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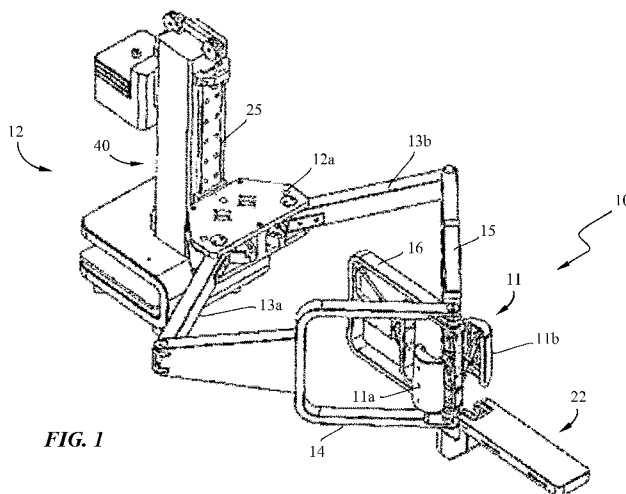


FIG. 1

(57) Abstract: The invention relates to an upper limb rehabilitation system for rehabilitating an upper limb of a subject and comprising a mobile platform coupled to a fixed platform. The mobile platform comprises an articulate handle assembly movable, during a rehabilitation session, within a plane which is substantially coplanar or parallel to the transverse plane of the subject, wherein the handle assembly (10) is provided with a gripping device (11) comprising a shaft (18). The articulate handle assembly (10) according to the invention comprises: a supporting structure having a first and a second holding elements (14, 15) pivotally connected together to rotate about a first axis of rotation ( $\theta_1$ ) perpendicular to said transverse plane; a third holding element (16) connected to said supporting structure; and a fourth holding element (17) supporting the shaft (18) of the gripping device (11) and pivotally connected to said third holding element (16) to rotate about a second axis of rotation ( $\theta_2$ ) which is perpendicular to the first axis of rotation ( $\theta_1$ ). Said first and second axis of rotation ( $\theta_1, \theta_2$ ) as well as the central axis ( $\theta_3$ ) of the shaft (18) of the gripping device (11) always intersect each other at one point independently from the orientation of each of the first, second, third and fourth holding elements (14, 15, 16, 17).



## UPPER LIMB REHABILITATION SYSTEM

### FIELD OF THE INVENTION

5           The present invention relates to the field of rehabilitation systems, more particularly to an upper limb rehabilitation system for rehabilitating the upper limb of a subject and to an integrated rehabilitation platform that combines robotics and interactive gaming to enable individual undergoing rehabilitation to improve performance of coordinated movements of the shoulder, the forearm, the hand and the fingers. The present invention also relates to a  
10           method for the rehabilitation of the upper limb of the subject.

### BACKGROUND OF THE INVENTION

          In the last 15 years, technological development has mainly focused on two kinds of  
15           rehabilitation systems: robotic systems and sensor based systems. Sensor based systems target to develop small portable devices enabling to monitor functional movement in natural settings like at home. However, only subjects with a certain level of strength can fully profit from sensor based systems. Robots on the other hand have shown to be able to facilitate repetitive training in stroke subjects with all functional levels which has proven to address  
20           brain plasticity improving sensorimotor function. Moreover, robotic systems, such as the MIT-Manus, the Haptic Master and the MIME, guarantee a large variability of goal-tailored training exercises which encourages subjects to use all their capabilities to improve their motor performances.

          A recent review paper on rehabilitation technology advocates for a general  
25           improvement in short-term and long-term strength of upper limbs movements after training with robotics. Inversely, experimental evidence speaks against an improvement of the activity level. This might be because most rehabilitation systems support analytical training methods rather than task-oriented training. Indeed, studies using neuroimaging techniques have shown that functional recovery from stroke is positively affected by task-specific  
30           arm/hand sensorimotor input characterizing training or everyday use. Moreover, motor control studies have suggested that movements are planned as the combination of a relatively

small number of muscle co-contraction patterns called synergies. Currently, only few systems are able to provide task-oriented exercises for the upper extremity. Of these systems, only ADLER allows for training of the entire arm and hand (but without an actuated hand gripping tool) and despite the MIT-MANUS team recently developed a hand module to  
5 complete the previous systems, this will not allow to train all joints of the upper limb at the same time. Another robotic system as disclosed in US2008/0161733 allows three dimensional arm movements but not actuated and coordinated reaching-grasp movements. Therefore, these solutions are still not offering the training of movement strategies as needed during real life arm-hand performance.

10 US2006/0106326 discloses wrist and upper extremity motion system which includes a series of motors that can apply torques to a wrist about the three axes of wrist rotation: pronation/supination, flexion/extension, and adduction/abduction. In particular, the pronation/supination (PS) axis extends parallel to the longitudinal axis of the device. Rotation of the device about the PS axis will cause or result from pronation and supination of  
15 the subject's wrist and arm. The flexion/extension (FE) axis extends through the subject's wrist perpendicular to the PS axis. Rotation of the system about the FE axis will cause or result from flexion and extension of the subject's wrist. The abduction/adduction (AA) axis is perpendicular to the FE and PS axes and extends below the handle of the system. Rotation of the system about the AA axis will cause or result from abduction and adduction of the  
20 subject's wrist.

The configuration of this system is however mainly configured for the wrist rehabilitation of a subject. This system is therefore not adapted to simulate for example an interaction with a virtual object which is translating and rotating about an axis passing by its centre of gravity for training the hand and fingers' movements of the subject, thereby  
25 reducing the capability of the system to help retraining the whole functions of the impaired upper limb.

