobbin of Figure 12 is attached to a motor with the bobbin in a disassembled state.

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Detailed Description of the Preferred Embodiment

Figure 1 is a side view of a hand 100 of a user or patient wearing a portable movement facilitation device 200 according to a preferred embodiment of this invention. It should be appreciated that the portable movement facilitation device 200 does not have a primary mechanical structural support and relies on the hand 100 for structural support. In this way, a lighter device 200 may be achieved.

15 Figure 2 is a view of the back 106 of the hand 100 and Figure 3 is a view of the palm 108 of the hand 100, together with the portable movement facilitation device 200. The hand 100 has five digits 102a-102e – four fingers and a thumb, and joined by a wrist 104.

20 As it can be appreciated from Figures 1-3, the portable movement facilitation device 200 comprises a GUI module 202, a signal cable 204, an actuating device 205, flex strings 208, guide rings 210, a holding mechanism 214, abrasion protector 216, ribbon cable 218, IR distance sensor 220, splint 222, a main processor 300 and a lanyard 302. These components are shown as block

diagrams in Figure 4b. Each of these components will be further described below:

1. GUI module 202

5 Graphical User Interface (GUI) module 202 provides a main interface between the portable movement facilitation device 200 and a user and allows the user to select appropriate settings and types of exercise to perform. The module 202 includes a wrist strap 224 (see Figure 3) for strapping the module 202 to the wrist 104 of the user. Figure 4a shows a block diagram of the GUI module 202
10 and the module 202 includes an I/O port 202a, a LCD display 202b, capsense buttons 202c, a wireless transceiver module 202d, a USB port 202e, a battery source 202f and power supply and charging circuit 202g.

The GUI module 202 receives instructions from the capsense buttons 202c
15 which uses capacitive sensing technology to receive selections by the user. For example, the capsense buttons 202c allow the user to manually adjust tension of each flex strings 208 depending on the size of the hand 100. The input buttons 202c also allows manual triggering of the flexion or clenching of any of the digits 102a-102e. These features might be useful to a rehabilitation
20 therapist.

The LCD display 202b provides a visual display to the user to provide acknowledgement of the selections and/or to provide the status of the GUI module 202 or information to the user or patient. For example, the LCD panel

202b may display the number of the successful flexing and clenching of the digits 102a-102e.

The battery source 202f is in the form of Li-ion batteries to power the GUI module 202 and also other components of the device 200. The Li-ion batteries are rechargeable by the power supply and charging circuit 202g using power supplied from the USB port 202e. In other words, the USB port 202e provides an inlet to supply electricity to the power supply and charging circuit 202g for charging or recharging the battery source 202f, and also functions as a data transfer port.

The wireless transceiver 202d enables the GUI module 202 to communicate wirelessly with other devices. The I/O port 202a provides an input and output interface between the GUI module 202 and the other components of the device 200 as shown in Figures 4a and 4b.

2. Signal cable 204

The signal cable 204 is a multi-way cable and one end of which is communicatively coupled to the I/O port 202a of the GUI module 202. The other end of the signal cable 204 is coupled to the main processor 300 as shown in Figure 4b. A main function of the signal cable 204 is to carry the signals from and to the GUI module 202. In addition, the signal cable 204 also carries electricity to power the electrical/electronic components which are located at the hand 100.

3. Holding mechanism 214

In this embodiment, the holding mechanism 214 comprises five fingertip holders 214a-214e and each is made of elastic material such as rubber and is substantially cylindrical to form a loop for receiving a respective end of the digits 102a-102e. The elastic material of the holders 214a-214e enable the holders 214a-214e to fit snugly around the ends of each digit so that the holders 214a-214e are secured to each digit 102a-102e. Each of the fingertip holder 214a-214e is attached to a respective flex string 208 by sewing each flex string 208 to a respective fingertip holder 214a-214e.

4. Actuating device 205

The actuating device 205 of this embodiment includes an active actuator 206 and a passive actuator 212. The active actuator 206 comprises six separate DC motors 206a-206f, one for actuating each flex string 208 (one flex string for each digit 102a-102e and one flex string for flexing/unflexing the joint at the base of the thumb), and they are powered by the battery source 202f. Each of the DC motors 206a-206f is a multi-turn motor of a miniature size to reduce the overall size of the device 200. Also, for better use of space, control circuitry 209 for each of the motors 206a-206f is mounted on top of the respective motor's body.

A flexible board 226 made of elastic plastic is used to carry each of the motors 206a-206f and also the necessary electronic/electrical circuits 207 for the device 200 on the back of the hand 100. Each of the motors 206a-206e are affixed to the flexible board 226 and include a bobbin 206g for stowing and dispensing a length of one of the flex strings 208 and an optical encoder 217

(see Figure 4b and Figure 14) for converting the linear displacement of the flex string 208 into digital representations for transmission to the main processor 300 . The flex string 208 runs from a respective motor 206a-206f and routes via the abrasion protector 216 and to the digits 102a-102e.

