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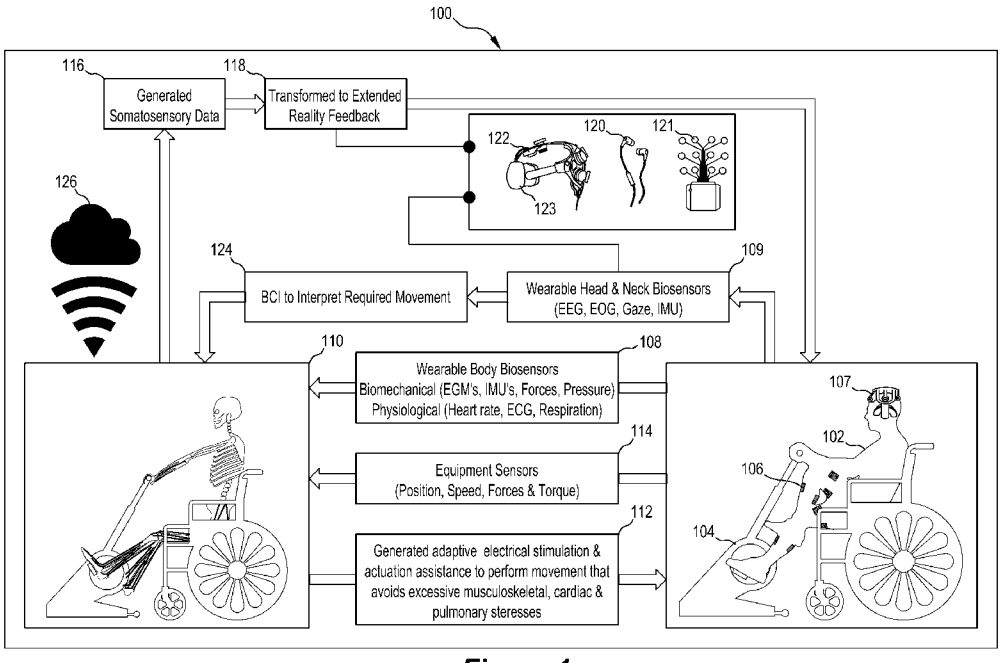


Figure 1

(57) **Abstract:** The present invention relates to a rehabilitation system for rehabilitating a person with a neurological condition, such as a spinal cord injury (SCI). The system includes exercise equipment for enabling the person to exercise. One or more sensors are provided for sensing information from the person during exercise. The system also includes a model of the exercising person configured to receive the sensed information from the sensors and generate electrical stimulation for the person. Advantageously, the personalized computer model may be used to generate suitable electrical stimulation for the person, and avoid excessive stresses on the person which can lead to the fracturing of bones.

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BIOSPINE: A DIGTIAL TWIN NEUROREHABILITATION SYSTEM

TECHNICAL FIELD

[0001] The present invention generally relates to a neurorehabilitation system for a person with an acquired or developmental neurological condition such as spinal cord injury, brain injury, cerebral palsy, or spasticity. The preferred embodiment of the invention will be presented for application to spinal cord injury (SCI).

BACKGROUND

[0002] The reference to any prior art in this specification is not, and should not be taken as an acknowledgement or any form of suggestion that the prior art forms part of the common general knowledge.

[0003] For thousands of years SCI was thought to be irreversible. This view is now changing. Recent scientific evidence has shown that thought-controlled rehabilitation robots can restore some voluntary movement in SCI. Further evidence suggests that providing motor sensory feedback can restore damaged spinal pathways.

[0004] Other studies have also shown that electrically stimulating spinal cord or muscles can help. However, such stimulation has been known to activate muscles to fracture bones that have been weakened through non-use over time.

[0005] Further studies have shown that rehabilitation using motor-driven exoskeletons can help regain voluntary movement in SCI. Since the motors, and not the stimulated muscles' activation, generate the SCI patient's movement this form of rehabilitation can protect against over loading. However, motor-driven rehabilitation does not facilitate use of stimulated muscle activation and action to generate movement, as enabled by electrical stimulation.