Accordingly, the aim of the present invention is to provide an upper limb rehabilitation system which is adapted to simulate a wide range of interactions with an object including reaching and grasping movements for training the shoulder, elbow, wrist, hand and  
30 fingers' movements of a subject in order to help retraining the whole function of the impaired upper limb of the subject.

## SUMMARY OF THE INVENTION

This aim and other advantages are achieved by an upper limb rehabilitation system for rehabilitating an upper limb of a subject and comprising a mobile platform coupled to a fixed platform. The mobile platform comprises an articulate handle assembly movable, during a rehabilitation session, within a plane which is substantially coplanar or parallel to the transverse plane of the subject wherein the handle assembly is provided with a gripping device comprising a shaft. The system according to the invention is characterized in that the articulate handle assembly comprises:

- 10 - a supporting structure having a first and a second holding elements pivotally connected together to rotate about a first axis of rotation perpendicular to said transverse plane,
- a third holding element connected to said supporting structure, and
- a fourth holding element supporting the shaft of the gripping device and pivotally connected to said third holding element to rotate about a second axis of rotation which is perpendicular to the first axis of rotation,

15 wherein said first and second axis of rotation as well as the central axis of the shaft of the gripping device always intersect at one point independently from the orientation of each of the first, second, third and fourth holding elements.

20 In one embodiment of the invention, the upper limb rehabilitation system is provided with motors. The position and orientation of the mobile platform is measured in relation to the fixed platform in six degrees of freedom. The force exerted by the subject against the mobile platform is also measured in said six degrees of freedom. The measured position and measured force are forwarded to a controller interface and fed to a programmable computer which determines desired force feed-back to be applied by the controller interface to the mobile platform through the motors to assist and/or impede the movements of the subject. The programmable computer can also provide a virtual reality three-dimensional graphic simulation of exercises to simulate upper limb (i.e. shoulder, elbow, wrist, hand and fingers) movements of the subject, thereby providing sensory (e.g. visual, haptic) feedback to the user.

30 In one alternate embodiment of the invention, the motors of the rehabilitation system are substituted with brakes. In this configuration, the system cannot assist the movements of

the subject but can still be used as a haptic interface by actuating the brakes to simulate a physical interaction with a virtual or augmented object.

Another aspect of the invention is to provide an integrated rehabilitation platform comprising: the upper limb rehabilitation system according to the invention; a display device  
5 to simulate virtual reality and to present sensorimotor integration tasks to the subject; a sensor interface including at least one sensor for sensing at least one of force, load, torque, angular displacement, angular velocity, displacement and position of said rehabilitation system; and a controlling interface that is adapted to control operation of the rehabilitation device.

10 A further aspect of the invention is to provide a method for the rehabilitation of an upper limb of a subject comprising the steps of: i) mapping the movements of the subjects into virtual or augmented reality environments in which the subject receive visual feedback concerning his/her own movements as well as visual feedback about a virtual/augmented environment whose physical properties are simulated through the upper limb rehabilitation  
15 system according to the invention or through any other haptic display coupled with said system or in contact with the subject; ii) recording physiological signals such as brain signals of the subject as well as movements parameters of the upper limb rehabilitation system when the subject is operating said system; and iii) controlling the movements of said system in function of the recorded physiological signals or movement parameters.

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## **BRIEF DESCRIPTION OF FIGURES**

The invention will be better understood thanks to the following detailed description of the invention with reference to the attached figures, in which:

25

- FIG. 1 shows a perspective view of the upper limb rehabilitation system according to the invention in a neutral/resting position,
- FIG. 2 shows a perspective view of the handle assembly of the upper limb rehabilitation system in a neutral/resting configuration,

- FIG. 3 shows another perspective view of the handle assembly in which the gripping device is in a first active position,
- FIG. 4 shows a further perspective view of the handle assembly in which the gripping device is in a second active position,
- 5 - FIG. 5a shows a perspective view of the gripping device of the handle assembly in an deployed/resting position,
- FIG. 5b shows a perspective view of the gripping device in a retracted position,
- FIG. 5c shows a front view of a foldable structure of the gripping device,
- FIG. 5d shows a detailed perspective view of one of two complementary parts of the  
10 gripping device,
- FIG. 6 shows a top view of the upper limb rehabilitation system of FIG. 1,
- FIG. 7 shows a top view of the upper limb rehabilitation system in a first active position,
- FIG. 8 shows a top view of the upper limb rehabilitation system in a second active  
15 position,
- FIG. 9 shows a top view of the upper limb rehabilitation system in a third active position,
- FIG. 10 shows a top view of the upper limb rehabilitation system in a fourth active position,
- 20 - FIG. 11 shows the upper limb rehabilitation system clamped on a table,
- FIG. 12 shows a perspective view of the fixed platform of the upper limb rehabilitation system comprising gravity compensation means,
- FIG. 13 shows the subject's hand operating the handle assembly of the rehabilitation system,
- 25 - FIG. 14a and FIG. 14b show a detailed view of a motor transmission arranged on a first, respectively a second degree of freedom of the rehabilitation system,
- FIG. 15a and FIG. 15b show a braking device in a unactuated and actuated configuration respectively.

## DETAILED DESCRIPTION OF THE INVENTION

An upper limb rehabilitation system, for improving performance of coordinated movements of an upper limb (i.e. shoulder, elbow, wrist, hand and fingers) of a subject, is described herein and is seen generally in Figure 1. The compact and lightweight characteristics of the system allow it to be used in any restricted-space area in medical and rehabilitative facilities. In addition, the upper limb rehabilitation system is advantageously transportable and configured to be easily clamped to any appropriate supporting structure such as a table 50 as shown in Figure 11 allowing on-site therapeutic procedures at home.