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Figure 12 is an enlarged perspective view of the internal structure of the bobbin 206g and it comprises a circular inner drum 380 received within a circular housing 382 with an overall diameter less than 20mm. The inner drum 380 includes a cylindrical bobbin core 382 sandwiched between two circular flanges 384 of a diameter larger than the diameter of the bobbin core 382. The inner drum 380 includes a central axial bore 386 through which an axle shaft of one of the motors 206 (reference 206 this being used to represent one of the motors 206a-206f) is inserted therethrough. The bobbin core 382 also includes a radial hole 388 through which a screw (not shown) is inserted to secure the inner drum 380 to the axle shaft of the motor 206 so that as the axle shaft rotates, this also rotates the inner drum 380. A length of the flex string 208 is arranged to be wound around the bobbin core 382 with one end tied to an aperture 390 formed at one of the flanges 384 and the other end of the flex string 208 being arranged to pass through a housing aperture 392 of the housing 382 and routed to be attached to a respective fingertip holder 214a-214e as explained earlier.

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The housing 382 has a side surface 394 for coupling to the motor 206 and the side surface 394 includes a central bore 396 through which the axle shaft of the motor passes through. Two attachment holes 398 (only one shown in Figure 12

with the other one shown in Figure 14) is formed on the side surface for securing the housing 382 and thus, the bobbin 206g to the motor 206.

Figure 14 illustrates how the bobbin 206g is attached to the motor 206. The motor 206 includes the axle shaft 400 which is inserted through a mounting plate 402 carrying the optical encoder 217, an encoder plate 404 and the central bore 396 of the housing 382. The housing 382 is mounted to the mounting plate 402 of the motor 206 via screws through the attachment holes 398. The encoder plate 404a is made of thin reflective metal and includes radial strips spaced angularly for detection or reading by the optical encoder 217. The encoder plate 404 is placed between the inner drum 380 and the side surface 394 of the bobbin housing 382, again to maximise the use of space.

The optical encoder 217 is carried by the mounting plate 402 and arranged to detect the rotation of the encoder plate 404 through an aperture (not shown) formed on the side surface 394 of the housing 382. Thus, the rotation of the inner drum 380 is detected by the optical encoder 217. In this way, the dispensing direction, speed and displacement of the flex string is determined by the processor 300.

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The passive finger actuator 212 does not require power supply to operate and the actuator 212 actuates based on its structure rather than due to electrical excitation. In this embodiment, the actuator 212 comprises five narrow strips of resilient members 212a-212e made of elastic plastic such as polypropylene or PVC and placed at the back of each digit (i.e. at the back of the hand 100).

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Each resilient member 212a-212e is biased towards an extended position which maintains a respective digit 102a-102e in an extended or flex position – i.e. substantially straight position – this being an initial rest state for the resilient members 212a-212e. As explained above, when the motors 206a-206f actuate the respective fishing lines 208, this pulls the fishing lines 208 and the respective fingertip holders 214a-214e and creates a forceful movement of the digits 102a-102e to move the digits 102a-102e towards the clench position. This movement causes the resilient members 212a-212e to coil and creates a biasing force in each of the resilient members which urges the digits 212a-212e to the flex positions. As a result, the pulling force created by the fishing lines 208 and the motors 206a-206f needs to exceed the biasing force of the resilient members 212a-212e in order to cause the digits 102a-102e to clench. When the motors 206a-206f release the pulling force of the fishing lines 208, the biasing force of the resilient members 212a-212e urges the respective digits 102a-102e to the stretched positions, which is shown in Figure 3.

Each resilient member 212a-212e also includes a flex sensor 213 (not shown in Figures 103 but see schematic representation in Figure 4b) for detecting the bend of the digits 102a-102e and the flex sensor 213 is disposed near or at an end of the resilient member adjacent to the finger nail of the digit, including one wing flex sensor (denoted as 213a see Figures 2 and 13, but not shown in Figure 1) to detect the “wing” muscle or the base of the thumb. A holder 215 is used to hold the wing flex sensor 213a in place. The flex sensor is configured to determine a maximum limit for clenching or flexing of the fingers is reached.

5. Flex strings 208

In this embodiment, the flex strings 208 comprises six lengths of fishing lines 208a-208f with each coupled to a respective motor 206a-206f as explained earlier. Five lengths of the fishing lines 208a-208e are connected to respective
 5 fingertip holders 214a-214e with the sixth fishing line 208f connected to a part of the abrasion protector 216 which is near the base of the thumb 102a. The fishing lines are made of monofilament which has good tensile strength and is lightweight.

10 The fishing lines 208a-208f are routed from the back of the hand 100 via the abrasion protector 216 and to the palm 108 of the hand 100. As it can be appreciated from Figure 3, each fishing line 208a-208f runs from the abrasion protector 216 and along the central part of the finger on the palm side of the hand 100 via the guide rings 210 and is attached to a corresponding fingertip
 15 holder 214a-214e. When the motors 206a-206f rotates the bobbins 206g to stow the respective fishing lines 208a-208f, this action pulls the fishing lines 208a-208f and the fingertip holders 214a-214e inwardly and causes the digits 102a-102e to clench. In this way, the device 200 facilitates movement of the digits 102a-102e of the hand 100.

