



(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
02.10.2019 Bulletin 2019/40

(21) Application number: **16831818.6**

(22) Date of filing: **22.11.2016**

(51) Int Cl.:
A61B 5/04 (2006.01) **A61B 5/0488** (2006.01)
A61B 5/11 (2006.01) **A61B 5/00** (2006.01)
A61F 2/50 (2006.01) **A61B 5/22** (2006.01)
A61F 2/54 (2006.01) **A61F 2/58** (2006.01)
A61F 2/68 (2006.01) **A61B 8/00** (2006.01)

(86) International application number:
PCT/ES2016/070833

(87) International publication number:
WO 2018/096188 (31.05.2018 Gazette 2018/22)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

(71) Applicants:
• **Fundación Tecnalia Research & Innovation**
48160 Derio - Bizkaia (ES)
• **The Regents of the University of California**
Oakland, CA 94607 (US)
• **Eberhard Karls Universität Tübingen**
72074 Tübingen (DE)

(72) Inventors:
• **RAMOS MURGUIALDAY, Ander**
20009 Donostia (Guipúzcoa) (ES)
• **SARASOLA, Andrea**
72074 Tübingen (DE)
• **CARMENA RAMON, Jose Miguel**
Berkeley, California 94720-3370 (US)
• **MCINTYRE, Joseph**
20009 Donostia (Guipúzcoa) (ES)

(74) Representative: **ZBM Patents - Zea, Barlocchi & Markvardsen**
Plaza Catalunya, 1 2nd floor
08002 Barcelona (ES)

(54) **PARETIC LIMB REHABILITATION METHOD AND SYSTEM**

(57) Generator systems are provided for generating a neuromuscular-to-motion decoder from a healthy limb. The generator system is configured to receive neuromuscular signals from neuromuscular sensors associated to predefined muscle/nerve locations of at least one pair of agonist and antagonist muscles/nerves of the healthy limb, obtained during performance by the person of a predefined exercise (defined by predefined exercise data) with the healthy limb; to receive motion signals from motion sensors associated to predefined positions of the healthy limb, during performance by the person of the predefined exercise with the healthy limb; and to generate the neuromuscular-to-motion decoder by mapping the neuromuscular signals to the motion signals over time using a mapping method. Rehabilitation systems are also provided for rehabilitating a paretic limb by using a neuromuscular-to-motion decoder produced by a generator system. Methods and computer programs suitable for being performed in said generator systems and rehabilitation systems are also provided.

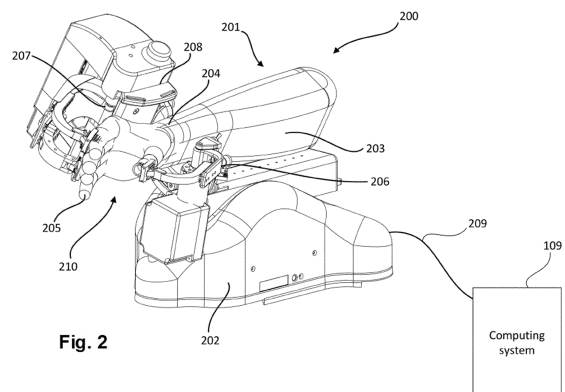


Fig. 2

Description

[0001] The present disclosure relates to methods, systems and computer programs for rehabilitating a paretic limb of a patient.

5

BACKGROUND

[0002] Brain vascular accidents caused by stroke, brain injury, or cerebral paralysis are one of the main causes of long-term motor disability worldwide and in more than 85% of these cases functional deficits in motor control occur. Incidence of first stroke in Europe is about 1.1 million and prevalence about 6 million. Of all stroke survivors showing no active upper limb motion at hospital admission 14% showed complete recovery, 30% showed partial recovery and 56% show little or no recovery, and the grand majority retained sensory function.

10

[0003] Electromyography (EMG) is an electro-diagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles. An EMG signal represents the electric potential generated by muscle cells when these cells are electrically or neurologically activated. The EMG signals are generally used to detect medical abnormalities, activation level, or recruitment order, or to analyse the biomechanics of human or animal movement.

15

[0004] Systems and methods for rehabilitating a paretic limb are known in the state of the art, which are based on using EMG signals from the paretic limb and applying an assistive motion/force through a robot-aided tool.

[0005] Some of said systems/methods use EMG signals of the paretic limb as an indicator of the overall generated effort, and trigger a pre-programmed assistive movement when the amplitude of the muscle activation goes over a predefined threshold.

20

[0006] Other known EMG-based systems and methods comprise implemented proportional controllers in which the amount of the provided assistive force is proportional to the amplitude of the EMG signal recorded from the impaired limb.

[0007] In some other known EMG-based systems and methods, the direction and amplitude of the intended movement are deduced depending on the EMG signals (from the paretic limb) themselves.

25

[0008] WO2016076886 (A1) discloses a system for motor rehabilitation of a paretic limb of a patient comprising: a first plurality of sensors for registering brain neuro-signals of the patient; a body-actuator couplable to, at least, the paretic limb; a hybrid brain machine interface for decoding brain neurosignals into movements of the body-actuator. The system further comprises: a second plurality of EMG sensors couplable to the paretic limb for registering its neuromuscular activity; means for providing the patient with instructions relative to a series of exercises and/or tasks to be carried out with the paretic limb; and in that upon carrying out a series of training sessions, each session comprising at least a set of such instructions. The hybrid brain machine interface is configured to switch between controlling the movements of the body-actuator based on the decoded brain neurosignals and a hybrid control of the movements of the body-actuator, when a significant level of decodable neuromuscular activity has been registered, the hybrid control being an EMG-gated brain control. The invention also relates to a method for motor rehabilitation of the paretic limb.

30

35

[0009] An object of the present disclosure is improving the methods, systems and computer programs for rehabilitating a paretic limb of a patient.

SUMMARY

40

[0010] In a first aspect, a generator system is provided for generating a neuromuscular-to-motion decoder from a healthy limb of a person. The generator system comprises neuromuscular sensors, motion sensors, and a controller system.

[0011] The controller system (of the generator system) is configured to receive neuromuscular signals obtained by the neuromuscular sensors associated to predefined muscle and/or nerve locations of at least one pair of agonist and antagonist muscles/nerves of the healthy limb. The neuromuscular signals are obtained during performance by the person of a predefined exercise with the healthy limb. The predefined exercise is defined by predefined exercise data.

45

[0012] The controller system (of the generator system) is further configured to receive motion signals obtained by the motion sensors associated to predefined positions of the healthy limb. The motion signals are obtained during performance by the person of the predefined exercise with the healthy limb. The predefined positions of the healthy limb may be such that motions resulting from neuromuscular activity (represented by the obtained neuromuscular signals) are suitably sensed by the motion sensors.

50

[0013] The controller system (of the generator system) is still further configured to generate the neuromuscular-to-motion decoder by mapping the neuromuscular signals to the motion signals over time using a mapping method.

55

[0014] The proposed generator system may be very useful in the sense that the neuromuscular-to-motion decoder produced by the generator system may be used for effectively rehabilitating a paretic limb of a patient.

[0015] The neuromuscular-to-motion decoder may be a mathematical function or module defining a mapping or cause-effect relationship between both types of signals, i.e. an evolution over time of motion signals (effect) depending on

neuromuscular signals (cause).

[0016] In an example, the neuromuscular-to-motion decoder may be generated in the form of a mathematical function by using a statistical method such as e.g. a regression method. In another example, the neuromuscular-to-motion decoder may be a mathematical module implementing e.g. an artificial neural network or the like. The mathematical function or module implementing the neuromuscular-to-motion decoder may be trained based on a machine learning method using the neuromuscular and motion signals from the healthy limb.

[0017] The neuromuscular-to-motion decoder may be used as a model representing which motion is derived from which neuromuscular activity in the healthy limb. The neuromuscular-to-motion decoder may thus be used for rehabilitating a paretic limb of a patient by taking the neuromuscular-to-motion decoder as a neuromuscular behaviour of reference to be finally achieved by the paretic limb.

[0018] The generator system may be used to generate an initial version of the neuromuscular-to-motion decoder from a healthy limb of a person, and said initial version may be subsequently enriched by using the generator system applied to a healthy limb of other people. Hence, the proposed generator system may be properly used to obtain a powerful neuromuscular-to-motion decoder from several healthy limbs, one of which belonging to a patient to be rehabilitated or not.

[0019] In a second aspect, a rehabilitation system is provided for rehabilitating a paretic limb of a patient by using a neuromuscular-to-motion decoder generated by a generator system as the one described before. The rehabilitation system comprises neuromuscular sensors, motion sensors, and a controller system. The paretic limb may be of a same type as a healthy limb taken into account in the generation of the neuromuscular-to-motion decoder.

[0020] The controller system (of the rehabilitation system) is configured to receive neuromuscular signals obtained by the neuromuscular sensors associated to predefined muscle and/or nerve locations of the paretic limb corresponding to predefined muscle and/or nerve locations of one (or more) healthy limb(s) taken into account in the generation of the neuromuscular-to-motion decoder. The neuromuscular signals are obtained during an attempt by the patient to perform with the paretic limb a predefined exercise defined by predefined exercise data taken into account in the generation of the neuromuscular-to-motion decoder.

[0021] The controller system (of the rehabilitation system) is further configured to input the neuromuscular signals to the neuromuscular-to-motion decoder for causing the neuromuscular-to-motion decoder to output first motion commands. That is, the cause-effect relationship between neuromuscular signals and motion signals from one (or more) healthy limbs is used to infer a motion to be performed by the paretic limb.

[0022] The controller system (of the rehabilitation system) is still further configured to receive motion signals obtained by the motion sensors associated to predefined positions of the paretic limb corresponding to predefined positions of the healthy limb taken into account in the generation of the neuromuscular-to-motion decoder. The motion signals are obtained during the attempt by the patient to perform the predefined exercise with the paretic limb.

[0023] The controller system (of the rehabilitation system) is additionally configured to determine trajectory data defining a trajectory to be followed by the paretic limb depending on a deviation between the motion signals and the predefined exercise data, and to determine second motion commands depending on the determined trajectory data to be followed by the paretic limb.

[0024] The controller system (of the rehabilitation system) is still additionally configured to determine final motion commands depending on the first motion commands and the second motion commands, and to send the final motion commands to a body actuator associated to the paretic limb for controlling the body actuator so as to stimulate (or induce) the patient to perform the predefined exercise with the paretic limb.

[0025] The proposed rehabilitation system permits inducing a "hybrid" motion of the paretic limb combining a motion component due to neuromuscular activity detected in the paretic limb (first motions commands), and another motion component aimed at guiding the paretic limb towards a valid trajectory according to the predefined exercise data (second motion commands).

[0026] Once the patient has achieved a high level of rehabilitation, the guiding component (second motion commands) may be highly reduced for causing the neuromuscular activity of the paretic limb (first motion commands) to be the main driving inducer of the motion of the paretic limb.

[0027] During initial and intermediate (i.e. non-final) rehabilitation stages, the first motion commands may represent an incorrect motion of the paretic limb and the second motion commands may represent a correction of said incorrect motion aimed at redirecting the limb towards a valid trajectory according to the predefined exercise data.

[0028] This hybrid motion may cause a visual and/or proprioceptive feedback on the patient when guiding the patient to finally complete the exercise. This feedback may provide the patient with information about the correctness of his/her muscular activations and hence, may establish a closed-loop system that might lead to the activation of neuro-plastic mechanisms that can restore the motor function. Other types of feedback that can be provided are e.g. haptic, auditory, etc.

[0029] The generator and rehabilitation systems proposed herein permit predicting kinematic (or motion) signals from the neuromuscular activity of the paretic limb and, therefore, establishing a continuous myoelectric control of the body actuator (e.g. an exoskeleton).