As particularly shown in Figure 1, the rehabilitation system comprises essentially a gripping device 11 mounted on an articulated handle assembly 10 which is pivotally connected to a fixed platform 12 in a manner that the gripping device 11 is movable within a plane which is substantially coplanar or parallel to the transverse plane of the subject, referred hereafter as the working plane, during a working session. The handle assembly 10 is supported by a holding unit 12a which is slidably mounted along a linear guide 25 arranged vertically on a tower 40 forming part of the fixed platform 12. The holding unit 12a comprises locking means (not shown) in order to be locked in an appropriate height in function of the supporting structure and/or the position of the subject to adjust the working plane at a desired height. In a variant, the holding unit 12a of the rehabilitation system is arranged to freely move upwards and downwards along the linear guide 25 to provide a further degree of freedom to the system thereby allowing the subject to perform exercises in a three dimension environment with partial or full compensation of his forearm thanks to gravity compensation means as described subsequently.

The handle assembly 10 comprises a first and a second holding element 14, 15 which have each a general  $\square$ -shaped construction and which are each oriented within a plane perpendicular to the plane of the supporting structure 50 on which the fixed platform 12 of the rehabilitation system is clamped. These first and second holding element 14, 15 are pivotally connected to a supporting structure which comprises a first and a second connecting link 13a, 13b which are both pivotally connected to the holding unit 12a of the fixed platform 12 to allow movements of the handle assembly 10 in two orthogonal directions within the working plane.

Referring to Figure 2 , the extremities of the upper and lower parts of the first holding element 14 are pivotally connected to the corresponding extremities of respective upper and lower parts of the second holding element 15 such that said first and second holding elements 14, 15 of the handle assembly 10 are both rotatable about a first axis of rotation  $\theta_1$  which is perpendicular to the transverse plane of the subject. Referring now to Figure 3, the handle assembly 10 further comprises a third and a fourth holding element 16, 17, both of which have also a general  $\square$ -shaped construction. The extremities of lower and upper parts of the third holding element 16 are pivotally connected to respective upper and lower parts of the first and second holding elements 14, 15. The gripping device 11 is mounted on a shaft 18 whose extremities are rotatably mounted on opposite sides of the fourth  $\square$ -shaped holding element 17. The latter is pivotally connected to the third holding element 16 to rotate about a second axis of rotation  $\theta_2$  perpendicular to the first axis of rotation  $\theta_1$  within said third holding element 16 in order to allow forearm pronation movements and forearm supination movements of the subject through an angle up to +/- 90 degrees as shown in Figure 3 as well as wrist flexion movements about a third axis of rotation  $\theta_3$  as shown in Figure 4 corresponding to the longitudinal/central axis of the shaft 18. According to the configuration of the system, the first and second axes of rotation  $\theta_1$ ,  $\theta_2$  as well as the longitudinal/central axis of the shaft 18 of the gripping device 11 always intersect each other at one point independently from the orientation of each of the first, second, third and fourth holding elements 14, 15, 16, 17 as shown particularly in Figures 2 and 3. This configuration allows the system to simulate a wide range of interactions with an object including reaching and grasping movements for training the shoulder, elbow, wrist, hand and fingers' movements of a subject in order to help retraining the whole function of the impaired upper limb of the subject.

Turning now in particular to Figures 5a to 5d, the gripping device 11 of the handle assembly 10 comprises two complementary parts 11a, 11b which are each connected to a foldable structure 19 (Figure 5c) mounted on both sides of the shaft 18. Each foldable structure 19 comprises a first and a second intersecting link 19a, 19b pivotally mounted together at their centre. The first intersecting link 19a is further connected at one end to the shaft 18 while its other end is slidably mounted along a rail 19c arranged on the upper inner side of the corresponding complementary part 11a, 11b of the gripping device 11. The second intersecting link 19b, for its part, is connected at one end to the lower inner side of said complementary part 11a, 11b while its other end is connected to a travel nut 20 of a ball

screw 21 mounted inside the shaft 18. Each foldable structure 19 is folded between the shaft 18 and the inner side of the corresponding complementary part 11a, 11b of the gripping device 11 when the latter is in a retracted position as shown in Figure 5b. The configuration of the gripping device allows hand grasp movements and hand release movements of the  
5 subject.

The upper limb rehabilitation device according to the invention further comprises a forearm supporting structure 22 which is pivotally connected to handle assembly 10 to rest the subject's forearm, during a rehabilitation session, when operating the handle assembly 10 in the two orthogonal directions within the working plane as shown specifically in Figures 6  
10 to 10.

According to one embodiment of the invention, the upper limb rehabilitation system as described above is adapted to provide active forces and/or torques to assist the subject's motions as well as resistive active movement in response to the subject motion to simulate the interaction with a virtual object. More specifically, the rehabilitation system according to  
15 this embodiment comprises two motors 30, 31 as shown in Figure 12 coupled with the first, respectively the second connecting link 13a, 13b to assist or impede movements of the handle assembly 10 in the two orthogonal directions within the working plane. Figures 14a shows a detailed view of the motor 30 coupled to a driving pulley 30a which is connected to a driven pulley 32 through a cable/belt 33 and which is arranged at one extremity of the  
20 connecting link 13a. A third motor 34 is mounted on the third  $\square$ -shaped holding element 16 as shown for example in Figure 14b. A driving pulley 35 is mounted on the motor's shaft and is coupled to a driven pulley 36 through a cable/belt 37 to assist or impede rotational movement of the fourth holding element 17 along with the gripping device 11 about the second axis of rotation  $\theta_2$ . The cable transmission configuration amplified the torque  
25 produced by the motors 30, 31 and 34 by a factor equal to the ratio between the radiuses of the driven and the drive pulley respectively. Cable transmissions are preferred over more standard solutions such as gear boxes which have the disadvantage of introducing friction and backlash preventing a smooth interaction of the rehabilitation system with the subject.