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6. Guide rings 210

There are five sets of guide rings 210 and each set is referenced using the reference numerals 210a-210e – one set for each digit. Each guide ring is an endless ring made of plastic. In the alternative, the guide rings may be made of

coils of the flex string material to reduce the ring thickness and also makes the rings aesthetically more presentable.

The first set of guide ring 210a comprises two guide rings 210a for the thumb
5 102a and the two guide rings 210a are placed near the two hinged joints of the thumb but adjusted so that the guide rings 210a do not impede the bending of the thumb 102a.

Each of the other four sets has three guide rings 210b-210e and each guide
10 ring 210b-210e is also strategically placed near respective hinged joints of each finger 102b-102e.

7. Abrasion protector 216

The abrasion protector 216 is a protective pad made of polypropylene or PVC
15 which is used to prevent abrasion or hurting the hand 100 when the fishing lines 208a-208e are pulled. As shown in Figures 1 and 3, the abrasion protector 216 comprises two portions 216a,216b with the first portion 216a wrapped around the palm near the base of the thumb 102a and the second portion 216 is wrapped around the palm bear the base of the four fingers 102b-102e. Both
20 portions 216a,216b fit snugly around the palm and in particular the first portion 216a which is attached to one of the fishing lines 208f for flexing of the muscles/joint at the base of the thumb 102a to a clenching position. The abrasion protector 216 is attached to the flexible board 226 using nylon rivets to form a space for a user's hand to be inserted through the space. In the
25 alternative, cable ties or nylon nuts and bolts may be used.

8. Main processor 300

The main processor 300 is mounted on an electronic circuit board which is attached to the abrasion protector 216 at the rear of the palm. The main processor 300 processes the signals received from the GUI module 202 via the cable 204, and the other components such as the flex sensors 213, encoders 217 and provides instructions to drive the motors 206a-206f.

The device 200 also includes a safety mechanism which stops the operation of the device 200 by pulling the emergency lanyard 302. As shown in Figure 4b, when the lanyard 302 is pulled, this triggers the processor 300 to stop operation of the motors 206a-206f.

9. IR distance sensor 220

The infrared red (IR) distance sensor 220 is arranged to detect distance of object (not shown) in front of the palm 108 for the clenching operation and it is strategically placed between the wrist 104 and the palm of the hand 100. The IR distance sensor 220 transmits the distance measurement via a ribbon cable (not shown) to the main processor 300 for the main processor to process and determine the distance of the patient's palm or hand to an object to be grabbed by the user. The distance measurement thus allows the main processor 300 to determine when to drive each of the motors 206a-206f (independently or simultaneously) to flex the fingers 102a-102e in order for the user to grab the object.

10. Splint 222

The splint 222 has an elongate shape with a raised end 222a placed strategically at the centre of the palm 108 and the other end 222b extending to the wrist strap 224 of the GUI module 202. The raised end 222a thus props up the palm 108 and the hand 100 into a grasping position. The splint 222 may be made of metal, plastic, wood or other suitable material.

11. Memory Card Slot 304

The movement facilitation device 200 also includes a memory card slot 304 (not shown in Figures 1-3 but see Figure 4b) which is configured to be compatible with microSD memory cards (not shown) and the memory cards provide information for the main processor 300 to process. For example, the memory cards may store various exercise or rehabilitation routines and based on the selection by a user, the main processor 300 retrieves the selected exercise routine and generates output signals to the various components of the portable movement facilitation device 200, for example to drive the motors to actuate the flex strings 208. The main processor may also store data to the memory card, for example to record the number of successful flexing or clenching of the digits 102a-102e.

12. Capsense buttons 306

Capsense buttons 306 are provided on the device 200 to detect whether the device 200 is being worn by a user or not. Once the processor 300 detects that

a user is wearing the device 200, it then activates the corresponding components or circuits.

13. Device Accelerometer 308

- 5 A device accelerometer 308 is also provided near the capsense buttons on the palm side of the device 308 to track movement of the hand.

It should be appreciated that the movement facilitation device 200 tracks the position of the digits 102a-102e based on the following means:

- 10 - encoders 217 in the motors 206a-206e which detects the displacement of the fishing line.
- the flex sensor 213 mounted to the passive finger actuator 212 (at the back of the fingers). The flex sensor enables the movement facilitation device 200 to detect amount of bend or flex when a finger flexes.
- 15 - current sensors of the motors 206a-206e which allows the movement facilitation device 200 to detect the load the motor is handling. The motor loading is directly proportional to the amount of clenching.

More of these means will be described later.