[0030] In some examples, a body actuator other than an exoskeleton may be used, in which case additional decoding(s)

may be needed. For example if a Functional electrical stimulation (FES) system is used, the motion signals may be mapped into electrostimulation signals that may cause motions of the paretic limb according to the motion signals.

5 [0031] An exoskeleton and a FES system may cooperate to function as body actuator. Other neuromuscular stimulation systems based on e.g. ultrasound waves and/or optical (e.g. infrared) waves may also be used as body actuator, in cooperation or not with an exoskeleton and/or a FES system.

[0032] The person taken into account by the generator system to generate the neuromuscular-to-motion decoder and the patient rehabilitated by the rehabilitation system may coincide or not. In the first case, a mirrored effect may be achieved in the sense that the neuromuscular behaviour of the healthy limb of the patient may be somehow replicated on the paretic limb of the patient using the rehabilitation system. In the second case, a neuromuscular-to-motion decoder generated from one or more healthy limbs of people different from the patient may be used to rehabilitate the patient through the rehabilitation system also with acceptable results.

10 [0033] When the person "processed" by the generator system coincides with the patient "processed" by the rehabilitation system, the use of neuromuscular and kinematic/motion signals from the healthy limb to generate the neuromuscular-to-motion decoder enables the creation of a subject-specific model of correct activity.

15 [0034] The participation of agonist-antagonist muscle/nerve pairs permits suitably controlling the compensatory over-activation of antagonist muscles/nerves inherent in stroke patients.

[0035] Providing intuitive feedback based on a model of healthy activity could inhibit pathological synergies and enhance the re-integration of the correct and natural patterns of muscle/nerve activations.

20 [0036] The suggested rehabilitation system has been proven to be applicable not only to mild and moderate but also to severely paralysed patients, who often retain some residual neuromuscular activity in spite of being unable to produce any movement of the affected limb. Hence, patients who are not eligible for many prior art rehabilitation methods (and systems) may benefit from the proposed rehabilitation system.

25 [0037] This proposed neuromuscular-powered (rehabilitation) system may require continuous activation of the paretic muscles/nerves to drive the movement of the body actuator, thereby guaranteeing the engagement of the patient at all times during the rehabilitation therapy.

[0038] Given final motion commands causing an actuation of the body actuator and given neuromuscular signals from which said final motion commands are derived, less than 300ms may elapse between the actuation of the body actuator and the obtaining of the neuromuscular signals. Such a contingent link between action and feedback may effectively promote plasticity and, hence, learning and rehabilitation in the patient.

30 [0039] The proposed generator and rehabilitation systems may thus permit an effective rehabilitation without the need of processing brain neuro-signals, as it is required in the case of some prior art systems. Hence, the suggested generator and rehabilitation systems may be significantly simpler and cheaper than prior art systems based on processing brain neuro-signals.

35 [0040] In some examples of the generator system and/or the rehabilitation system, the neuromuscular sensors may comprise one or more electromyography (EMG) sensors, and/or one or more electroneurography (ENG) sensors, and/or one or more ultrasound sensors, and/or one or more optical sensors. Said sensors may be invasive or not.

[0041] ENG sensors generate ENG signals representing measurements of the electrical activity of a nerve, ultrasound sensors measure mechanical properties of a muscle/nerve based on ultrasound waves, and optical sensors measure optical properties of a muscle/nerve based on optical waves (e.g. infrared waves).

40 [0042] The generator system and/or the rehabilitation system may be constituted by means which may be electronic means or computing means used interchangeably. That is, a part of the means may be electronic means and the other part may be computer means, or all the means may be electronic means (fully electronic system) or all the means may be computer means (fully computing system).

45 [0043] Examples of systems comprising only electronic means may be a CPLD (Complex Programmable Logic Device), an FPGA (Field Programmable Gate Array) or an ASIC (Application-Specific Integrated Circuit).

[0044] More detailed descriptions of the generator and rehabilitation systems and optional features thereof are disclosed in other parts of the description.

50 [0045] In a third aspect, a generator method is provided for generating a neuromuscular-to-motion decoder from a healthy limb of a person. The generator method comprises receiving neuromuscular signals obtained by neuromuscular sensors associated to predefined muscle and/or nerve locations of at least one pair of agonist and antagonist muscles/nerves of the healthy limb. The neuromuscular signals are obtained during performance by the person of a predefined exercise with the healthy limb. The predefined exercise is defined by predefined exercise data.

[0046] The generator method further comprises receiving motion signals obtained by motion sensors associated to predefined positions of the healthy limb. The motion signals are obtained during performance by the person of the predefined exercise with the healthy limb.

55 [0047] The generator method still further comprises generating the neuromuscular-to-motion decoder by mapping the neuromuscular signals to the motion signals over time using a mapping method. The neuromuscular-to-motion decoder may be used for rehabilitating a paretic limb.

[0048] Since the proposed generator method is suitable for being performed by the generator system, all the aspects and principles commented with respect to the generator system can be similarly attributed to the generator method.

[0049] In a fourth aspect, a rehabilitation method is provided for rehabilitating a paretic limb of a patient by using a neuromuscular-to-motion decoder generated by a generator method as the one previously described.

[0050] The rehabilitation method comprises receiving neuromuscular signals obtained by neuromuscular sensors associated to predefined muscle and/or nerve locations of the paretic limb corresponding to predefined muscle and/or nerve locations of a healthy limb taken into account in the generation of the neuromuscular-to-motion decoder. The neuromuscular signals are obtained during an attempt by the patient to perform with the paretic limb a predefined exercise defined by predefined exercise data taken into account in the generation of the neuromuscular-to-motion decoder.

[0051] The rehabilitation method further comprises inputting the neuromuscular signals to the neuromuscular-to-motion decoder for causing the neuromuscular-to-motion decoder to output first motion commands.

[0052] The rehabilitation method still further comprises receiving motion signals obtained by motion sensors associated to predefined positions of the paretic limb corresponding to predefined positions of the healthy limb taken into account in the generation of the neuromuscular-to-motion decoder. The motion signals are obtained during the attempt by the patient to perform the predefined exercise with the paretic limb.

[0053] The rehabilitation method additionally comprises determining trajectory data defining a trajectory to be followed by the paretic limb depending on a deviation between the motion signals and the predefined exercise data, and determining second motion commands depending on the determined trajectory data to be followed by the paretic limb.

[0054] The rehabilitation method still additionally comprises determining final motion commands depending on the first motion commands and the second motion commands, and sending the final motion commands to a body actuator associated to the paretic limb for controlling the body actuator so as to stimulate (or induce) the patient to perform the predefined exercise with the paretic limb.

[0055] Since the proposed rehabilitation method is suitable for being performed by the rehabilitation system, all the aspects and principles commented with respect to the rehabilitation system can be similarly attributed to the rehabilitation method.

[0056] In a fifth aspect, a computing system is provided comprising a memory and a processor, embodying instructions stored in the memory and executable by the processor, the instructions comprising functionality to execute a generator method for generating a neuromuscular-to-motion decoder from a healthy limb of a person.

[0057] This computing system may be a part of the generator system, i.e. a computing system inside the generator system, or may be the generator system itself.

[0058] In a sixth aspect, a further computing system is provided comprising a memory and a processor, embodying instructions stored in the memory and executable by the processor, the instructions comprising functionality to execute a rehabilitation method for rehabilitating a paretic limb of a patient.

[0059] This further computing system may be a part of the rehabilitation system, i.e. a computing system inside the rehabilitation system, or may be the rehabilitation system itself.

[0060] In a seventh aspect, a computer program product is provided comprising program instructions for causing a computing system to perform a generator method for generating a neuromuscular-to-motion decoder from a healthy limb of a person.

[0061] The computing system executing these program instructions may be a part of the generator system (i.e. a sub-system inside the generator system configured to reproduce the generator method described above) or may be the generator system itself.

[0062] In an eighth aspect, a further computer program product is provided comprising program instructions for causing a computing system to perform a rehabilitation method for rehabilitating a paretic limb of a patient.

[0063] The computing system executing these program instructions may be a part of the rehabilitation system (i.e. a sub-system inside the rehabilitation system configured to reproduce the rehabilitation method described above) or may be the rehabilitation system itself.

[0064] Any of the aforementioned computer program products may be embodied on a storage medium (for example, a CD-ROM, a DVD, a USB drive, on a computer memory or on a read-only memory) or carried on a carrier signal (for example, on an electrical or optical carrier signal).

[0065] Any of said computer programs may be in the form of source code, object code, a code intermediate source and object code such as in partially compiled form, or in any other form suitable for use in the implementation of the corresponding method. The carrier may be any entity or device capable of carrying the computer program.

[0066] For example, the carrier may comprise a storage medium, such as a ROM, for example a CD ROM or a semiconductor ROM, or a magnetic recording medium, for example a hard disk. Further, the carrier may be a transmissible carrier such as an electrical or optical signal, which may be conveyed via electrical or optical cable or by radio or other means.

[0067] When any of the computer programs is embodied in a signal that may be conveyed directly by a cable or other device or means, the carrier may be constituted by such cable or other device or means.

[0068] Alternatively, the carrier may be an integrated circuit in which the computer program is embedded, the integrated circuit being adapted for performing, or for use in the performance of, the relevant methods.

[0069] These and other advantages and features will become apparent in view of the detailed description and drawings.

5 BRIEF DESCRIPTION OF THE DRAWINGS

[0070] Non-limiting examples of the present disclosure will be described in the following, with reference to the appended drawings, in which:

10 Figure 1 is a schematic representation of a generator system according to examples.

Figure 2 is a schematic representation of a rehabilitation system according to examples.

15 Figure 3 is a flow chart schematically illustrating a generator method according to examples.

Figure 4 is a flow chart schematically illustrating a rehabilitation method according to examples.

20 Figures 5 - 7 are flow charts schematically illustrating various examples of determining the final motion commands depending on first and second motion commands, in the context of a rehabilitation method similar to the one shown in Figure 4.

DETAILED DESCRIPTION OF EXAMPLES

25 **[0071]** An example of generator system is schematically shown in Figure 1, and an example of rehabilitation system is schematically shown in Figure 2. The generator system may be comprised in the rehabilitation system or not.

[0072] The generator system 100 may be configured to be applied to a healthy arm 110 but, in other examples, the system 100 could be configured to be applied to a healthy leg.

30 **[0073]** The generator system 100 may comprise a plurality of neuromuscular sensors 101 - 104, a control unit 106 and corresponding connections 105 connecting the neuromuscular sensors 101 - 104 and the control unit 106. In the particular case shown, the connections 105 are wired connections. However, all or part of said connections may be wireless. The generator system 100 may further comprise a computing (or controller) system 109.

[0074] The neuromuscular sensors 101 - 104 may comprise EMG sensor(s) and/or ENG sensor(s) and/or ultrasound sensor(s) and/or optical sensor(s) aimed at the same purpose. The neuromuscular sensors 101 - 104 may be invasive or not.

35 **[0075]** The control unit 106 may comprise a neuromuscular signal amplifier 107 for amplifying analogic neuromuscular signals from the neuromuscular sensors 101 - 104, and an Analog-to-Digital (AD) converter 108 for converting the amplified neuromuscular signals into digital neuromuscular signals.

40 **[0076]** A first set of neuromuscular sensors 101, 102 may be configured to be applied to a first pair of agonist and antagonist muscles/nerves of the arm (or leg) 110. A second set of neuromuscular sensors 103, 104 may be configured to be applied to a second pair of agonist and antagonist muscles/nerves of the arm (or leg) 110. Other sensor configurations different from the one shown are also possible. For example, the number of sensors applied to an agonist and to its antagonist may not coincide, i.e. unbalanced numbers of sensors are also possible.