With reference to Figure 5c, a fourth motor 38 is arranged inside the shaft 18 of the  
30 gripping device 11 and is coupled to the ball screw 21 to assist or impede grasp movements of the subject's hand. More particularly, the motor 38 is configured to be driven to rotate the ball screw 21 clockwise or anticlockwise to cause the travel nut 20 to move upwards or

downwards thereby bringing the two complementary parts 11a, 11b of the gripping device, through the foldable structure 19, against each other or moving said complementary parts 11a, 11b away from each other.

According to this embodiment, the rehabilitation system can advantageously be used  
5 in an integrated robotic platform that combines robotics and interactive gaming to facilitate performance of task-specific repetitive, upper extremity/hand motor tasks, to enable individual undergoing rehabilitation to improve performance of coordinated movements of the forearm and hand. To this end, the robotic integrated platform comprises a gaming interface which is provided with a display device to simulate virtual reality and to present  
10 sensorimotor integration tasks to the subject. The rehabilitation device is used as a haptic interface to simulate the interaction with objects in a virtual reality world presented in the display device. Positions sensors (not shown) such as encoders or potentiometers are placed on the rehabilitation system on strategic locations to track the movement of the system. The integrated robotic platform further comprises a controller interface that is adapted to monitor  
15 and forward continuously, during the rehabilitation session, the outputs from the sensors to a programmable computer which determines desired force feedback to be applied by the controller interface to the corresponding motors 30, 31, 34 and 38 of rehabilitation system.

The level of assistance can be tuned on-line (e.g. during a working session) providing adapting time-dependent force fields. For example, given a specific task in which the subject  
20 has to follow a certain trajectory, the robotic platform can provide different level of support, from complete assistance, i.e. movements of the rehabilitation system are entirely driven by its motors, to full transparency, i.e. movements of the rehabilitation system are entirely caused by the subject upper limb's movements. The robotic platform can also provide force perturbation to increase the difficulty of the task.

25 The robotic integrated platform optionally comprises a controller arranged to monitor different physiological signals of the subject such as EEG or EMG and to drive the motors of the rehabilitation system for real time correlation between the movement of the device and brain activity pattern of the subject.

According to one alternate embodiment of the invention, the upper limb rehabilitation  
30 system as described above is adapted to provide resistive movements only, in response to the subject's motions. In this configuration, the motors are replaced by braking devices. For example, forearm pronation movements and forearm supination movements of the subject

around the second axis of rotation  $\theta_2$  can be hindered by a braking device as shown in Figures 15a, 15b. The braking device comprises for example a fixed part 45 mounted on the third holding element of the rehabilitation system (not shown) and a rotating part 46 rotatably mounted on the fixed part 45 and fixed to the fourth holding element in order to rotate about  
5 the second axis of rotation  $\theta_2$  of the system. A linear actuator 47 is mounted on the fixed part 45 to engage upon actuation into one of several arcuate slots 48 disposed along a circular path on the rotating part 45 thereby stopping its rotation in order to simulate a physical contact with a virtual object.

The rehabilitation system according to the invention preferably comprises gravity  
10 compensation means that can provide different levels of gravity compensation either passively (i.e. counterweights or springs) or actively (i.e. motors). Figure 12 illustrates an example of gravity compensation means which comprise a counterweight holder 41 slidably mounted along a vertical rail 41a on the rear side of the tower 40 of the fixed platform 12. At least one cable 42 is arranged on pulleys 43 located on the top of the tower 40 to connect the  
15 holding unit 12a with the counterweight holder 41. The latter is adapted to receive one or several counterweight 41b in function of the desired level of gravity compensation.

The method for the rehabilitation of an upper limb of a subject according to the invention comprises the steps of:

20 i) mapping the movements of the subjects into virtual or augmented reality environments in which the subject receive visual feedback concerning his/her own movements, for example through the projection of an avatar replicating his/her movements, as well as visual feedback about a virtual/augmented environment that includes several settings and objects whose physical properties (e.g. stiffness) are simulated through the upper  
25 limb rehabilitation system or through any other haptic display (able to render temperature, roughness etc) coupled with the system or in contact with the subject;

ii) recording physiological signals of the subject such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), functional near-infrared spectroscopic imaging (fNIRS), electrocardiography (ECG), skin conductance or  
30 electromyography (EMG) as well as movements parameters such as trajectories, velocities, accelerations and forces when the subject is operating the upper limb rehabilitation system; and