- 20 To provide a more aesthetic look and for ease of use, the portable movement facilitation device 200 may include a glove 250 and components such the fishing lines 208a-208f, the guide rings 210a-210e, the resilient members 212a-212e, the fingertip holders 214a-214e, the abrasion protector 216, the splint 222 and the main processor 300 etc are housed within the glove as shown in Figure

To use the portable movement facilitation device 200, a user puts on the glove 250 and inserts each digit 102a-102e through a glove finger 250a-250e which guides each digit 102a-102e through the guide rings 210a-210e. The wearing of the device 200 is detected by the capsense buttons 306 and this is picked up by the processor 300. The user then straps the GUI module 202 to his wrist 104 using the wrist strap 224 and proceeds to insert a SD memory card which contains the various exercise routines into the card slot 304. The user then selects the desired rehabilitation exercise using the capsense buttons 202c based on information displayed on the LCD display 202b. When the desired rehabilitation exercise is selected, the main processor 300 controls the motors 206a-206f to pull the respective fishing lines 208a-208f accordingly. For example, the desired rehabilitation exercise may require bending the index finger 102b five times at five second intervals and this would require the main processor 300 to control the motor 206b to actuate the fishing line 208b by pulling it against the biasing force of the corresponding resilient member 212b and cause the index finger 102b to bend. Thereafter, the processor 300 controls the motor 206b to release the pull of the fishing line 208b (by rotating the corresponding bobbin 206g to dispense the fishing line 208b) and the passive actuation of the actuator 212b biases the index finger 102b to the extended position.

Such a portable device 200 has many uses. For example, a doctor may set up a series of training programs for the patient (or user) and store these in a SD memory card. The doctor then provides a rehabilitation schedule to the patient

which corresponds to the training program. The patient or user loads the memory card into the card slot 304 and select the training programs according to the rehabilitation schedule to carry out the therapy sessions. As a result, the patient or user has convenience of performing the rehabilitation at home without supervision of the doctor or trained medical profession.

The use of fishing lines 208a-208f makes the device 200 lightweight and creates a much smaller device, and yet, rather unexpectedly has the required tensile strength. Further, the fishing lines 208a-208f has the flexibility to follow or accommodate to the bend or flexing of the digits 102a-102e resulting in a less cumbersome device 200. Even if one of the fishing lines 208a-208f breaks, it is relatively inexpensive and easy to replace or repair. Also, the use of active actuation using the motors 206a-206f and fishing line for flexing of the fingers together with passive actuation using the resilient member 212a-212e for extending the digits 102a-102e create a much simpler and yet effective movement facilitation device 200.

It should be appreciated that, unlike conventional movement facilitation devices, the portable movement facilitation device 200 does not have a primary mechanical structure in the sense the device relies on the skeletal structure of the hand, in particular the digits 102a-102e, for the device to carry out its functions of actuating the fingertip holders to move the digits. This can be appreciated from Figure 13 which shows the portable movement device 200 separate from the hand 100.

To enhance its features, the portable movement facilitation device 200 of Figure 5 further comprises two biosensors modules 252,260 as shown in Figure 6. The first biosensor module 252 is strapped to an upper arm 110 and the second biosensor module 260 is strapped to a lower arm 112. Each of the biosensors 252,260 are configured to perform electromyography (EMG) which detects firing of muscles' nerves from the surface of the skin at the respective locations of the arm. The firing of the muscles represents the user (or patient's) intent for example, to clench the digits 102a-102e, and thus, it is possible to obtain the user's intention based on the EMG readings.

Each of the biosensor modules 252,260 also includes a 3-dimensional accelerometer (not shown) which tracks x-y-z axis movements of the upper and lower arms 110,112 respectively.

Figure 7 is a schematic block diagram of one of the biosensor modules 252 (which is the same as the other biosensor module 260). The biosensor module 252 includes a biosensor processor 350, LCD display 352, input buttons 354, RF circuit 356, an accelerometer 358, power supply circuit 360, battery power source 362 and an electromyography (EMG) analogue circuit 364.

The LCD display 352 provides a display for the user to see the status of the biosensor module 250. The input buttons 354 enables a user or therapist to set the EMG threshold to activate the device 200 to flex or unflex the fingers. The RF circuit 356 transmits data between the biosensor module 252 and the GUI module 202 (via the wireless transceiver 202d of the GUI module). The

battery power source 362 provides power to the power supply circuit 360 for powering the biosensor processor 350. The biosensor processor 350 processes inputs, for example, from the input buttons 354 and the accelerometer 358 and communicates the data to the GUI module 202 via the RF circuit 356. The EMG
 5 analogue circuit has three skin electrodes 366 (see Figure 6) which are placed at strategic locations on the skin of the arm to detect firing of the muscles.

The output readings from the biosensor modules 252,260 are:

a) First biosensor module 252:

- 10 i) EMG1 – EMG reading of the first biosensor module 252.
- ii) ACC1 – accelerometer vector readings of the first biosensor module 252.

b) Second biosensor module 260

- 15 i) EMG2 – EMG reading of the second biosensor module 260
- ii) ACC2 - accelerometer vector readings of the first biosensor module 260

c) Robotic Glove accelerometer/device accelerometer 308

- 20 i) ACC0 - accelerometer vector readings of the Robotic Glove (if a glove is used, or the device accelerometer if a glove is not used).