[0006] Numerous studies have also explored the use of biofeedback in rehabilitation, using visual, haptic, or auditory monitors to provide information to the user and improve their training. Commonly this involves directly providing visual information

regarding joint angles or body position. However, our brain does not directly receive information regarding the position of our joints during movement, instead it subconsciously interprets the electrical signals from mechanical sensors in our muscles and tendons (i.e. muscle spindles and golgi tendon organs, respectively), which generate electrical signals that are associated with length, velocity and tension of the muscles in which the sensors are embedded.

[0007] The use of all mentioned methods for SCI rehabilitation can be complex and need considerable training. Health professionals are therefore reticent to use these approaches, relying on more time-consuming and less effective hands-on rehabilitation methods.

[0008] The preferred embodiment provides an improved rehabilitation system for rehabilitating a person with a SCI. The preferred system integrates all aforementioned aspects of rehabilitation to help safely regain voluntary movement in SCI. Furthermore, the preferred system, through careful design and use of computer modelling will facilitate the systems ease of use in a clinical setting.

SUMMARY OF THE INVENTION

[0009] According to one aspect of the present invention, there is provided a rehabilitation system for rehabilitating a person with a neurological condition, the system including:

exercise equipment for enabling the person to exercise;

a human machine interface with one or more sensors for sensing information from the person's head, neck and body during exercise;

a human machine interface that has somatosensory feedback enabled by visual feedback, preferably via virtual/augmented reality, tactile via haptic feedback, or auditory by ear phones;

a personalized computer model of the exercising person on the exercise equipment configured to receive the information flow from the sensors and generate functional or spinal cord electrical stimulation and motorised assistance, for the person; and

a personalized computer model that is able to synthesize and generate somatosensory feedback.

[00010] According to another aspect of the present invention, there is provided a rehabilitation system for rehabilitating a person with a neurological condition, the system including:

exercise equipment for enabling the person to exercise;

one or more sensors for sensing information from the person during exercise; and

a model of the exercising person configured to receive the sensed information from the sensors and generate (functional or spinal cord) electrical stimulation for the person.

[00011] Advantageously, the personalized computer model may be used to generate suitable functional or spinal cord electrical stimulation for the person, and avoid excessive stresses on the person which can lead to the fracturing of bones.

[00012] The personalized computer model may include a neuromusculoskeletal model.

[00013] The sensors may include biomechanical and/or physiological biosensors on the person's head, neck and/or body. The sensed information may relate to any one or more of electromyography (EMG), inertial measurement units, electroencephalography (EEG), electrooculography (EOG), eye gaze, heart rate, electrocardiography (ECG), and respiration.

[00014] The sensors may include wearable sensors worn by the person.

[00015] The exercise equipment may include a recumbent ergometer, upper-arm ergometer or articulated system, rowing system, or walking system. The system may further include an actuator(s) to assist the person to perform the exercise on the equipment. The actuator may include a motor.

[00016] The sensors may further include one or more equipment sensors for sensing information of the equipment that is also provided to the model for generating the functional or spinal cord electrical stimulation, and/or actuation assistance . The equipment sensors may include speed, motor current, force and/or torque sensors.

[00017] The model may be configured to be a human machine interface (HMI) between the person and equipment. The HMI my include a headset, in turn, including an EEG system that will provide data to the brain computer interface (BCI) model to classify the person's exercise intention and intensity. The intent and intensity may trigger the model to generate functional or spinal cord electrical stimulation and actuation assistance to enable the person to perform the desired exercise on the equipment.

[00018] The model may be further configured to generate sensory data to be feedback to the person via the HMI. The sensory data may include somatosensory, cardiac and/or respiratory data. Sensory data may be provided to person by visual, auditory and/or intact haptic feedback pathways. The HMI headset may provide these extended reality feedback by including virtual or augmented reality, or via ear phones and/or haptic devices.