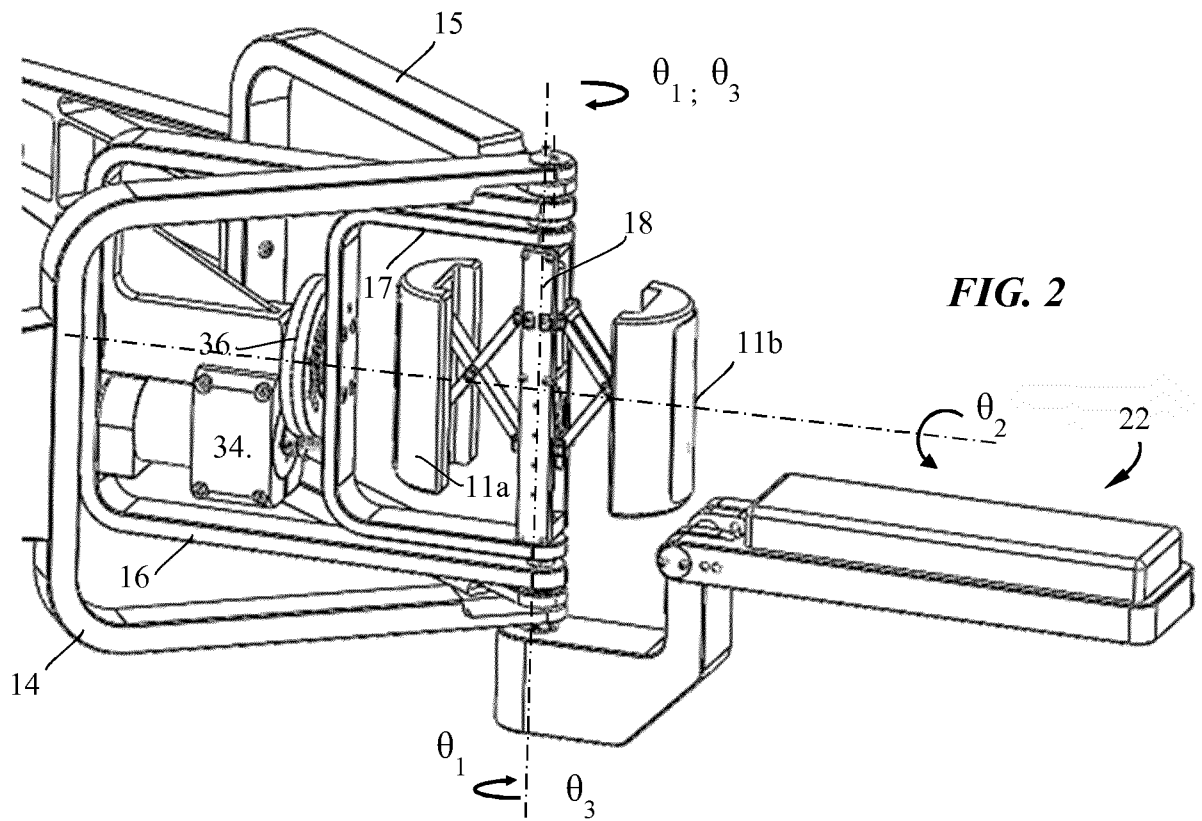
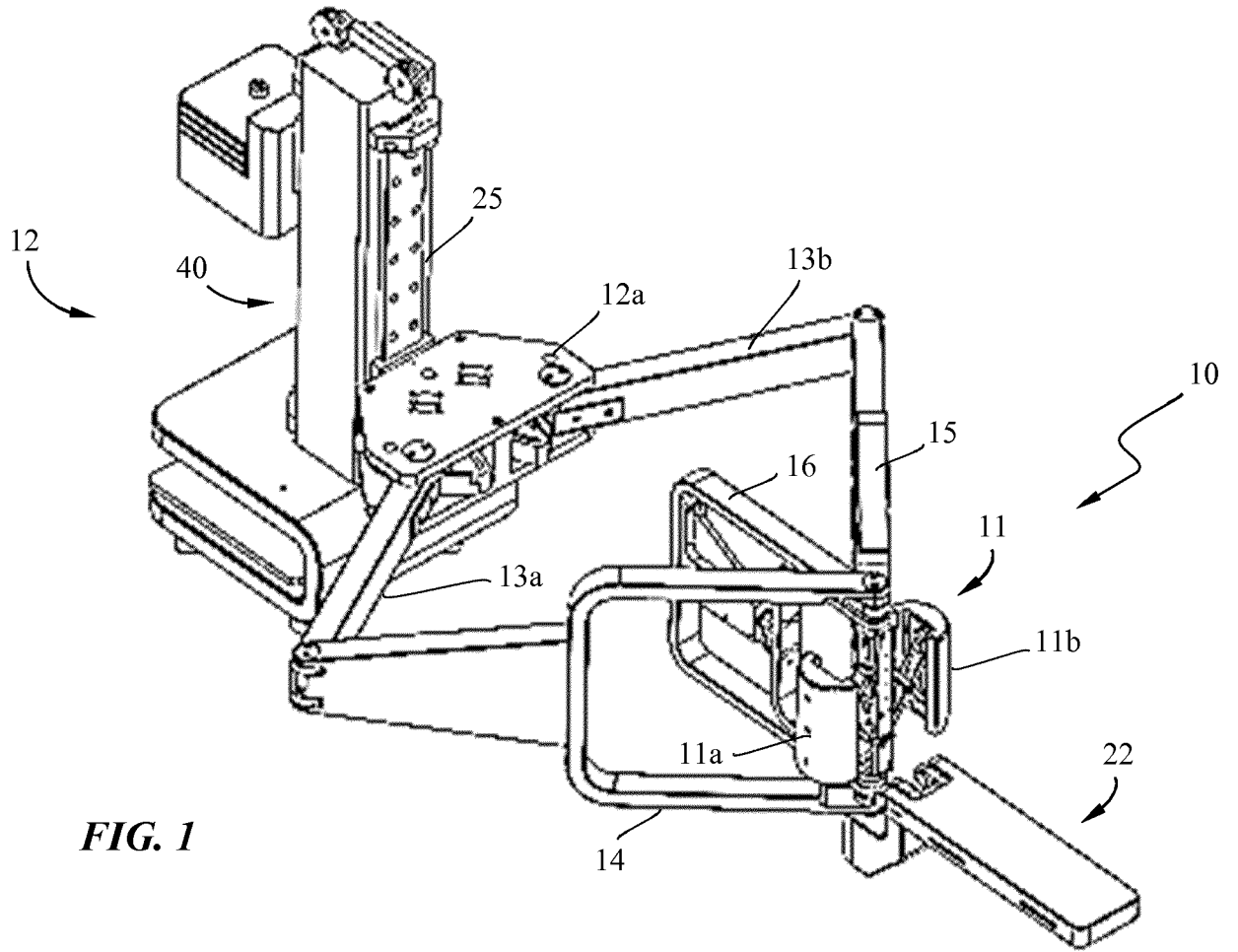
iii) controlling the movements of said system in function of the recorded physiological, brain or movement signals.