Each of the accelerometer vector readings comprises distance (D), x-y axis angle ($\angle$ x-y) and x-z axis angle ($\angle$ x-z).

As explained earlier, each biosensor module 252,260 is able to communicate wirelessly with the transceiver module 202d of the GUI module 202, and this enables the biosensor modules 252,260 to transmit the EMG readings EMG1,EMG2 and the x-y-z arm movements ACC1,ACC2 to the GUI module 202, which then sends these to the main processor 300 via the cables 204. Based on the EMG readings ACC1, ACC2, ACC0 and the arm movements, the main processor 300 is able to compute accurately and track the vector (direction and distance) displacements of the different parts of the patient's arm. In this way, the device 200 is able to detect the patient's voluntary actuation of the fingers.

In addition to the biosensor modules 252,260, the IR distance sensor 220 enables the device 200 to measure and track the distance of the patient's palm or hand to an object to be grabbed by the patient. The distance IR0 also provides an indication of the intention of the patient since a nearer distance would suggest that the patient intends to grab the object as compared to a further distance. The distance measurement also aids the main processor 300 to know when to control the motors 206a-206f to flex the fingers 102a-102e in order for the user to grab the object.

The use of the biosensor modules 252,260 and the IR distance sensor 220 provide means for determining whether certain conditions are satisfied before the main processor 300 controls the motors 206a-206f to actuate the fishing lines 208a-208f to flex the digits 102a-102e. The conditions are prescribed by a medical professional such as a rehabilitation therapist. The scripting process is

done on a medical tablet 1000 and the output of the scripting process is the "condition script" which is downloaded in an external memory and inserted into the card slot 304 for access and processing by the main processor 300.

- 5 It should be mentioned that the main processor 300 and the biosensor modules 252,260 each has a recordation mode which allows the user to capture an ideal exercise movement. The EMG readings, accelerometer readings and IR sensor inputs to achieve this ideal exercise movement may be uploaded to the medical tablet (preferably wirelessly, via the transceiver 202d). A therapist may then use
10 these readings and inputs to design an exercise regime using the condition script.

The condition script includes threshold values which may be set by a medical professional and the threshold values are derived based on a normal person's
15 normal usage of a hand to clench or flex the fingers. Relationship between the threshold values and the readings, EMG1, EMG2, ACC0, ACC1, ACC2, and IR0 is based on the following notations:

- Greater than: >
- Less than: <
- 20 • Greater or equal to: >=
- Less than or equal to: <=

The relationship between the readings is defined by using the following operators:

- 25 • OR

- AND
- Group – denote by brackets

Two examples of a condition script will now be described. A first example is shown in Table 1 below and this includes conditions to determine whether the fishing lines 208a-208f should be actuated to clench the digits 102a-102e.

Condition Line 1	ACC0: D>10cm AND $\angle x-y > 25^\circ$ AND $\angle x-y < 35^\circ$ AND $\angle x-z > 45^\circ$ AND $\angle x-z < 55^\circ$
Condition Line 2	(EMG1 > 2 AND EMG2 > 2)
Condition Line 3	IR0 < 5cm

Table 1

It should be appreciated that it may not be necessary to use all the inputs as conditions to trigger the flexion or clench.

10

A second example relates to a condition script for flexion of the digits 102a-102e and this is shown in Table 2 below:

Condition Line 1	ACC0: D>10cm AND $\angle x-y > 300^\circ$ AND $\angle x-y < 320^\circ$ AND $\angle x-z > 250^\circ$ AND $\angle x-z < 270^\circ$
Condition Line 2	(EMG1 < 4 AND EMG2 < 4)

Table 2

An example of using the movement facilitation device 200 by a patient to perform rehabilitation will now be described using the above condition scripts and based on a rehabilitation routine shown in Figure 7. Basically, the routine
5 requires the patient or the user of the movement facilitation device 200 to undergo clenching exercises followed by flexing exercise of the fingers. As explained above, the conditions scripts of Table 1 and Table 2 are loaded from the medical tablet 1000 and stored into a SD memory card and the card is inserted into the memory card slot 304 prior to the start of the rehabilitation
10 routine.

At step 802, the processor 300 determines whether sensor conditions for clenching is fulfilled or not and this step is further elaborated in Figure 9. At step 902, the processor 300 interrogates the condition script of Table 1 noting that
15 Condition Line 1 requires the ACC0 readings. The processor 300 then proceeds to step 904 which directs the processor 300 to obtain and compute the readings from the sensor to obtain the readings for ACC0. When the readings for ACC0 are computed, the processor 300, at step 906, compares these readings with the conditions set out in Condition Line 1 of Table 1. If the conditions in
20 Condition Line 1 are not fulfilled, the processor 300 branches to step 904 again to obtain and compute new readings for ACC0 before proceeding to step 906 for the comparison. If the conditions are not fulfilled, the hand 100/digits 102a-102e would be at a previous stage of the exercise since the exercise cannot proceed.