[00019] According to another aspect of the present invention, there is provided a rehabilitation method for rehabilitating a person with a neurological condition, the method including:

exercising the person with exercise equipment;

sensing information from the exercising person and exercise equipment; and

receiving the sensed information and generating functional electrical stimulation and actuator assistance for the person using a model of the exercising person using the exercise equipment.

[00020] Any of the features described herein can be combined in any combination with any one or more of the other features described herein within the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[00021] Preferred features, embodiments and variations of the invention may be discerned from the following Detailed Description which provides sufficient information for those skilled in the art to perform the invention. The Detailed Description is not to be regarded as limiting the scope of the preceding Summary of the Invention in any way. The Detailed Description will make reference to drawing as follows:

[00022] Figure 1 is a schematic view of a rehabilitation system in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[00023] According to an embodiment of the present invention, there is provided a rehabilitation system 100 for rehabilitating a person 102 with a SCI. The system 100 includes exercise equipment 104, maybe in the form of a recumbent cycle or ergometer, which enables the person 102 to exercise. Personal wearable head, neck and body biosensors 106 and 107 (biomechanical and physiological biosensors) are provided for sensing personal information 108 and 109 from the person 102 during exercise.

[00024] The system 100 further includes a personalized computer model 110 of the exercising person 102 on the exercise equipment 104 for receiving the sensed personal information 108 and 109 from the sensors 106 and 107 and generating electrical stimulation and actuation assistance 112 for the person. Advantageously, the personalized model 110 is used in generating suitable adaptive electrical stimulation for the person 102, and avoids excessive musculoskeletal, cardiac and pulmonary stresses on the person 102 as well as the potential fracturing of bones.

[00025] The rehabilitation system 100 further includes equipment sensors (e.g. speed, torque, etc.) for sensing equipment information 114 of the equipment 104. The equipment information 114 is also provided to the model 110 and used in generating the electrical stimulation and actuation assistance 112.

[00026] The model 110 is configured to generate sensory data 116 to be provided to the person 102 through extended reality feedback 118 in the HMI 119. The extended reality 118 in HMI 119 includes a virtual or augmented reality headset 122 with visual 123, auditory 120 and tactile feedback 121. The HMI 119 will employ a brain computer interface (BCI) 124 that may use EEG, EOG, eye gaze sensor data 109 in the headset 122 worn by the person 102. The model 110 is also configured to receive data from the BCI 124 that is the interpretation of the person's required movement when the person 102 thinks about an action. The model 110 is typically stored in the cloud 126 and IoT enabled.

[00027] The functionality of the system 100 is now described in greater detail below.

[00028] The neuromusculoskeletal model 110 incorporates a Digital Twin, which is a computer representation of the person's bones, muscles, joints, and nervous system. The Digital Twin technology is used in real-time to virtually bypass the site of SCI, again connecting sensory and motor pathways between brain, spinal cord, and muscles.

[00029] The model 110 includes BioSpine, which is an innovative application of Digital Twin technology through the HMI headset 122 that is combined with virtual/augmented reality 123, auditory 120 and haptic devices 121, and biosensors 106 and 107. BioSpine integrates a unique set of intelligent rehabilitation assistive technologies controlled by the Digital Twin to restore the interrupted motor and sensory connections in the spine. BioSpine integrates the following discrete technologies into the seamless system 100: HMI 119, wearable biosensors 106 and 107, electrical stimulation 112 of lower limb muscles of the person 102, motor-assisted leg cycling in the case presented, augmented somatosensory signals 116 transformed extended reality 118 with visual 123, auditory 120 and haptic 121 biofeedback.

[00030] The system 100 is intuitively and automatically controlled by the personalised Digital Twin of the patient 102.

[00031] Personalised Digital Twins of each participant 102 can be developed combining magnetic resonance imaging (MRI) [2] and artificial intelligence methods.. Electroencephalograms (EEG) can be captured via a portable wireless headset (e.g. Wearable Sensing DSI7 or DSI-VR300, Switzerland) 122 and processed in the BCI 124 using AI methods to discriminate whether the patient wishes to perform, and how intensely they wish to do, in this example case, the cycling exercise.