45 **[0077]** The sensors (e.g. electrodes) 101 - 104 may be, for example, bipolar surface electrodes with conductive gel, and may be provided (or not) as an array with a high density of electrodes. The sensors (e.g. electrodes) 101 - 104 may be configured to be adhered (or, in some examples, implanted) to the skin of the patient for sensing neuromuscular activity at corresponding muscle and/or nerve locations. The sensors 101 - 104 may comprise e.g. subcutaneous sensors (e.g. electrodes).

50 **[0078]** The generator system may further comprise motion sensors (not shown) including e.g. inertial, magnetic or optical sensors (such as e.g. accelerometers, gyroscopes, etc.) arranged and configured to provide functionalities of motion detection and quantification. These sensors may be included (or embedded) in suitable devices, such as e.g. data gloves or the like, or even in an exoskeleton movable by the healthy limb with or without guiding functionalities aimed at guiding the healthy limb to perform a predefined exercise.

55 **[0079]** The control unit 106 may be connected to the computing system 109 in such a way that the computer 109 may receive neuromuscular signals from the sensors 101 - 104 during performance of a predefined exercise. Suitable connections between the motion sensors and the computing system 109 may also exist for the computer 109 to receive motion signals generated by the motion sensors.

[0080] The computing system 109 may comprise a memory and a processor. The memory may store a computer program comprising instructions that are executable by the processor for causing the performance of a generator method

for generating a neuromuscular-to-motion decoder from a healthy limb. This "generator" computer program may be a standalone program or may require the loading of external module(s) or other pieces of software.

[0081] A resulting neuromuscular-to-motion decoder may be stored in a repository (e.g. hard disk) associated to the computing system 109. This repository may be local or remote with respect to the computer system 109.

[0082] Figure 2 is a schematic representation of a rehabilitation system for rehabilitating a paretic limb, according to examples. The rehabilitation system may comprise a configuration similar to the one shown in Figure 1, with neuromuscular sensors for obtaining signals representing the neuromuscular activity of the paretic limb during performance of a predefined exercise. This predefined exercise may be the same as the one taken into account for obtaining the neuromuscular-to-motion decoder to be used for rehabilitating the paretic limb. The rehabilitation system may further comprise corresponding motions sensors and a computing (or controller) system 109.

[0083] In some examples, a generator system such as the one shown in Figure 1 may be comprised in a rehabilitation system such as the one shown in Figure 2. In this case, the neuromuscular sensors used to generate the neuromuscular-to-motion decoder may be reused to obtain neuromuscular signals from a paretic limb to be rehabilitated. The same computing system 109 may be employed for e.g. executing both a generator method and a rehabilitation method as explained in other parts of the description.

[0084] In the particular case of Figure 2, it is shown a robotic exoskeleton 200 (as body actuator) configured to be applied to an arm 201. However, in other examples, the robotic exoskeleton 200 may be mountable to a leg. In other examples, the body actuator may be a Functional electrical stimulation (FES) system, or any other type of system that could provide the patient with feedback about his/her neuromuscular activity. In further examples, an exoskeleton and a FES system may cooperate to function as a hybrid body actuator or the like. Neuromuscular stimulation systems based on ultrasound waves and/or optical waves may also be used, in combination or not with an exoskeleton and/or a FES system for body actuation.

[0085] The robotic exoskeleton 200 may be movable according to a number of degrees of freedom so as to permit the motion of different segments of the arm 201, such as e.g. upper arm (not shown), forearm 203, wrist 204 and fingers 205. The exoskeleton 200 may be configured to permit functional movements of the arm (or leg).

[0086] In particular examples, the robotic exoskeleton 200 may comprise a mobile base 202 and a hand-module 210 that may be mountable on the mobile base 202.

[0087] The mobile base 202 may have, in some examples, three degrees of freedom and may (optionally) include a camera for tracking bi-dimensional movements of the base on a plane of reference. Other quantities of degrees of freedom different from three may be considered in other examples.

[0088] The hand-module 210 may have, in some examples, four degrees of freedom and (optionally) may be configured to track the motion of the wrist 204 and/or fingers 205. Other numbers of degrees of freedom may be considered in different examples.

[0089] The robotic exoskeleton 200 may comprise motors 206 - 208 each configured to cause movement of the exoskeleton in a corresponding degree of freedom.

[0090] For the sake of simplicity, only some motors 206 - 208 are indicated in the figure. The exoskeleton 200 may however comprise other quantities of motors, depending on e.g. the number of degrees of freedom under consideration.

[0091] A controller of the motors 206 - 208 of the exoskeleton 200 may be connectable to the computer system 109 through a connection 209 that may be e.g. a USB connection. Other types of connections are also possible, such as e.g. wireless connections.

[0092] Different motors 206 - 208 of the exoskeleton 200 may communicate between them through a CAN communication, so that a proper communication channel between the computer system 109 and the motors 206 - 208 may be defined.

[0093] The exoskeleton 200 may also provide functionalities of motion detection and quantification. These functionalities may be provided through e.g. rotary encoders (a type of motion sensors) configured to generate motion signals representing motion conditions associated to different degrees of freedom. A (rotatory) encoder may be included in a corresponding motor 206 - 208.

[0094] Motion sensors similar to the ones described with reference to generator system (of Figure 1) may also be comprised in rehabilitation system (of Figure 2). In the case that the generator system is comprised in the rehabilitation system, the motion sensors of the generator system may be reused to participate in rehabilitating a paretic limb.

[0095] In any case, with respect to motion sensors of either a generator or rehabilitation system or a combination thereof, a motion condition (sensed by a motion sensor) may comprise e.g. at least one of a position, a velocity, an acceleration, a torque, a force etc. in a given degree of freedom.

[0096] Additionally or alternatively to the encoders described before, known inertial, magnetic or optical sensors embedded in suitable devices, such as e.g. data gloves, or in wearable parts of the exoskeleton, may be used to implement the functionalities of motion detection and quantification.

[0097] The communication channel(s) established between the computer system 109 and the motors 206 - 208 of the exoskeleton 200 may permit the computer system 109 to receive the motion signals (from encoders). As explained in

detail in other parts of the description, said motion signals may be suitably processed by the computer system 109 in the context of methods for rehabilitating a paretic limb.

[0098] The communication channel(s) between the computer system 109 and the motors 206 - 208 of the exoskeleton 200 may permit the computer system 109 to generate and send (final) motion commands to the exoskeleton 200. These (final) motion commands may induce the exoskeleton 200 to move as required in the context of methods for rehabilitating a paretic limb. Details about this are disclosed in other parts of the description.

[0099] The camera included in the mobile base 202 may also be connectable to the computer system 109 through e.g. a USB or wireless connection and/or may optionally permit determining bi-dimensional positions of the base 202 on the plane of reference. Said positions may be determined, for example, by decoding Data-matrix codes printed on a table defining the plane of reference.

[0100] The exoskeleton 200 may be configured to be indistinctly applied to a (right or left) healthy arm/leg, and to a (right or left) paretic arm/leg. This way, the same exoskeleton 200 may be used for performing both a generator method (with healthy limb or limbs) and a rehabilitation method (with paretic limb). Details about how the exoskeleton may be used in said generator and rehabilitation methods are explained in detail in other parts of the description.

[0101] Alternatively to an exoskeleton, such as the one of Figure 2, the rehabilitation system may comprise another type of body actuator, such as e.g. a neuromuscular stimulation system or a combination thereof. Examples of neuromuscular stimulation systems are e.g. a Functional electrical stimulation (FES) system, a neuromuscular stimulation system based on ultrasound waves, a neuromuscular stimulation system based on optical waves, etc.

[0102] The neuromuscular stimulation system (e.g. FES system) may be configured to provide functionalities of motion induction substantially equivalent to those provided by the exoskeleton as described before. That is, based on received motion commands, the (FES) system may (electro-) stimulate the arm (or leg) 201 in such a way that required motions of the arm (or leg) 201 are induced with same or similar results as if the exoskeleton were used.

[0103] Permitted motion directions substantially equivalent to the degrees of freedom described in relation to the exoskeleton may be taken into account if a neuromuscular stimulation system (e.g. FES system) is used as body actuator. That is, in the case of using a FES system instead of an exoskeleton, the arm 201 may be electro stimulated so as to cause the motion of the arm 201 only in said permitted motion directions.

[0104] The memory of the computing system 109 may further store a computer program comprising instructions that are executable by the processor for performing a rehabilitation method for rehabilitating a paretic limb. This "rehabilitation" program may be a separate program with respect to the "generator" program described in relation to Figure 1, or not. In this last case, the "rehabilitation" program and the "generator" program may be different subprograms (or sub-modules) of a same computer program providing both types of (generator and rehabilitation) functionalities.

[0105] The neuromuscular-to-motion decoder to be used by the rehabilitation system may be retrieved from a repository (e.g. hard disk) associated to the computing system 109. This repository may be local or remote with respect to the computer system 109.

[0106] Figure 3 shows a flowchart schematically illustrating an example of a generator method for generating a neuromuscular-to-motion decoder from a healthy limb. This generator method may take into account (neuromuscular and motion) signals from a healthy arm of a person during performance of a predefined exercise by the person with the healthy arm.

[0107] This generator method may be performed by using a generator system equal or similar to the ones described before with reference to previous figures. References to said previous figures may be thus included along the following description about Figure 3.

[0108] At block 300, the method may be started as a result of receiving a starting condition, such as e.g. a user request inputted by an operator of the generator system.

[0109] At this point, the person may be requested to perform the predefined exercise with the healthy arm. The predefined exercise may be defined by predefined exercise data which is available to the computer system 109.

[0110] In some examples, the computer system 109 may process the predefined exercise data to generate reproducible data and send it to a reproducing system, so as to provide audio and/or visual instructions to the person of how to perform the predefined exercise.

[0111] At block 301, neuromuscular signals may be received (by the computer system 109) from neuromuscular sensors 101 - 104 attached to the healthy arm, during performance of the predefined exercise.

[0112] The neuromuscular sensors 101 - 104 may be attached to regions of the healthy arm associated to predefined muscle and/or nerve locations of at least one pair of agonist and antagonist muscles/nerves of the healthy arm. The attachment of the neuromuscular sensors 101 - 104 may be equal or similar to the attachment shown in Figure 1, for example.

[0113] At block 302, motion signals may be received from motion sensors associated to predefined positions of the healthy limb, during performance of the predefined exercise. The nature of said motion sensors and corresponding motion signals are explained in detail in other parts of the description, in any case wherein an exoskeleton or a stimulation system (e.g. FES system) or a combination thereof is employed.

[0114] At block 303, a neuromuscular-to-motion decoder may be generated for each of all or some of the degrees of freedom (in exoskeleton-based examples) or permitted motion directions (in examples based on a stimulation system) under consideration.

[0115] Given a particular degree of freedom (or permitted motion direction), a neuromuscular-to-motion decoder may be generated by mapping the received neuromuscular signals and motion signals corresponding to said degree of freedom (or permitted motion direction). It is also possible to generate a single neuromuscular-to-motion decoder with different outputs corresponding to different degrees of freedom.

[0116] A neuromuscular-to-motion decoder may be, for example, a mathematical function or module defining a cause-effect relationship between both types of signals, i.e. an evolution over time of motion signals (effect) depending on neuromuscular signals (cause).

[0117] A diversity of mapping methods may be used to generate the neuromuscular-to-motion decoder, such as e.g. machine learning methods, statistical methods, datamining methods, etc. or a combination of at least some of them. In particular, linear regression, non-linear regression, Lasso regression, ridge regression, Kalman filter, support vector machine, neural network, fuzzy logic, etc. may be employed for that purpose.

[0118] For instance, a mathematical module may result from e.g. training a machine learning model based on the received neuromuscular signals and motion signals. A mathematical module may therefore result from said training that is configured to output motion values corresponding to input neuromuscular values.