After step 906, if the conditions of Condition Line 1 are fulfilled, the main processor 300 goes to step 908 to detect presence of a script marker which signifies the end of the script. If the script marker is not detected, the processor 300 goes back to step 902 to read the next line of conditions of the condition script of Table 1 i.e. Condition Line 2 which requires the EMG1 and EMG2 readings. Thus, at step 904, the main processor 300 obtains and computes the EMG1 and EMG2 readings from the biosensors 252,260. At step 906, the main processor 300 proceeds to compare the computed EMG1 and EMG 2 readings with the thresholds a set out in Condition Line 2. If the conditions are not fulfilled, again, the main processor 300 goes back to step 904 to obtain new EMG1 and EMG2 values and this loops until the conditions in Condition Line 2 are satisfied. In the alternative, it is envisaged that all the readings (eg. ACC0, EMG1, EMG 2) may be read at the same time which obviates a need to repeat step 902.

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When the conditions in Condition Line 2 are satisfied, the routine goes back to step 902 to obtain Condition Line 3 which requires the IR0 value. The main processor 300 next proceeds to steps 904,906 and if the condition in Condition Line 3 is met, the routine ends and this takes the processor 300 to step 804 of Figure 8.

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Since the conditions in step 802 are satisfied, the rehabilitation routine instructs the main processor 300 to perform the clenching of the digits 102a-102e and this step is further explained in the process steps of Figure 10.

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At step 1002, the motors 206a-206f are started and at step 1004, the processor 300 sets the first motor 206a as a current motor to check whether the first motor 206a fulfils conditions stated in steps 1006 to 1016 by actuating the corresponding fishing line 208a. When the fishing line 208 is actuated, this pulls
5 the corresponding fingertip holder 212a and the digit 102a starts to bend. The main processor 300 then goes to step 1006 to detect whether the first motor 206is stalling or not.

The stalling of the motor 206a is detected by the current sensor in the motor
10 206a and the values of the current sensor are feedback to the main processor 300. Loading of the motor 206a determines whether the motor would stall or not and the loading is directly proportional to the amount of clenching by the digit 102a. This is because as the digit 102a clenches, resistance experience by the motor 206a increases. The resistance is caused by the digit (which are not
15 functioning properly) and the biasing force of the resilient members 212a. If, for some reason, the pulling force created by the motor 206a is not able to overcome the resistance, the motor 206a would stall, and the current running through the motor 206a would peak. This peak is detected by the current sensor in the motor 206a which communicates this to the main processor 300 and the
20 process jumps to step 1010 which stops the actuation by the motor 206a. Once the first motor 206a is stopped, the process goes to step 1018 to determine if all the motors 206a-206f have stopped and if yes, the process ends. If not, the process jumps to step 1014.

If at step 1006, no stalling of the motor 206a is detected, the flow goes to step 1008 in which the main processor 300 determines whether maximum clench is detected based on the readings from the flex sensor 213 (located with the resilient member 212a). The reading from the flex sensor is configured to be
5 inversely proportional to the clenching which means that maximum clench is considered to be reached when the reading from the flex sensor is at a minimum, and the minimum is maintained for more than 250ms. When these conditions are satisfied, the main processor 300 considers that the maximum clench position is reached. When this happens, the process goes to step 1010
10 to stop the corresponding motor and subsequently to step 1018.

If the maximum clench is not detected, the process goes to step 1012 which checks a maximum count of the motor encoder 217 of the first motor 206a. As explained earlier, the encoder 217 measures the amount of rotation by the
15 motor 206a and enables the main processor 300 to determine the amount of displacement of the fishing line 208a. In this embodiment, the maximum count is set to 10cm which means that the maximum displacement of the fishing line does not go beyond 10cm. Needless to say, other values of maximum count and maximum displacement may be selected depending on application. The
20 encoder 217 includes a counter which is reset at step 1012. The main processor 300 checks the encoder for the amount of displacement of the fishing lines 208a. If the encoder 217 detects a displacement of the fishing line to be greater than 10cm, this causes the process to proceed to step 1010 which stops the corresponding motor 206a.

If the maximum count is not reached, the process goes to step 1014 to check whether the motor is the last motor or not. If it is not, the process goes to step 1016 which sets the second motor 206b as the active motor and the process jumps to step 1006 to repeat this and steps 1008 to 1014.

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If at step 1014, the motor is the last motor, then the process jumps to step 1004 which sets the current motor to the first motor 206a to check whether the conditions are fulfilled.

- 10 It should be appreciated that the steps in Figure 10 proposes actuating the motor individually to give flexibility to the therapist to activate one or more motors. This is to allow the possibility of doing therapy like picking a pencil with 3 fingers (pointer, middle and thumb to grip pencil while ring and pink fingers in clench position). However, it is envisaged that the motors 206a-206f may be
- 15 actually simultaneously.