[00032] In the example case of cycling, the patient's motor intention to cycle data 124 will control the Digital Twin, which in turn will optimally stimulate muscles via electrical stimulation 112 and provide appropriate motorised assistance 112 to achieve cycling. Importantly, the Digital Twin coordinates the electrical stimulation 112 and motorised assistance 112 to ensure that stimulated muscle activation assists, rather than opposes, the motorised actuation to perform the movement. Biomechanical and physiological information 108 from multiple wearable biosensors 106 (e.g., electromyography, inertial measurement units, heart rate, electrocardiogram, and respiration) can be interpreted

by the patient's Digital Twin to progressively adapt the amount of ergometer pedal-assistance in order to maximally engage the patient 102, while also maintaining musculoskeletal tissue loads and cardiovascular demand within safe levels [3, 4].

[00033] Finally, the patient's Digital Twin can synthesise somatosensory information 116 that will be redirected to higher somatosensory areas via extended reality 118, visual 123, auditory 120 and/or haptic 121 feedback [4, 5].

[00034] Off-the-shelf known pharmacological adjuncts (e.g., buspirone) with an established safety profile utilised in prior studies [6-10] can be added to measure their additive effect on neural plasticity. The system 100 is designed to retrofit and update existing, commercially available equipment 104.

[00035] A person skilled in the art will appreciate that many embodiments and variations can be made without departing from the ambit of the present invention.

[00036] The system 100 may further include an actuator, such as a robotic motor coupled to the drive crank, for actuating the exercise equipment 104. In use, the model 110 actuates the actuator to some extent to assist the person 102.

[00037] In compliance with the statute, the invention has been described in language more or less specific to structural or methodical features. It is to be understood that the invention is not limited to specific features shown or described since the means herein described comprises preferred forms of putting the invention into effect.

[00038] Reference throughout this specification to 'one embodiment' or 'an embodiment' means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearance of the phrases 'in one embodiment' or 'in an embodiment' in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more combinations.

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The claims defining the invention are as follows:

1. A rehabilitation system for rehabilitating a person with a neurological condition, the system including:

exercise equipment for enabling the person to exercise;

one or more sensors for sensing information from the person during exercise; and

a model of the exercising person configured to receive the sensed information from the sensors and generate electrical stimulation for the person.

2. A rehabilitation system as claimed in claim 1, wherein model is personalized and generates suitable electrical stimulation for the person, and avoids excessive stresses on the person which can lead to the fracturing of bones.

3. A rehabilitation system as claimed in claim 1, wherein the sensors include biomechanical and/or physiological biosensors.

4. A rehabilitation system as claimed in claim 1, wherein the sensed information relates to any one or more of electromyography, inertial measurement units, heart rate, electrocardiogram, and respiration.

5. A rehabilitation system as claimed in claim 1, wherein he sensors further include one or more equipment sensors for sensing information of the equipment that is also provided to the model for generating the electrical stimulation.

6. A rehabilitation system as claimed in claim 5, wherein the equipment sensors include speed or torque sensors.

7. A rehabilitation system as claimed in claim 1, wherein the model is further configured to generate somatosensory data to be provided to the person through extended reality.

8. A rehabilitation system as claimed in claim 7, wherein the somatosensory data may be further provided via visual, auditory and/or haptic feedback.

9. A rehabilitation system as claimed in claim 7, wherein the model is configured to receive intention of movement data from a brain-computer interface (BCI).

10. A rehabilitation system as claimed in claim 7, wherein the BCI includes a virtual or augmented reality headset with visual, auditory and/or tactile feedback

11. A rehabilitation system as claimed in claim 1, wherein the sensors include wearable sensors worn by the person.

12. A rehabilitation system as claimed in claim 1, wherein the model is personalized and includes a neuromusculoskeletal model or a digital twin.