[0119] In other examples, the received neuromuscular and motion signals (for different degrees of freedom or permitted motion directions under consideration) may be correlated (mapped), so that a shape or profile of a "cloud" of points corresponding to the neuromuscular and motion signals over time is modelled. A function may result from said correlation that is configured to output motion values corresponding to input neuromuscular values according to said modelling of the cloud of neuromuscular-motion points.

[0120] Figure 4 is a flow chart schematically illustrating a rehabilitation method for rehabilitating a paretic arm (or leg) of a patient. This rehabilitation method may use the neuromuscular-to-motion decoder(s) generated by a generator method such as the one described with reference to Figure 3.

[0121] This rehabilitation method may take into account (neuromuscular and motion) signals from the paretic arm of the patient during an attempt by the patient of performing the predefined exercise with the paretic arm.

[0122] This rehabilitation method may be performed by using a rehabilitation system similar to the ones described before with reference to previous figures. A computer program implementing the rehabilitation method may be stored and performed by the computer system 109. References to previous figures may also be included along the following description of Figure 4.

[0123] At block 400, the rehabilitation method may be started when desired by an operator of the rehabilitation system. The rehabilitation method may hence be triggered upon reception of a corresponding request inputted by the operator, for example.

[0124] At block 401, neuromuscular signals may be received (by the computer system 109) from neuromuscular sensors 101 - 104 attached to the paretic arm, during performance of the predefined exercise.

[0125] The attachment of the neuromuscular sensors 101 - 104 may be such that the neuromuscular sensors are associated to predefined muscle and/or nerve locations of the paretic arm (or leg) corresponding to predefined muscle and/or nerve locations of the healthy arm (or leg) taken into account in the generation of the neuromuscular-to-motion decoder to be used.

[0126] The rehabilitation system may provide audio and/or visual instructions to the patient of how to perform the predefined exercise.

[0127] At block 402, the neuromuscular signals may be inputted to the neuromuscular-to-motion decoder generated by corresponding generator method, for causing the neuromuscular-to-motion decoder to output first motion commands in different degrees of freedom (in exoskeleton-based examples) or permitted motion directions (in examples based on stimulation e.g. FES) under consideration.

[0128] The first motion commands may be seen as inductors of a motion due to the neuromuscular activity of the paretic arm, according to a cause-effect relationship between neuromuscular activity (cause) and motion (effect) of corresponding healthy arm, previously determined in the generator method.

[0129] At initial rehabilitation stages, said first motion commands may probably define a certainly erratic motion of the arm, so that a reduced weight may be initially attributed to the first motion commands.

[0130] At block 403, motion signals may be received from motion sensors (of the rehabilitation system) associated to predefined positions of the paretic arm (or leg) corresponding to predefined positions of the healthy arm (or leg) taken into account in the generation of the neuromuscular-to-motion decoder.

[0131] These motion signals may represent the motion that the paretic arm is actually following in the different degrees of freedom (or permitted motion directions) under consideration. The motion actually followed by the paretic arm may not match the trajectory to be followed as defined by the predefined exercise data.

[0132] At block 404, trajectory data defining a trajectory to be followed by the paretic arm may be determined depending

on a deviation between the motion signals and the predefined exercise data, in the different degrees of freedom (or permitted motion directions) under consideration.

[0133] The determined trajectory data may be seen as defining a corrected trajectory of the motion actually followed by the paretic arm (according to the received motion signals) for redirecting the motion of the arm towards a valid trajectory (according to the predefined exercise data).

[0134] In final rehabilitation phases, the trajectory defined by the received motion signals and the trajectory defined by the predefined exercise data may substantially coincide, in which case no redirection of the motion of the arm may be considered.

[0135] At block 405, second motion commands may be determined depending on the determined trajectory data to be followed by the paretic limb, in the different degrees of freedom (or permitted motion directions) under consideration.

[0136] The second motion commands may be seen as inductors of a corrective motion for redirecting (if needed) the paretic arm towards a valid trajectory according to the predefined exercise data.

[0137] In some examples, a Linear-quadratic regulator (LQR) method may be used for determining the trajectory data at block 404, and for determining the second motion commands at block 405.

[0138] At block 406, final motion commands may be determined depending on the first motion commands (from block 402) and the second motion commands (from block 405), in the different degrees of freedom (or permitted motion directions) under consideration.

[0139] The final motion commands may thus be seen as a combination of inductors of motion due to the neuromuscular activity of the paretic arm (first motion commands) and inductors of motion to redirect (if required) the paretic arm towards a valid trajectory (second motion commands).

[0140] At block 407, the final motion commands may be sent to the body actuator (robotic exoskeleton and/or stimulation system e.g. FES) so as to suitably stimulate (or induce) the patient to perform the predefined exercise with the paretic arm (or leg).

[0141] The execution of the final motion commands by the body actuator may provoke a visual and proprioceptive feedback about the correctness of muscle/nerve activations of the patient. The body actuator induces a "hybrid" motion on the paretic arm combining an incorrect motion component due to incorrect neuromuscular activity, and a corrective motion component aimed at redirecting the arm towards a valid trajectory (for completing the predefined exercise successfully). At final rehabilitation stages, the neuromuscular activity in the paretic arm may be correct or minimally incorrect, in which case the corrective component may be substantially negligible.

[0142] Blocks 401 - 407 may be continuously performed until the predefined exercise with the paretic arm has been completed. In this case, the rehabilitation method proceeds to final block 408.

[0143] The determination of the final motion commands depending on the first motion commands and the second motion commands, in the different degrees of freedom (or permitted motion directions) under consideration, may be performed in a diversity of manners.

[0144] Figure 5 is a flow chart that schematically illustrates an example of determining the final motion commands depending on the first and second motion commands, in the context of a rehabilitation method similar to the one described with reference to Figure 4.

[0145] At block 500, the first motion commands and the second motion commands may be compared for obtaining a first indicator of similarity, in each or some of the degrees of freedom (or permitted motion directions) under consideration.

This comparison may be performed, in some examples, using a normalized root-mean-square error (NRMSE) method and/or a correlation coefficient method.

[0146] In alternative examples, the indicator of similarity may be determined (with similar results) by comparing the neuromuscular signals (from paretic limb) and the neuromuscular signals (from healthy limb) taken into account to generate the neuromuscular-to-motion decoder. In this case, for example, the computing system 109 may store the neuromuscular signals from healthy limb, along with the neuromuscular-to-motion decoder.

[0147] At block 501, a first weight may be determined for the first motion commands and a second weight may be determined for the second motion commands depending on the first indicator of similarity (obtained at previous block 500).

[0148] The determination of the first weight and the second weight may be such that the higher is the first indicator of similarity, the higher is the first weight and the lower is the second weight. In particular examples, the second weight may be determined as a function of the first weight.

[0149] At block 502, the final motion commands may be determined based on the first motion commands weighted with the first weight and the second motion commands weighted with the second weight.

[0150] For example, the final motion commands may be determined according to the following formula:

$$V_{final} = V_{neuro} * w_1 + V_{assist} * w_2 = V_{neuro} * w_1 + V_{assist} * (1 - w_1) \quad \text{Formula 1}$$

wherein V_{final} is a final motion (e.g. velocity) command, V_{neuro} is a first motion command (due to neuromuscular activity), w_1 is a first weight, V_{assist} is a second motion command (for redirecting to valid trajectory) and w_2 is a second weight.

[0151] The first weight w_1 may be a value between 0 and 1, and the second weight w_2 may be equal to $1 - w_1$ (as indicated in second part of Formula 1). This way, $w_1 = 0$ implies that $w_2 = 1$ and $V_{final} = V_{assist}$ which means that a completely assistive motion is induced by the body actuator on the arm (neuromuscular activity is ignored). Accordingly, $w_1 = 1$ implies that $w_2 = 0$ and $V_{final} = V_{neuro}$ which means that a motion fully depending on neuromuscular activity is induced by the body actuator on the arm (assistive component is ignored).

[0152] The more similar are the first motion commands V_{neuro} (neuromuscular activity) to the second motion commands V_{assist} (assistive control) the better may be considered the neuromuscular activity generated by the patient on the paretic arm. So, in this case, the final motion commands V_{final} may be calculated with higher influence of V_{neuro} (higher w_1) and lower influence of V_{assist} (lower w_2).

[0153] The algorithm according to Figure 5 and, in particular, to Formula 1 may be applied for each or some of the different degrees of freedom (or permitted motion directions) under consideration.

[0154] Figure 6 is a flow chart that schematically illustrates a further example of determining the final motion commands depending on the first and second motion commands.

[0155] At block 600, input from a user, such as e.g. an operator of the rehabilitation system, may be received including an indicator of evolution of the rehabilitation of the patient. This indicator may be predetermined from previous executions of the rehabilitation method, for example.

[0156] At block 601, a third weight may be determined for the first motion commands and a fourth weight may be determined for the second motion commands, depending on the indicator of evolution of the rehabilitation (received at block 600).

[0157] The determination of the third weight and the fourth weight may be such that the higher is the indicator of evolution of the rehabilitation, the higher is the third weight and the lower is the fourth weight. In particular examples, the third weight may be determined as a function of the fourth weight.

[0158] At block 602, the final motion commands may be determined based on the first motion commands weighted with the third weight and the second motion commands weighted with the fourth weight.

[0159] For example, the final motion commands may be determined according to the following formula:

$$V_{final} = V_{neuro} * w_3 + V_{assist} * w_4 = V_{neuro} * w_3 + V_{assist} * (1 - w_3) \quad \text{Formula 2}$$

wherein V_{final} is a final motion (e.g. velocity) command, V_{neuro} is a first motion command (due to neuromuscular activity), w_3 is a third weight, V_{assist} is a second motion command (for redirecting to valid trajectory) and w_4 is a fourth weight.

[0160] The higher is the indicator of evolution of the rehabilitation the better may be considered the evolution and, hence, the neuromuscular activity generated by the patient on the paretic arm. So, in this case, the final motion commands V_{final} may be calculated with higher influence of V_{neuro} (higher w_3) and lower influence of V_{assist} (lower w_4). Weights w_3 and w_4 may be accordingly varied for that aim in a similar manner as described for weights w_1 and w_2 with respect to Figure 5 and Formula 1.

[0161] The algorithm according to Figure 6 and, in particular, to Formula 2 may be applied for each or some of the different degrees of freedom (or permitted motion directions) under consideration.

[0162] Figure 7 is a flow chart that schematically illustrates a still further example of determining the final motion commands depending on the first and second motion commands.

[0163] At block 700, the first motion commands and the second motion commands may be compared for obtaining a second indicator of similarity between the first motion commands and the second motion commands, in each or some of the degrees of freedom (or permitted motion directions) under consideration.

[0164] At block 701, the first motion commands may be transformed based on the second indicator of similarity (between the first motion commands and the second motion commands). The first motion commands may be transformed based on a projection of vectors representing first motion commands on vectors representing second motion commands, for example. The first and second motion commands may be e.g. velocity vectors.

[0165] At block 702, the final motion commands may be determined based on the transformed first motion commands and the second motion commands.

[0166] For example, the final motion commands may be determined according to the following formula:

$$V_{final} = transformed(V_{neuro}) + V_{assist} \quad \text{Formula 3}$$

wherein V_{final} is a final motion (e.g. velocity) command, V_{neuro} is a first motion command (due to neuromuscular activity),

V_{assist} is a second motion command (for redirecting to valid trajectory) and $transformed(V_{neuro})$ is the transformed first motion command.

[0167] The algorithm according to Figure 7 and, in particular, to Formula 3 may be applied for each or some of the different degrees of freedom (or permitted motion directions) under consideration.

[0168] In any of the described examples based on weights, said weights may be updated in real-time (within same rehabilitation session or same execution of rehabilitation method). Alternatively, said weights may be kept fixed during one or more rehabilitation sessions or executions of rehabilitation method.