Upon completion of the process of Figure 10, the routine goes to step 806 of Figure 8. At this step, a flow similar to that of Figure 9 is executed but instead of executing the condition script of Table 1, the condition script of Table 2 is

20 executed. In other words, at steps 904 and 906, the main processor 300 determines whether the Conditions Line 1 and Condition Line 2 of Table 2 are fulfilled or not and if they are fulfilled, then the routine goes to step 808 of Figure

8.

At step 808, the patient undergoes the second rehabilitation routine which is to flex the fingers, and the general actions of step 808 are illustrated in Figure 11. As it can be appreciated, the steps 1102,1104,1106,1110,1112,1114,1116,1118 are similar to the steps 1002,1004,1006,1010,1012,1014, 1016,1018 of Figure 10, except that instead of clenching, the exercise in Figure 11 is the flexion of fingers. Thus, these steps in Figure 11 would be understood based on the earlier description of Figure 10.

Step 1108 of Figure 11 corresponds to step 1008 of Figure 10 but for detecting the maximum flexion at step 1108, the maximum values of the flex sensors are required, instead of the minimum values. When the maximum values are reached and do not change for more than 250ms, the processor 300 would regard that the maximum flex position is reached.

When the maximum flexion is detected, the motors 206a-206f are stopped, and the process goes to step 810 of Figure 8 to determine whether the number of clenching and flexion is more than or less than a counter value. This counter value is determined by the therapist depending on the requirement of the patient, and likewise is scripted into the condition script (although not shown in Table 1 or 2). If the number of clenching and flexion is below this counter value, the flow goes back to step 802 and this is repeated together with the rest of the exercise i.e. steps 804, 806, 808 and 810, until the counter value is reached at step 810 and then the exercise routine ends.

As it can be appreciated from the above, the movement facilitation device 200 enables detection of the intention of the patient and based on the intention, assist the patient to actuate the fingers in a voluntary manner. Further, by using the patient or user's skeletal structure as the primary mechanical support to facilitate movement of the digits, this greatly reduces the complexity and size of the device 200. Broadly, the device 300 may be considered to have three sub-components – (i) robotics, (ii) reading patient's intent (to provide biofeedback – which is achieved by the biosensors 250,260) and (iii) navigation of the fingers and hand (via the biosensors 250,260, accelerometer and IR sensor 220). As a result, the device 200 is able to promote or enhance Nero-reorganisation and natural/normal finger and hand movements.

The described embodiment should not be construed as limitative. For example, the GUI module 202 of the described embodiment uses external memory (via the external memory card slot 304) for providing the various training routines but it is envisaged that the routines may also be stored in an internal memory, such as an internal memory of the processor 300. The training routines stored in the internal memory may be updated, revised or deleted via the USB port 202e.

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In the described embodiment, the passive actuator 212 is used to create the biasing force to flex the digits 102a-102e to the flex positions, and the active actuator 106 is used to actuate the fishing lines 208a-208f to move the digits 102a-102e from the flex positions to the unflex positions. However, the arrangement of the active actuator 206 and the passive actuator 212 may be

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swapped, or modified accordingly. For example, a passive actuator (not shown), similar to that used as the passive actuator 212, may be used to create a biasing force to urge the digits 102a-102e to the unflex position and an active actuator (not shown), similar to that used as the active actuator 206, is used to
5 actuate attachment means, such as flex strings 208, to move the digits 102a-102e from the unflex position to the flex position. In such an arrangement, the passive actuator may also be a resilient metallic or plastic strip but its rest state is the unflex position (e.g. clench position) and may be arranged adjacent the palm side of each of the digits 102a-102e. The active actuator may have a
10 similar configuration as the actuator 206, but the flex strings 208 are arranged along the fingernail side of each digit 102a-102e in order to be actuated to move the digits 102a-102e from the flex positions to the unflex positions.

Instead of using a passive actuator, it is also envisaged that there are
15 advantages in using active actuators for the movement of the digits 102a-102e between the flex and unflex positions.

In the described embodiment, in particular the flow charts of Figure 10, the digits 102a-102e are actuated one at a time but it would be appreciated that
20 more than one digit may be actuated together or simultaneously depending on the intention of the patient or training regime. In the described embodiment, the hand 100 is used as an example of a limb. However, the movement facilitation device 200 may be used to improve the function of a leg or foot and the movement facilitation device 200 is adapted to be used with the toes instead of
25 fingers.

In the described embodiment, the holders 214 are secured to each digit of the hand. However, it is envisaged that in a case of loss of function of some of the fingers, the device 200 may be adapted to be secured to those affected fingers, and not all of the fingers, and as a result, the device 200 may be adapted to facilitate movement of at least one finger.

Depending on accuracy desired, it is envisaged that it may not be necessary to use two bio sensor modules 250, 260 and instead one may be used in certain applications.

Having now fully described the invention, it should be apparent to one of ordinary skill in the art that many modifications can be made hereto without departing from the scope as claimed.