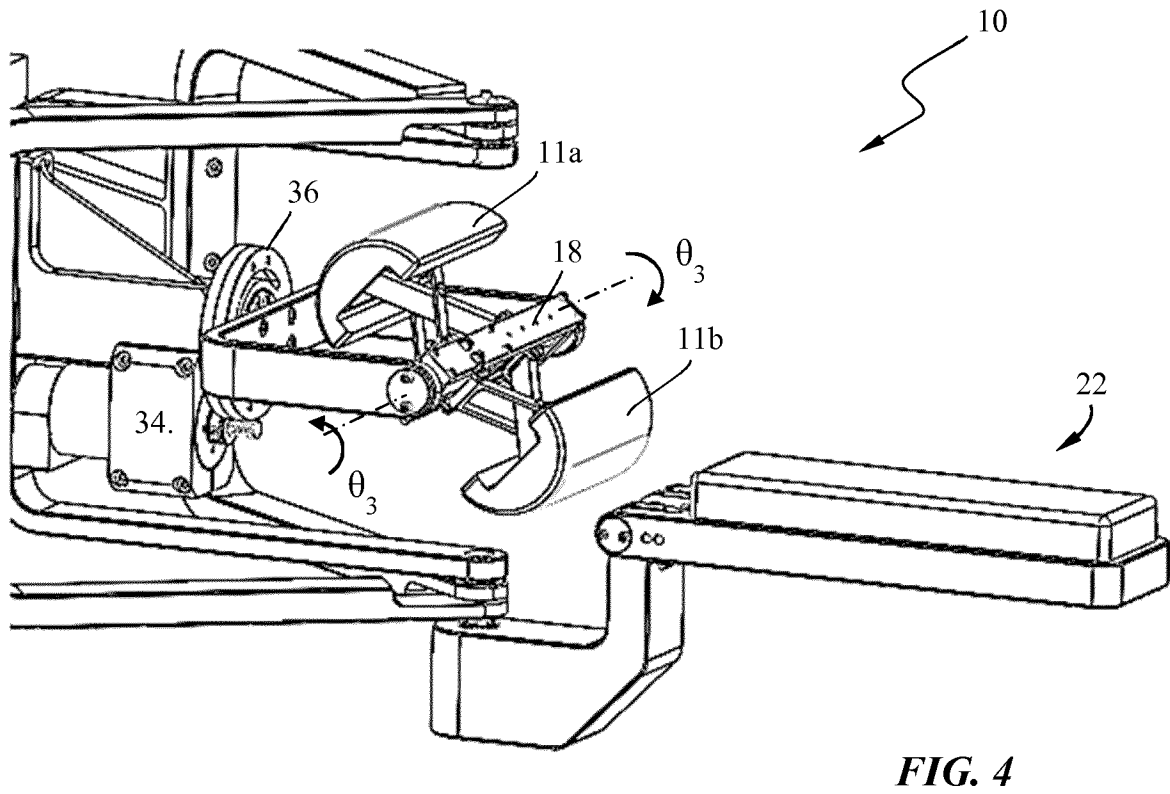
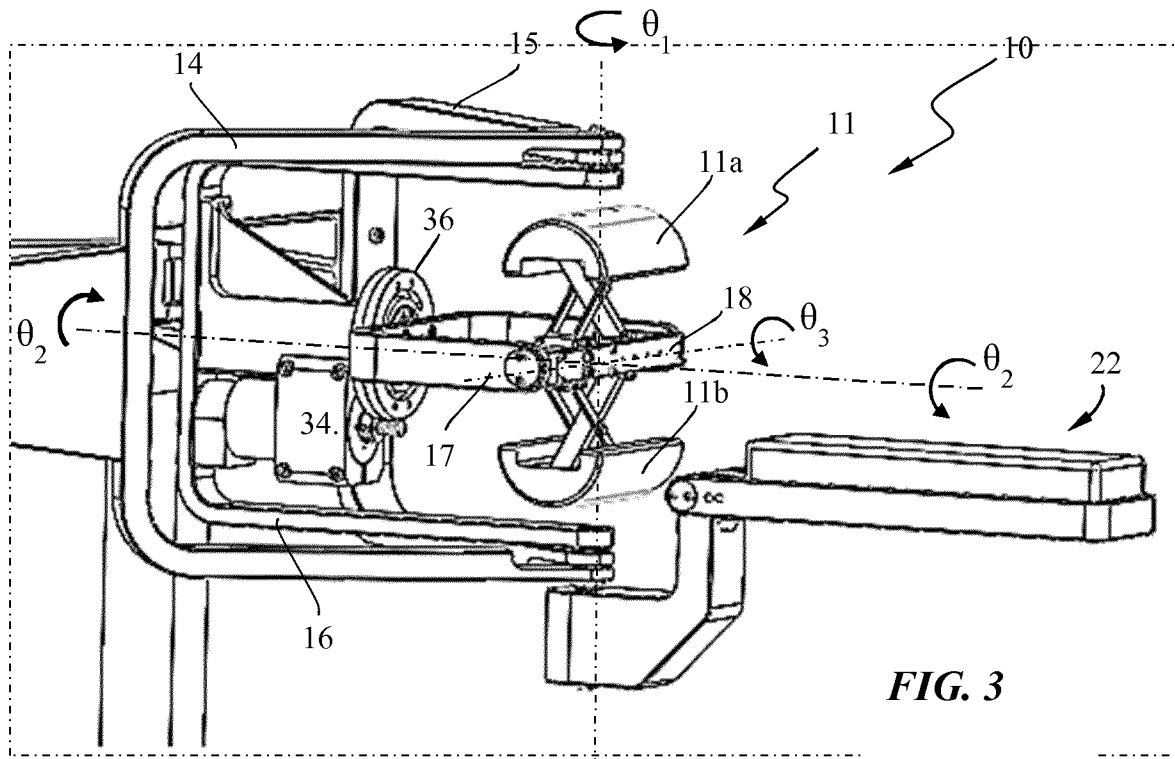
## CLAIMS