[0169] In any of the described examples relating to generator and rehabilitation methods, the received neuromuscular signals may be (optionally) rectified, and (optionally) filtered, and (optionally) processed by an algorithm of features extraction, and (optionally) normalized, and (optionally) processed by an algorithm of dimensionality reduction. Examples of algorithms of dimensionality reduction are Principal Component Analysis (PCA), Independent Component Analysis (ICA), Non-negative matrix factorization (NMF), etc. Examples of features that can be extracted from neuromuscular signals are time-domain features, frequency-domain features, muscle synergies, etc.

[0170] With respect to the normalization of the neuromuscular signals, it is aimed at adjusting the neuromuscular signals irrespective of any difference in amplitude between neuromuscular signals from healthy limb and neuromuscular signals from paretic limb. The normalization may be performed using e.g. a Z-score method or any other method aimed at the mentioned purpose.

[0171] According to the Z-score method, the normalization may be carried out by applying the following formula:

$$Normalized_Neuro = (Neuro - mean) / std \quad \text{Formula 4}$$

wherein *Neuro* is a neuromuscular signal to be normalized, *Normalized_Neuro* is the neuromuscular signal once normalized, *mean* is a mean of neuromuscular signals from same muscle/nerve location as *Neuro*, and *std* is a standard deviation of neuromuscular signals from same muscle/nerve location as *Neuro*.

[0172] Given a neuromuscular signal to be normalized, the mean and the standard deviation applicable to said signal may be calculated from neuromuscular signals previously received within the execution of the generator method or rehabilitation method.

[0173] In the case of generator method, the whole neuromuscular signals may be received (from healthy limb) and recorded in a first step and, subsequently, their normalization may be performed in a second step once the first step has been completed. This way, the mean and standard deviation to be used in the normalization may be calculated taking into account the whole neuromuscular signals (from healthy limb).

[0174] In the case of rehabilitation method, a predefined time interval of neuromuscular signals already received (from paretic limb) may be considered to calculate the mean and standard deviation. For example, the predefined time interval may comprise the last 60 seconds of already received neuromuscular signals.

[0175] Although only a number of examples have been disclosed herein, other alternatives, modifications, uses and/or equivalents thereof are possible. Furthermore, all possible combinations of the described examples are also covered. Thus, the scope of the present disclosure should not be limited by particular examples, but should be determined only by a fair reading of the claims that follow.

Claims

1. A generator system for generating a neuromuscular-to-motion decoder from a healthy limb of a person, the generator system comprising neuromuscular sensors, motion sensors, and a controller system that is configured to receive neuromuscular signals obtained by the neuromuscular sensors associated to predefined muscle and/or nerve locations of at least one pair of agonist and antagonist muscles/nerves of the healthy limb, said neuromuscular signals being obtained during performance by the person of a predefined exercise with the healthy limb, said predefined exercise being defined by predefined exercise data; receive motion signals obtained by the motion sensors associated to predefined positions of the healthy limb, said motion signals being obtained during performance by the person of the predefined exercise with the healthy limb; and generate the neuromuscular-to-motion decoder by mapping the neuromuscular signals to the motion signals over time using a mapping method whereby the neuromuscular-to-motion decoder is to be used for rehabilitating a paretic limb.
2. A generator system according to claim 1, wherein the neuromuscular sensors comprise one or more electromyography (EMG) sensors, and/or one or more electroneurography (ENG) sensors, and/or one or more ultrasound

sensors, and/or one or more optical sensors.

3. A generator system according to any of claims 1 or 2, wherein the neuromuscular sensors comprise one or more invasive sensors, and/or one or more non-invasive sensors.
- 5 4. A generator system according to any of claims 1 to 3, wherein the motion sensors are configured to generate the motion signals as velocity signals, and/or position signals, and/or torque signals, and/or force signals, and/or acceleration signals.
- 10 5. A generator system according to any of claims 1 to 4, wherein the mapping method comprises a machine learning method, or a statistical method, or a data mining method, or a combination of at least some of them.
6. A generator system according to claim 5, wherein the mapping method comprises a support vector machine method, or a neural network method, or a fuzzy logic method, or a linear regression method, or a non-linear regression method, or a Lasso regression method, or a ridge regression method, or a Kalman filter method, or a combination of at least some of them.
- 15 7. A generator system according to any of claims 1 to 6, wherein the controller system is configured to determine reproducible data of the predefined exercise based on the predefined exercise data; and send said reproducible data to a reproducing device so as to provide the person with audio and/or visual indications about the predefined exercise to be performed.
- 20 8. A generator system according to any of claims 1 to 7, comprising a body actuator.
- 25 9. A generator system according to claim 8, wherein the body actuator is a robotic exoskeleton configured to be mounted on the healthy limb.
10. A generator system according to claim 9, wherein the motion sensors are comprised in the robotic exoskeleton.
- 30 11. A generator system according to any of claims 9 or 10, wherein the robotic exoskeleton is configured to guide the person in performing the predefined exercise with the healthy limb based on the predefined exercise data.
- 35 12. A rehabilitation system for rehabilitating a paretic limb of a patient by using a neuromuscular-to-motion decoder generated by a generator system according to any of claims 1 to 11, the rehabilitation system comprising neuromuscular sensors, motion sensors, and a controller system that is configured to receive neuromuscular signals obtained by the neuromuscular sensors associated to predefined muscle and/or nerve locations of the paretic limb corresponding to predefined muscle and/or nerve locations of a healthy limb taken into account in the generation of the neuromuscular-to-motion decoder, the neuromuscular signals being obtained during an attempt by the patient to perform with the paretic limb a predefined exercise defined by predefined exercise data taken into account in the generation of the neuromuscular-to-motion decoder;
40 input the neuromuscular signals to the neuromuscular-to-motion decoder for causing the neuromuscular-to-motion decoder to output first motion commands;
receive motion signals obtained by the motion sensors associated to predefined positions of the paretic limb corresponding to predefined positions of the healthy limb taken into account in the generation of the neuromuscular-to-motion decoder, the motion signals being obtained during the attempt by the patient to perform the predefined exercise with the paretic limb;
45 determine trajectory data defining a trajectory to be followed by the paretic limb depending on a deviation between the motion signals and the predefined exercise data;
determine second motion commands depending on the determined trajectory data to be followed by the paretic limb;
50 determine final motion commands depending on the first motion commands and the second motion commands; and send the final motion commands to a body actuator associated to the paretic limb for controlling the body actuator so as to stimulate the patient to perform the predefined exercise with the paretic limb.
- 55 13. A rehabilitation system according to claim 12, wherein the controller system is configured to determine the final motion commands depending on the first motion commands and the second motion commands by weighting the first motion commands and the second motion commands based on a predefined weighting criterion; and determining the final motion commands based on the weighted first and second motion commands.

14. A rehabilitation system according to claim 13, wherein the controller system is configured to weight the first motion commands and the second motion commands based on the predefined weighting criterion by comparing the first motion commands to the second motion commands for obtaining a first indicator of similarity between the first motion commands and the second motion commands; and
 5 determining a first weight for the first motion commands and a second weight for the second motion commands depending on the first indicator of similarity, in such a way that the higher is the first indicator of similarity, the higher is the first weight and the lower is the second weight; and wherein
 10 the controller system is configured to determine the final motion commands based on the first motion commands weighted with the first weight and the second motion commands weighted with the second weight.
15. A rehabilitation system according to claim 14, wherein the controller system is configured to compare the first motion commands to the second motion commands by performing a normalized root-mean-square error (NRMSE) method and/or a correlation coefficient method.
16. A rehabilitation system according to any of claims 14 or 15, wherein the controller system is configured to determine the second weight as a function of the first weight.
17. A rehabilitation system according to claim 13, wherein the controller system is configured to weight the first motion commands and the second motion commands based on the predefined weighting criterion by
 20 receiving input from a user including an indicator of evolution of the rehabilitation; and
 weighting the first motion commands and the second motion commands based on the indicator of evolution of the rehabilitation.
18. A rehabilitation system according to claim 17, wherein the controller system is configured to weight the first motion commands and the second motion commands based on the indicator of evolution of the rehabilitation by
 25 determining a third weight for the first motion commands and a fourth weight for the second motion commands depending on the indicator of evolution of the rehabilitation, in such a way that the higher is the indicator of evolution of the rehabilitation, the higher is the third weight and the lower is the fourth weight; and wherein
 30 the controller system is configured to determine the final motion commands based on the first motion commands weighted with the third weight and the second motion commands weighted with the fourth weight.
19. A rehabilitation system according to claim 18, wherein the controller system is configured to determine the third weight as a function of the fourth weight.
20. A rehabilitation system according to claim 12, wherein the controller system is configured to determine the final motion commands depending on the first motion commands and the second motion commands by aggregating the first motion commands and the second motion commands.
21. A rehabilitation system according to claim 12, wherein the controller system is configured to determine the final motion commands depending on the first motion commands and the second motion commands by
 40 comparing the first motion commands to the second motion commands for obtaining a second indicator of similarity between the first motion commands and the second motion commands;
 transforming the first motion commands based on the second indicator of similarity between the first motion commands and the second motion commands; and
 45 determining the final motion commands based on the transformed first motion commands and the second motion commands.
22. A rehabilitation system according to claim 21, wherein the controller system is configured to transform the first motion commands based on a projection of the first motion commands on the second motion commands.
23. A rehabilitation system according to claim 13, wherein the controller system is configured to weight the first motion commands and the second motion commands based on the predefined weighting criterion by
 50 comparing the received neuromuscular signals to neuromuscular signals taken into account to generate the neuromuscular-to-motion decoder, for obtaining a third indicator of similarity between the received neuromuscular signals and the neuromuscular signals taken into account to generate the neuromuscular-to-motion decoder; and
 55 determining a fifth weight for the first motion commands and a sixth weight for the second motion commands depending on the third indicator of similarity, in such a way that the higher is the third indicator of similarity, the higher is the sixth weight and the lower is the fifth weight; and wherein

the controller system is configured to determine the final motion commands based on the first motion commands weighted with the fifth weight and the second motion commands weighted with the sixth weight.

- 5 **24.** A rehabilitation system according to any of claims 12 to 23, wherein the controller system is configured to determine reproducible data of the predefined exercise based on the predefined exercise data; and send said reproducible data to a reproducing device so as to provide the patient with audio and/or visual indications about the predefined exercise to be attempted.
- 10 **25.** A rehabilitation system according to any of claims 12 to 24, wherein the controller system is configured to determine the trajectory data defining the trajectory to be followed by the paretic limb based on a Linear-quadratic regulator (LQR) method.
- 15 **26.** A rehabilitation system according to any of claims 12 to 25, wherein the neuromuscular sensors comprise one or more electromyography (EMG) sensors, and/or one or more electroneurography (ENG) sensors, and/or one or more ultrasound sensors, and/or one or more optical sensors.
- 20 **27.** A rehabilitation system according to any of claims 12 to 26, wherein the neuromuscular sensors comprise one or more invasive sensors, and/or one or more non-invasive sensors.
- 25 **28.** A rehabilitation system according to any of claims 12 to 27, wherein the motion sensors are configured to generate the motion signals as velocity signals, and/or position signals, and/or torque signals, and/or force signals, and/or acceleration signals.
- 30 **29.** A rehabilitation system according to any of claims 12 to 28, comprising the body actuator.
- 35 **30.** A rehabilitation system according to claim 29, wherein the body actuator comprises a robotic exoskeleton configured to be mounted on the paretic limb.
- 40 **31.** A rehabilitation system according to claim 30, wherein the motion sensors are comprised in the robotic exoskeleton.
- 45 **32.** A rehabilitation system according to any of claims 29 to 31, wherein the body actuator comprises a Functional electrical stimulation (FES) system, and/or an ultrasound-based neuromuscular stimulation system and/or an optical-based neuromuscular stimulation system.
- 50 **33.** A rehabilitation system according to any of claims 12 to 32, comprising the generator system.
- 55 **34.** A rehabilitation system according to claim 33, wherein the neuromuscular sensors of the rehabilitation system and the neuromuscular sensors of the generator system are the same neuromuscular sensors.
- 35.** A rehabilitation system according to any of claims 33 or 34, wherein the motion sensors of the rehabilitation system and the motion sensors of the generator system are the same motion sensors.
- 36.** A generator method for generating a neuromuscular-to-motion decoder from a healthy limb of a person, the generator method comprising
receiving neuromuscular signals obtained by neuromuscular sensors associated to predefined muscle and/or nerve locations of at least one pair of agonist and antagonist muscles/nerves of the healthy limb, said neuromuscular signals being obtained during performance by the person of a predefined exercise with the healthy limb, and said predefined exercise being defined by predefined exercise data;
receiving motion signals obtained by motion sensors associated to predefined positions of the healthy limb, said motion signals being obtained during performance by the person of the predefined exercise with the healthy limb; and
generating the neuromuscular-to-motion decoder by mapping the neuromuscular signals to the motion signals over time using a mapping method whereby the neuromuscular-to-motion decoder is to be used for rehabilitating a paretic limb.
- 37.** A rehabilitation method for rehabilitating a paretic limb of a patient by using a neuromuscular-to-motion decoder generated by a generator method according to claim 36, the rehabilitation method comprising
receiving neuromuscular signals obtained by neuromuscular sensors associated to predefined muscle and/or nerve locations of the paretic limb corresponding to predefined muscle and/or nerve locations of a healthy limb taken into