CLAIMS

1. A portable movement facilitation device for facilitating movement of a limb, comprising
5 a holding mechanism for securing to at least one digit of the limb;
at least one flex string attached to the holding mechanism, the at least one flex string and the holding mechanism being configured to rely on the at least one digit's skeletal structure as a primary mechanical structure for movement of the at least one digit; and
10 an actuating device operable to actuate the at least one flex string to facilitate the movement of the at least one digit between an unflex position and a flex position.
2. A portable movement facilitation device according to claim 1, wherein the
15 actuating device comprises an active actuator operable to actuate the at least one flex string.
3. A portable movement facilitation device according to claim 2, wherein the
20 active actuator is operable to actuate the at least one flex string to move the at least one digit from the flex to the unflex position.
4. A portable movement facilitation device according to claim 2, wherein the
active actuator is operable to actuate the at least one flex string to move the at least one digit from the unflex to the flex position.

5. A portable movement facilitation device according to any of claims 1 to 3, wherein the actuating device comprises a passive actuator configured to create a biasing force when the at least one digit is moved to the unflex position; and wherein the biasing force is arranged to urge the at least one digit from the unflex to the flex position.
6. A portable movement facilitation device according to claim 4, wherein the actuating device comprises a passive actuator configured to create a biasing force when the at least one digit is moved to the flex position; and wherein the biasing force is arranged to urge the at least one digit from the flex position to the unflex position.
7. A portable movement facilitation device according to claim 3 wherein the active actuator is operable to actuate the at least one flex string to move the at least one digit from the unflex to the flex position.
8. A portable movement facilitation device according to claim any preceding claim, further comprising guide rings adapted to be worn by the at least one digit, the guide rings being arranged to guide the at least one flex string.
9. A portable movement facilitation device according to any preceding claim further comprising a flex sensor for detecting flexing of the at least one digit.

10. A portable movement facilitation device according to claim 5 or 6, wherein the passive actuator includes at least one resilient member arranged adjacent to the back of the at least one digit.
- 5 11. A portable movement facilitation device according to any of claims 1-4 and 7, wherein the active actuator includes at least one motor operable to pull the at least one flex string to move the digit to the unflex position or flex position.
- 10 12. A portable movement facilitation device according to claim 11, wherein the active actuator includes a bobbin for stowing the at least one flex string, and wherein the at least one motor is operable to rotate the bobbin to dispense or retract the at least one flex string.
- 15 13. A portable movement facilitation device according to any of claims 1-4, 7, 11 and 12, wherein the active actuator includes an encoder for encoding amount of displacement of the at least one flex string.
14. A portable movement facilitation device according to any preceding
20 claim, wherein the at least one flex string is selected from the group consisting of: fishing line, nylon string, and polyester string.
15. A portable movement facilitation device according to any preceding claim further comprising an abrasion protector to be worn by the limb.

16. A portable movement facilitation device according to any preceding claim, further comprising an IR distance sensor for detecting distance of an object relative to the IR distance sensor.
17. A portable movement facilitation device according to any preceding
5 claim, further comprising a bio sensor for performing electromyography measurements on the limb.
18. A portable movement facilitation device according to claim 17, wherein
10 the bio sensor includes an accelerometer for measuring movements of the limb.
19. A portable movement facilitation device according to claim 18, further
comprising a controller operable to control the actuation of the actuating
device based on a reading from the accelerometer.
- 15 20. A portable movement facilitation device according to claim 17, further
comprising a controller operable to control the actuation of the active
actuator based on the electromyography measurements.
- 20 21. A portable movement facilitation device according to any preceding
claim, wherein the limb is a hand, and the at least one digit is a finger or
thumb.
22. A portable movement facilitation device according to any preceding
25 claim, wherein the holding mechanism comprises a plurality of finger tip

holders, with each holder configured to be secured to a respective digit;
and

a plurality of flex strings with each flex string attached to respective ones
of the plurality of fingertip holders.

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23. A portable movement facilitation device according to any preceding
claim, further comprising a glove for carrying the holding mechanism, the
at least one flex string and the actuating device.

10 24. Use of a portable movement facilitation device according to any
preceding claim to maintain and/or improve condition of a person's limb
and digits.

15 25. A method of operating a portable movement facilitation device according
to any preceding claim, the device including a bio sensor according to
claim 17, the method comprising the steps of:
receiving an electromyography measurement;
comparing the electromyography measurement with a threshold and if
the measurement exceeds the threshold, controlling the actuating device
20 to actuate the at least one flex string to flex the at least one digit.

26. A method according to claim 25, wherein the bio sensor further
comprises an accelerometer according to claim 18, and the method
further comprises the step of
25 receiving a reading from the accelerometer;

comparing the reading with an accelerometer threshold and if the measurement exceeds the threshold, controlling the actuating device to actuate the at least one flex string to flex the at least one digit.

- 5 27. A method according to claim 25 or 26, wherein the device further comprises the flex sensor of claim 9, and the method further comprises the steps of:

receiving a reading from the flex sensor; and determining whether maximum clenching or maximum flexion has been achieved by the at
10 least one digit.

28. A method according to claim 27, further comprising the step of stopping the actuation of the actuating device when the maximum clenching or maximum flexion is reached.