13. A rehabilitation system as claimed in claim 1, wherein the exercise equipment includes a recumbent ergometer.

14. A rehabilitation system as claimed in claim 1, further including an actuator for actuating the exercise equipment.

15. A rehabilitation system as claimed in claim 14, wherein the actuator includes a motor.

16. A rehabilitation system for rehabilitating a person with a neurological condition, the system including:

exercise equipment for enabling the person to exercise;

a human machine interface with one or more sensors for sensing information from the person during exercise, the human machine interface having somatosensory feedback enabled by extended reality feedback, preferably via virtual reality, tactile via haptic feedback, or auditory by ear phones; and

a personalized computer model of the exercising person on the exercise equipment configured to receive the sensed information from the sensors and generate electrical stimulation, assisted by actuators, for the person, the personalized computer model able to synthesize and generate somatosensory feedback.

17. A rehabilitation method for rehabilitating a person with a neurological condition, the method including:

exercising the person with exercise equipment;

sensing information from the exercising person; and

receiving the sensed information and generating electrical stimulation for the person using a model of the exercising person.

18. A rehabilitation method as claimed in claim 17, involving generating the electrical stimulation for whilst avoiding excessive stresses on the person which can lead to the fracturing of bones.

19. A rehabilitation method as claimed in claim 17, wherein the sensing involves any one or more of somatosensory, visual feedback, tactile and auditory sensing.