account in the generation of the neuromuscular-to-motion decoder, the neuromuscular signals being obtained during an attempt by the patient to perform with the paretic limb a predefined exercise defined by predefined exercise data taken into account in the generation of the neuromuscular-to-motion decoder;
inputting the neuromuscular signals to the neuromuscular-to-motion decoder for causing the neuromuscular-to-motion decoder to output first motion commands;
receiving motion signals obtained by motion sensors associated to predefined positions of the paretic limb corresponding to predefined positions of the healthy limb taken into account in the generation of the neuromuscular-to-motion decoder, the motion signals being obtained during the attempt by the patient to perform the predefined exercise with the paretic limb;
determining trajectory data defining a trajectory to be followed by the paretic limb depending on a deviation between the motion signals and the predefined exercise data;
determining second motion commands depending on the determined trajectory data to be followed by the paretic limb;
determining final motion commands depending on the first motion commands and the second motion commands; and
sending the final motion commands to a body actuator associated to the paretic limb for controlling the body actuator so as to stimulate the patient to perform the predefined exercise with the paretic limb.

38. A rehabilitation method according to claim 37, comprising the generator method.

39. A computing system comprising a memory and a processor, embodying instructions stored in the memory and executable by the processor, the instructions comprising functionality to execute a generator method according to claim 36 for generating a neuromuscular-to-motion decoder from a healthy limb of a person.

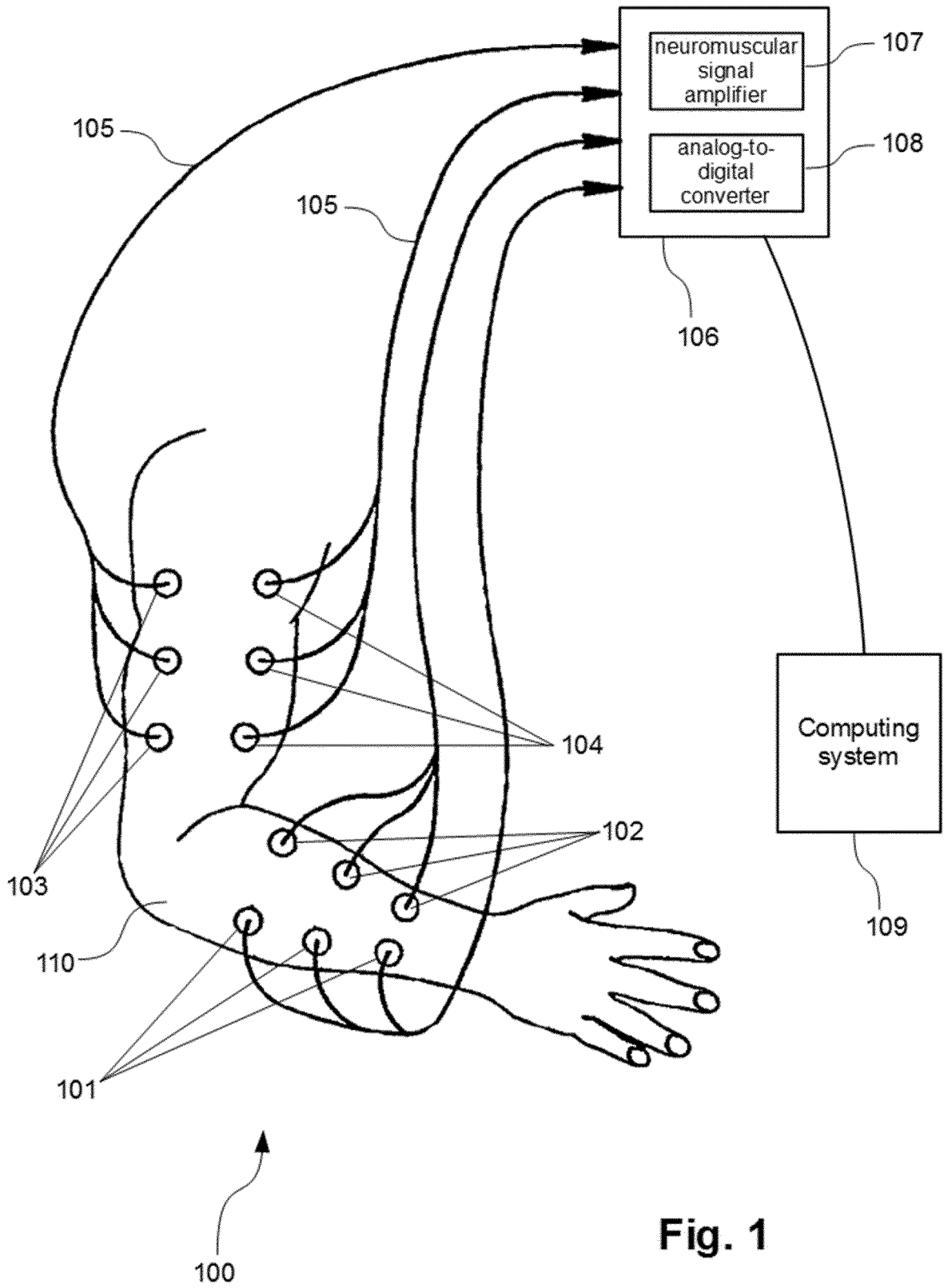
40. A computer program product comprising program instructions for causing a computing system to perform a generator method according to claim 36 for generating a neuromuscular-to-motion decoder from a healthy limb of a person.

41. A computer program product according to claim 40, embodied on a storage medium.

42. A computer program product according to claim 40, carried on a carrier signal.

43. A computing system comprising a memory and a processor, embodying instructions stored in the memory and executable by the processor, the instructions comprising functionality to execute a rehabilitation method according to any of claims 37 or 38 for rehabilitating a paretic limb of a patient.

44. Computer program product comprising program instructions for causing a computing system to perform a rehabilitation method according to any of claims 37 or 38 for rehabilitating a paretic limb of a patient.