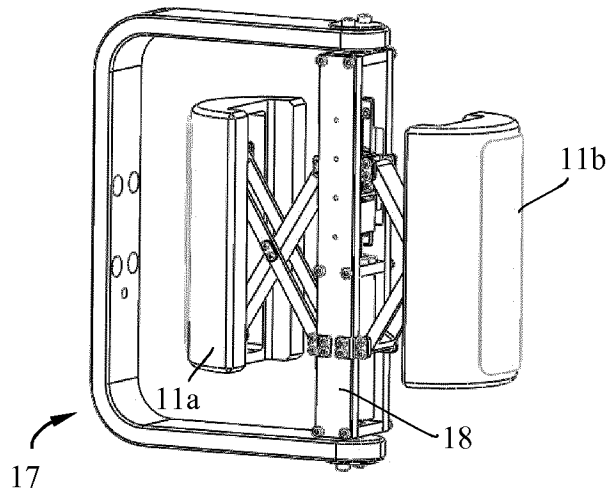
1. An upper limb rehabilitation system for rehabilitating an upper limb of a subject and comprising a mobile platform coupled to a fixed platform (12), which mobile platform comprises an articulate handle assembly (10) movable, during a rehabilitation session, within a plane which is substantially coplanar or parallel to the transverse plane of the subject, wherein the handle assembly (10) is provided with a gripping device (11) comprising a shaft (18), **characterized in that** said articulate handle assembly (10) comprises:
- a supporting structure having a first and a second holding elements (14, 15) pivotally connected together to rotate about a first axis of rotation ( $\theta_1$ ) perpendicular to said transverse plane,
  - a third holding element (16) connected to said supporting structure, and
  - a fourth holding element (17) supporting the shaft (18) of the gripping device (11) and pivotally connected to said third holding element (16) to rotate about a second axis of rotation ( $\theta_2$ ) which is perpendicular to the first axis of rotation ( $\theta_1$ ),
- and in that** said first and second axis of rotation ( $\theta_1, \theta_2$ ) as well as the central axis ( $\theta_3$ ) of the shaft (18) of the gripping device (11) always intersect at one point independently from the orientation of each of the first, second, third and fourth holding elements (14, 15, 16, 17).
2. The upper limb rehabilitation system according to claim 1, **characterized in that** each of said first and second holding elements (14, 15) of the supporting structure comprises upper and lower parts which are parallel to said transverse plane of the subject, wherein the upper part and lower parts of the first holding element (14) are pivotally connected respectively to the upper and lower parts of the second holding element (15) such that said first and second holding elements (14, 15) are both rotatable about said first axis of rotation ( $\theta_1$ ).
3. The upper limb rehabilitation system according to claim 2, **characterized in that** said third holding element (16) comprises upper and lower parts which are parallel to said transverse plane of the patient and pivotally connected to respective upper and lower parts of the first and/or second holding elements (14, 15).

4. The upper limb rehabilitation system according to claim 1, 2 or 3, **characterized in that** said first, second, third and fourth holding element (14, 15, 16, 17) have a general C- shaped or □ - shaped construction.
5. The upper limb rehabilitation system according to any one of the preceding claims, **characterized in that** the gripping device (11) of the handle assembly (10) comprises two ergonomic parts (11a, 11b) and two foldable structure (19) therebetween, the two ergonomic part (11a, 11b) being spaced apart in a resting position and arranged to be squeezed against each other by the hand grasp movements of the subject, wherein each foldable structure (19) is connected to the shaft (18) of the gripping device (11) and to a travel nut (20) of a ball screw (21) mounted inside said shaft (18), each foldable structure being further slidably mounted on the inner side of the corresponding complementary part (11a, 11b) of said gripping device (11).
6. The upper limb rehabilitation system according to claim 5, **characterized in that** each foldable structure (19) comprises two interconnected links (19a, 19b) pivotally mounted together at their centre, wherein one extremity of one intersecting link (19a) of each foldable structure (19) is connected to the shaft (18) of the gripping device (11), the other extremity of said one intersecting link (19a) being slidably mounted along a rail (19c) arranged on the inner side of the corresponding complementary part (11a, 11b) of the gripping device (11), and wherein one extremity of the other intersecting link (19b) is connected to the inner side of said complementary part (11a, 11b), the other extremity of said other intersecting link (19b) being connected to a travel nut (20) of a ball screw (21) mounted inside the shaft (18) of the gripping device (11).
7. The upper limb rehabilitation system according to any one of the preceding claims **characterized in that** a motor (34) is mounted on the third holding element (16) to assist and/or impede the rotation of the fourth holding element (17) about said second axis of rotation ( $\theta_2$ ).
8. The upper limb rehabilitation system according to claim 5, 6 or 7 **characterized in that** said system comprises a motor (38) arranged inside the shaft (18) of the gripping device (11), wherein said motor (38) is coupled to the ball screw (21) to assist or impede grasp movements of the subject's hand.