20. A rehabilitation method as claimed in claim 17, further involving actuating the exercise equipment.

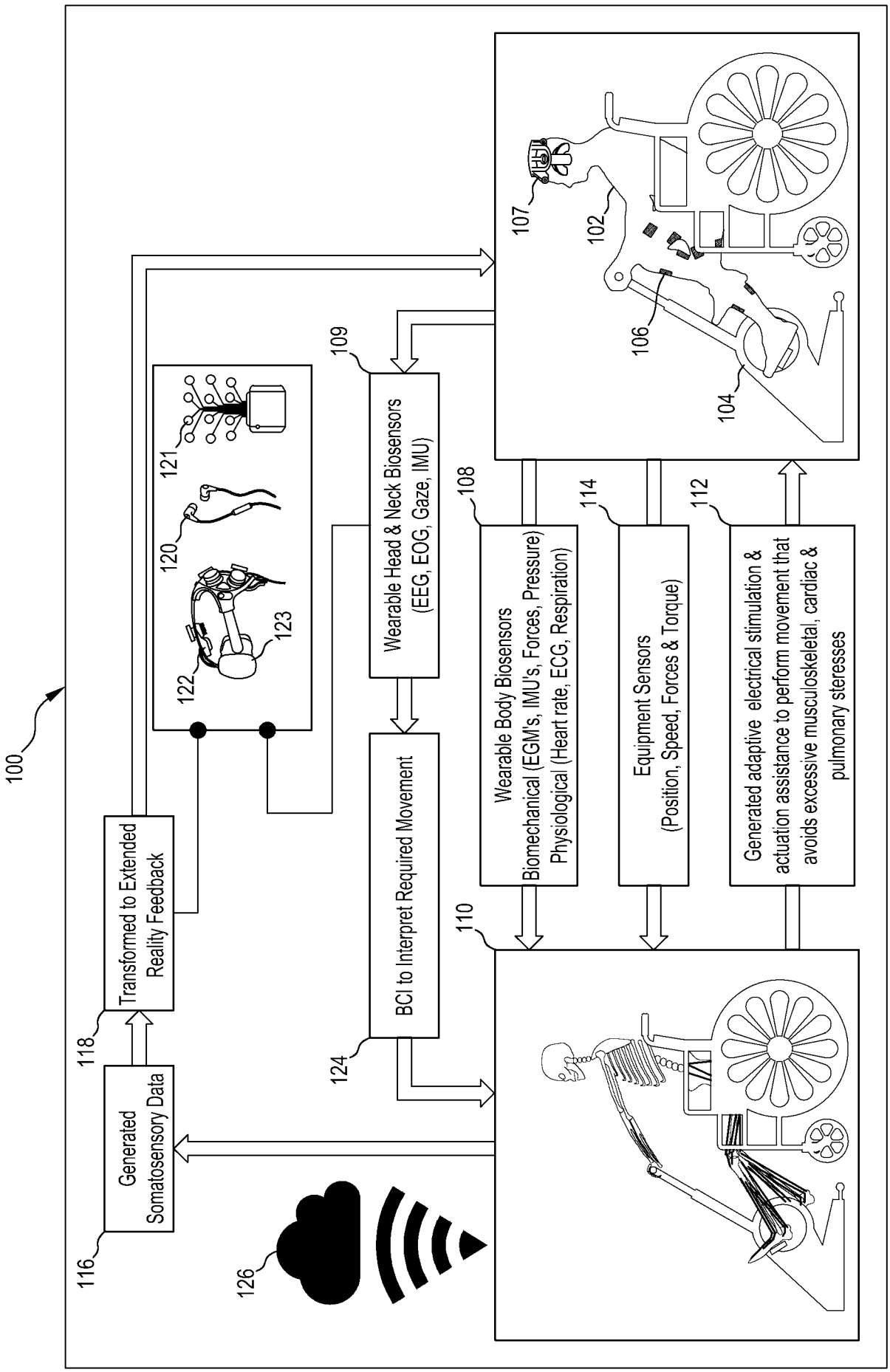

100
107
102
106
104
109
Wearable Head & Neck Biosensors
(EEG, EOG, Gaze, IMU)
121
120
123
122
108
Wearable Body Biosensors
Biomechanical (EGM's, IMU's, Forces, Pressure)
Physiological (Heart rate, ECG, Respiration)
114
Equipment Sensors
(Position, Speed, Forces & Torque)
112
Generated adaptive electrical stimulation &
actuation assistance to perform movement that
avoids excessive musculoskeletal, cardiac &
pulmonary steresses
110
118
Transformed to Extended
Reality Feedback
116
Generated
Somatosensory Data
124
BCI to Interpret Required Movement
126

Figure 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2020/050566

A. CLASSIFICATION OF SUBJECT MATTER

A61N 1/36 (2006.01) A63B 24/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PATENW: IPC/CPC: A63B2213/004, A61N1/36003, A61N1/0452, A61N1/0456, A61N1/3603, G06F3/011, A61B2505/09 and relevant lower terms

KEYWORDS: SOMATOSENSORY, TACTILE, SOUND, TOUCH, VISUAL, FEEDBACK?, VIRTUAL, REALITY and like terms

Google Patents/Google Scholar: Keywords: electrical stimulation rehabilitation and like terms

Applicant(s)/Inventor(s) name searched in PATENW, Google Scholar and internal databases provided by IP Australia

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C [X] 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

"D" document cited by the applicant in the international application

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"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

"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

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INTERNATIONAL SEARCH REPORT C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		International application No. **PCT/AU2020/050566**
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/0036531 A1 (WEARABLE LIFE SCIENCE GMBH) 08 February 2018 Fig. 1; Para [0035]-[0050], [0089]-[0096], [0253], [0264], [0291]	1-20
X	WO 2018/033591 A2 (ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE (EPFL)) 22 February 2018 Fig. 8-9; Page 18, ln 13 – Page 23, ln 30; Page 42, ln 1 – 19, Page 43, ln 19-27; Page 47, ln 1- 25	1-20
X	US 2014/0277582 A1 (NEUROLUTIONS, INC.) 18 September 2014 Fig. 1A-2; Para [0024]-[0030], [0037]-[0039], [0056], [0060]-[0065]	1-11, 13-20
X	US 8249714 B1 (HARTMAN et al.) 21 August 2012 Fig. 1-2b, 5, 7; Col. 4, ln 56 - 62, Col. 6, ln 7 - 61, Col. 9, ln 24 - Col. 11, ln 4, Col. 12, ln 4 - 11	1-2, 5-8, 13-20
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INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2020/050566**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

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Patent Document/s Cited in Search Report		Patent Family Member/s	
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Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2020/050566**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2020/050566**

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