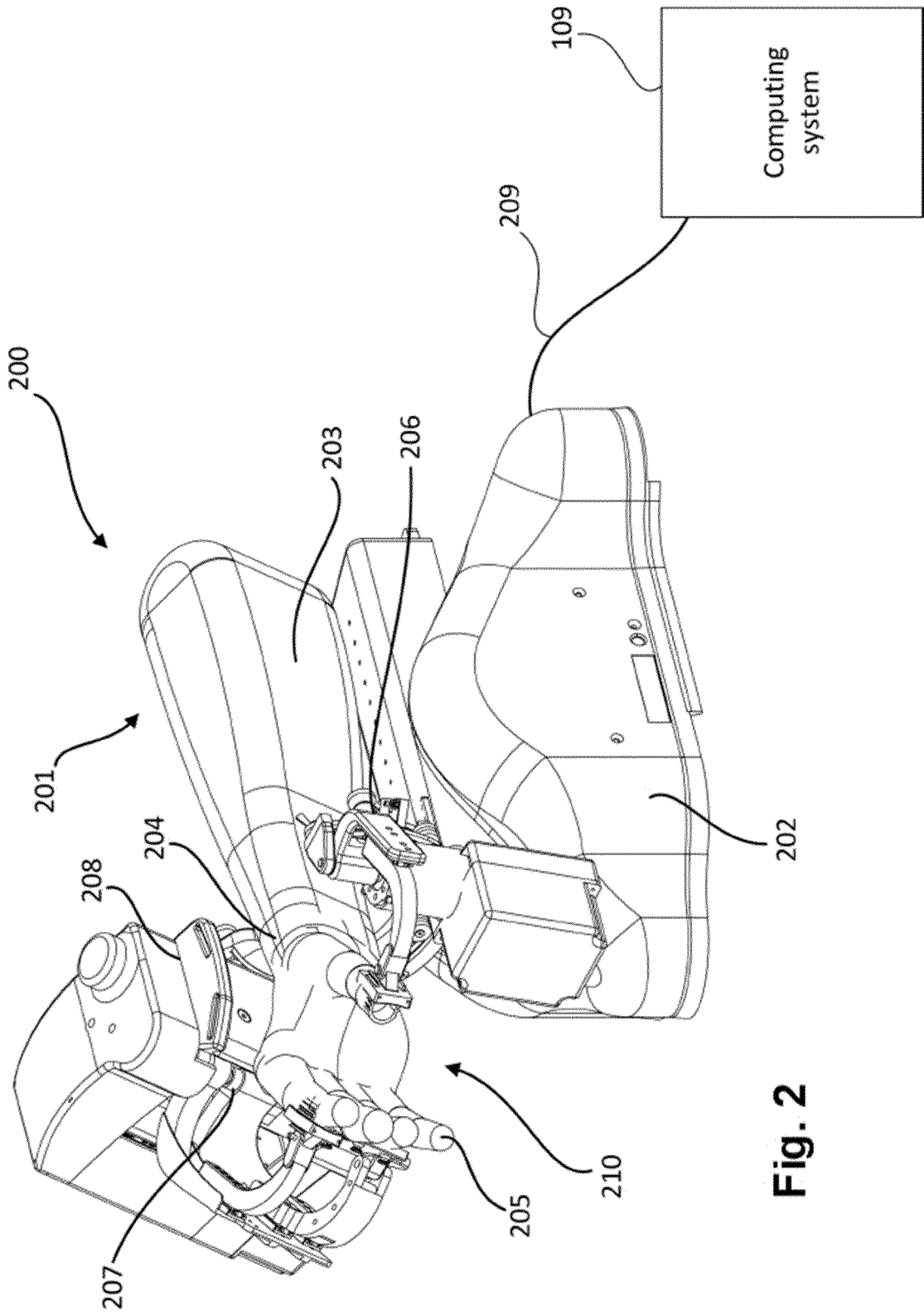


Fig. 2

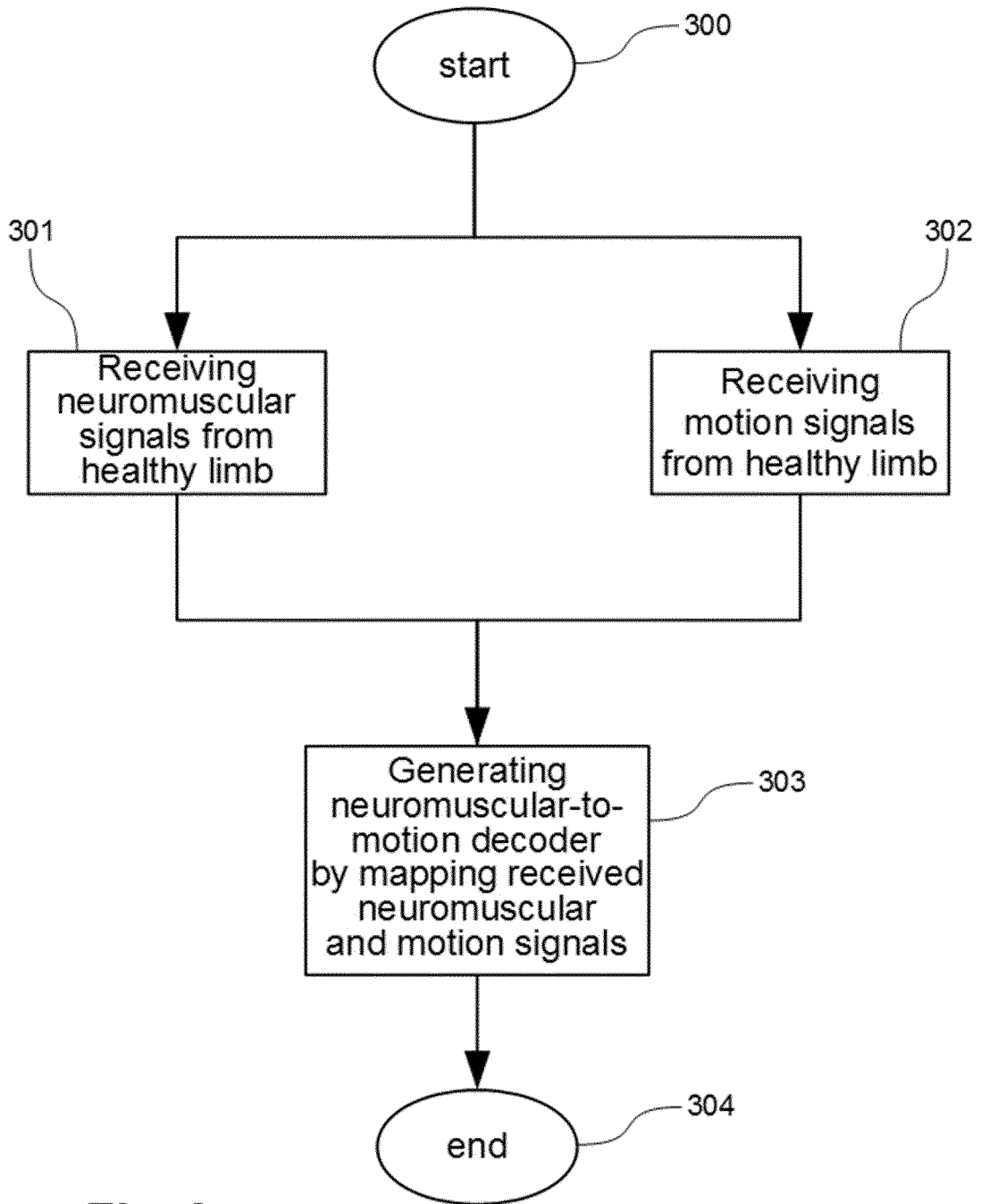


Fig. 3

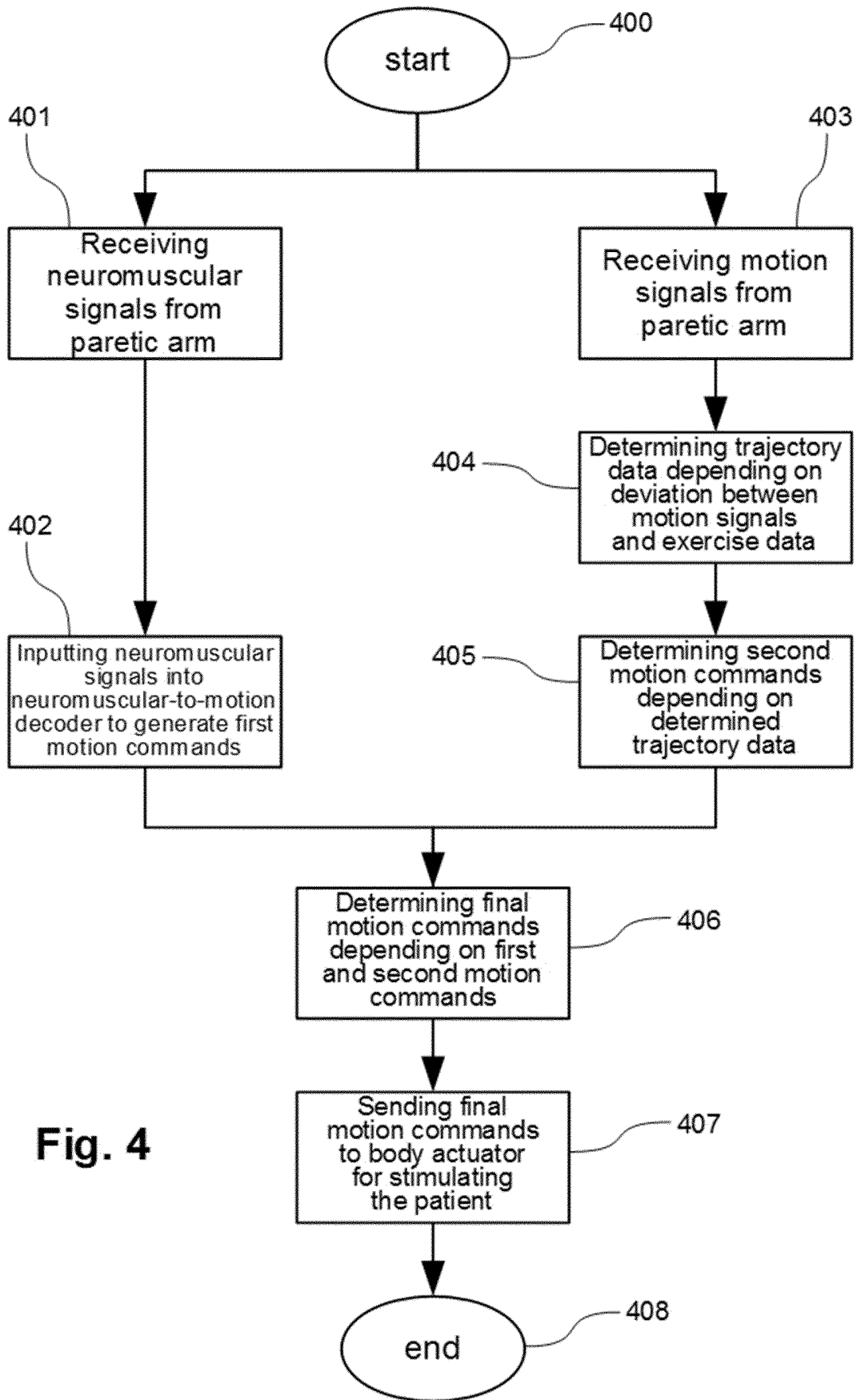


Fig. 4

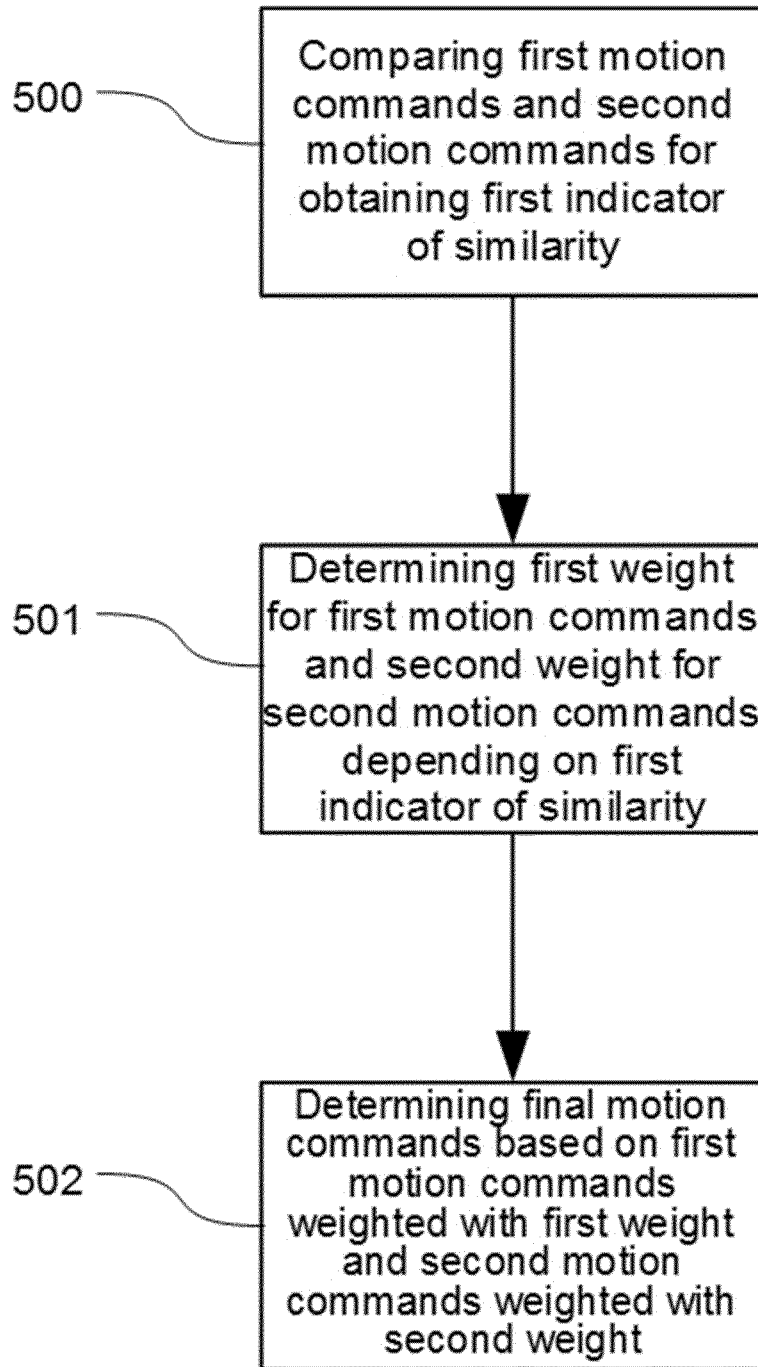


Fig. 5

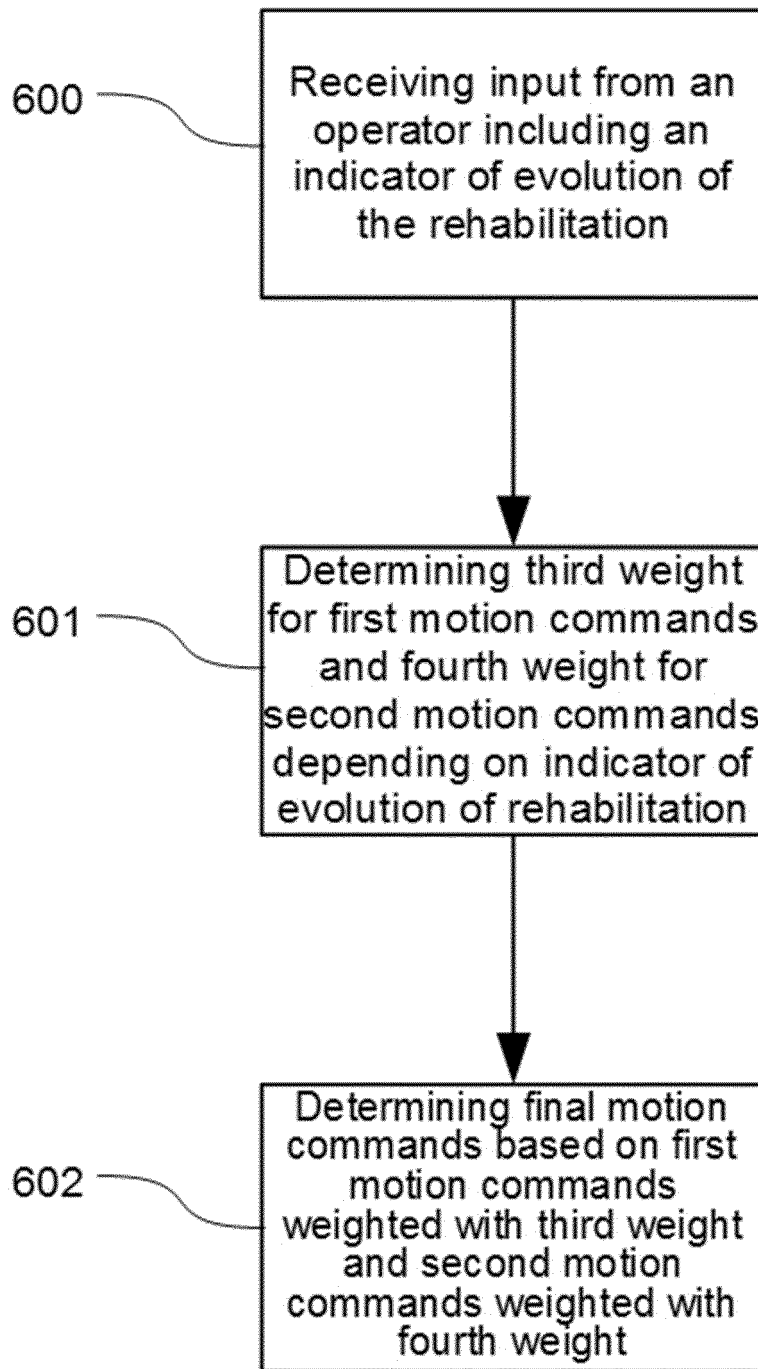


Fig. 6

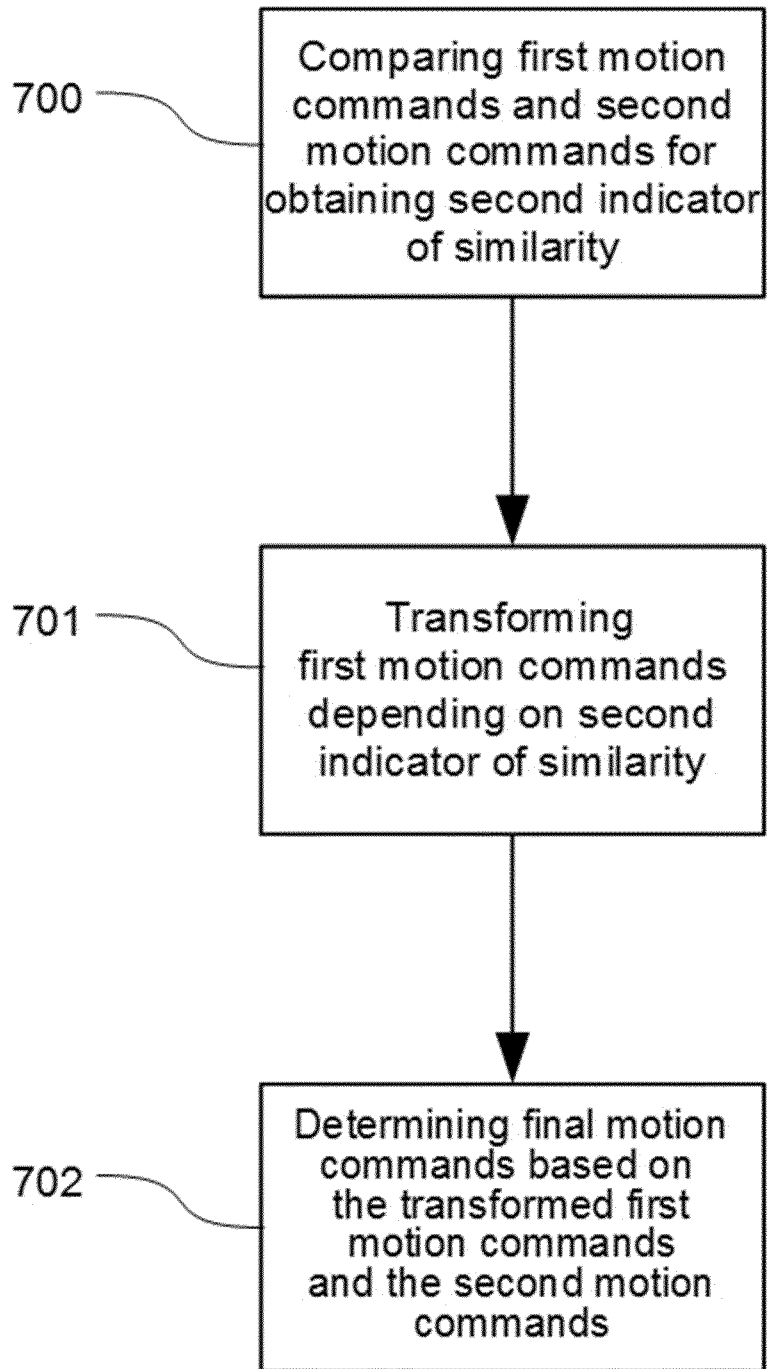


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/ES2016/070833

5

A. CLASSIFICATION OF SUBJECT MATTER					
INV.	A61B5/04	A61B5/0488	A61B5/11	A61B5/00	A61F2/50
ADD.	A61B5/22	A61F2/54	A61F2/58	A61F2/68	A61B8/00
According to International Patent Classification (IPC) or to both national classification and IPC					

10

B. FIELDS SEARCHED					
Minimum documentation searched (classification system followed by classification symbols) A61B A61F A61H					
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched					

15

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data					
--	--	--	--	--	--

20

C. DOCUMENTS CONSIDERED TO BE RELEVANT

25

30

35

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	M. MULAS ET AL: "An EMG-Controlled Exoskeleton for Hand Rehabilitation", REHABILITATION ROBOTICS, 2005. ICORR 2005. 9TH INTERNATIONAL CONFERENCE ON CHICAGO, IL, USA JUNE 28-JULY 1, 2005, 1 July 2005 (2005-07-01), pages 371-374, XP055391689, DOI: 10.1109/ICORR.2005.1501122 ISBN: 978-0-7803-9003-4 abstract section II; figures 1-4 section III; figure 5 section IV; figure 6 the whole document ----- -/--	1-36, 39-44

40

45

<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C.	<input checked="" type="checkbox"/> See patent family annex.
--	--

* Special categories of cited documents :	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

50

Date of the actual completion of the international search 19 July 2017	Date of mailing of the international search report 26/07/2017
---	--

55

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Sarcia, Regis
--	---

INTERNATIONAL SEARCH REPORT

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: 37, 38
because they relate to subject matter not required to be searched by this Authority, namely:
Claims 37-38 define a therapy method practised on the human or animal body in the meaning of Rule 39.1(iv) and Rule 67.1(iv) PCT. Therefore, according to Article 34(4)(a)(i) PCT no written opinion regarding novelty, inventive step or industrial applicability is given for these claims.
2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/ES2016/070833

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/076886 A1 (FUNDACION TECNALIA RES & INNOVATION [ES]; UNIV CALIFORNIA [US]; UNIV E) 19 May 2016 (2016-05-19) cited in the application page 6, line 35 - page 7, line 18; figure 1 page 7, line 22 - page 11, line 12; figure 2 page 11, line 14 - page 12, line 14; figure 3 page 3, lines 9-10 -----	1-36, 39-44
A	US 2010/114329 A1 (CASLER RICK [US] ET AL) 6 May 2010 (2010-05-06) paragraphs [0350] - [0356] paragraph [0094] the whole document -----	6,25
A	US 2015/112451 A1 (DECHEV NIKOLAI [CA] ET AL) 23 April 2015 (2015-04-23) paragraph [0016] - paragraph [0017] -----	2

5

10

15

20

25

30

35

40

45

50

55

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2016076886 A1 [0008]

专利名称(译)	肢体康复方法和系统		
公开(公告)号	EP3545833A1	公开(公告)日	2019-10-02
申请号	EP2016831818	申请日	2016-11-22
[标]申请(专利权)人(译)	加利福尼亚大学董事会		
申请(专利权)人(译)	基金会TECNALIA研究与创新 加利福尼亚大学董事会 EBERHARD卡尔斯Universität大学蒂宾根		
当前申请(专利权)人(译)	基金会TECNALIA研究与创新 加利福尼亚大学董事会 EBERHARD卡尔斯Universität大学蒂宾根		
[标]发明人	RAMOS MURGUIALDAY ANDER SARASOLA ANDREA CARMENA RAMON JOSE MIGUEL MCINTYRE JOSEPH		
发明人	RAMOS MURGUIALDAY, ANDER SARASOLA, ANDREA CARMENA RAMON, JOSE MIGUEL MCINTYRE, JOSEPH		
IPC分类号	A61B5/04 A61B5/0488 A61B5/11 A61B5/00 A61F2/50 A61B5/22 A61F2/54 A61F2/58 A61F2/68 A61B8/00		
CPC分类号	A61B5/04001 A61B5/04888 A61B5/1107 A61B5/1122 A61B5/1124 A61B5/1128 A61B5/224 A61B5/225 A61B5/4052 A61B5/4082 A61B5/6824 A61B5/6825 A61B5/6826 A61B2505/09 A61F2/54 A61F2/583 A61F2/68 A61F2002/543 A61F2002/6872 A61H1/0237 A61H1/0274 A61H2201/501 A61H2205/06 A61H2205/10 A61H2230/08 A61H2230/60 A61H2205/065 A61H2205/067 A61H2230/085 A61B5/0488 A61F2/70 A61F2/72		
外部链接	Espacenet		

摘要(译)

提供了生成器系统，用于从健康的肢体生成神经肌肉运动解码器。生成器系统被配置为从神经肌肉传感器接收与健康肢体的至少一对激动剂和拮抗肌肉/神经的预定一对肌肉/神经位置的预定肌肉/神经位置相关的神经肌肉信号，该预定时间在人进行预定运动（由预定运动定义）时获得。健康的肢体）；在人进行健康肢体的预定运动的过程中，从运动传感器接收与健康肢体的预定位置相关的运动信号；通过使用映射方法将神经肌肉信号随时间映射到运动信号来生成神经肌肉运动解码器。还提供了康复系统，用于通过使用由发电机系统产生的神经肌肉运动解码器来康复麻痹肢体。还提供了适合在所述发电机系统和康复系统中执行的方法和计算机程序。

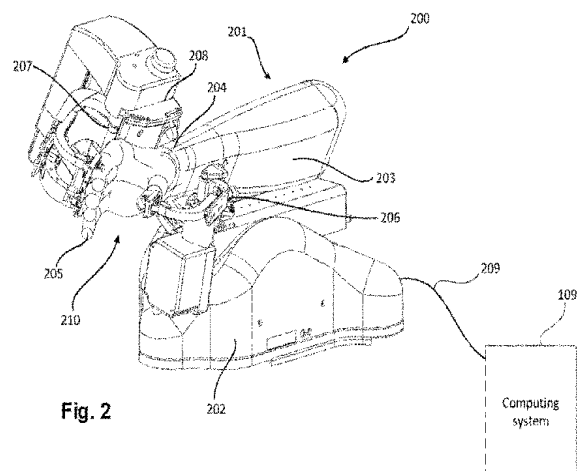


Fig. 2