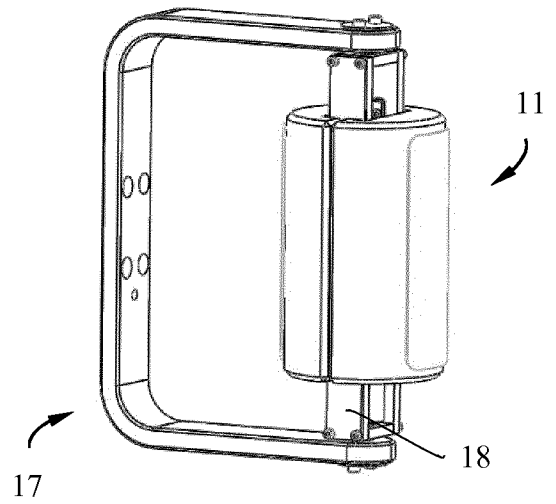
9. The upper limb rehabilitation system according to any one of the preceding claims **characterized in that** said system comprises a braking device, wherein said braking device comprises a fixed part (45) mounted on the third holding element (16) and a rotating part (46) rotatably mounted on the fixed part (45) and connected to the fourth holding element (17) in order to rotate about said second axis of rotation ( $\theta_2$ ), the  
5 braking device further comprising an actuator (47) configured to come into contact, upon actuation, with the rotating part (45) thereby stopping its rotation in order to simulate a physical contact with a virtual object.
10. An integrated rehabilitation platform comprising:
- 10 - the upper limb rehabilitation system according to any one of the preceding claims,  
- a display device to simulate virtual reality and to present sensorimotor integration tasks to the subject,  
- a sensor interface including at least one sensor for sensing at least one of  
15 force, load, torque, angular displacement, angular velocity, displacement and position of said rehabilitation system, and  
- a controlling interface that is adapted to control operation of the rehabilitation device.
11. Method for the rehabilitation of an upper limb of a subject comprising the steps of:
- 20 i) mapping the movements of the subjects into virtual or augmented reality environments in which the subject receive visual feedback concerning his/her own movements as well as visual feedback about a virtual/augmented environment whose physical properties are simulated through the upper limb rehabilitation system according to any one of claims 1 to 9 or through any other haptic display coupled  
25 with said system or in contact with the subject;
- ii) recording physiological signals such as brain signals of the subject as well as movements parameters of the upper limb rehabilitation system when the subject is operating said system; and
- iii) controlling the movements of said system in function of the recorded  
30 physiological signals or movement parameters.



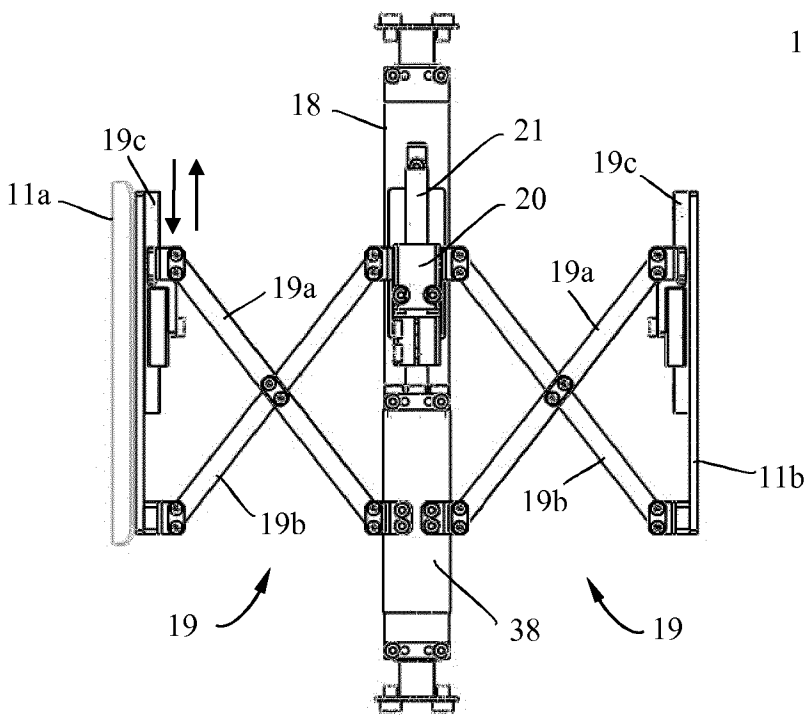




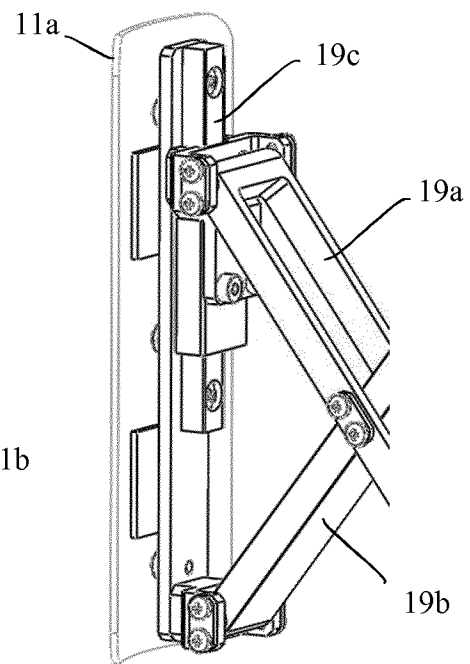
**FIG. 5a**



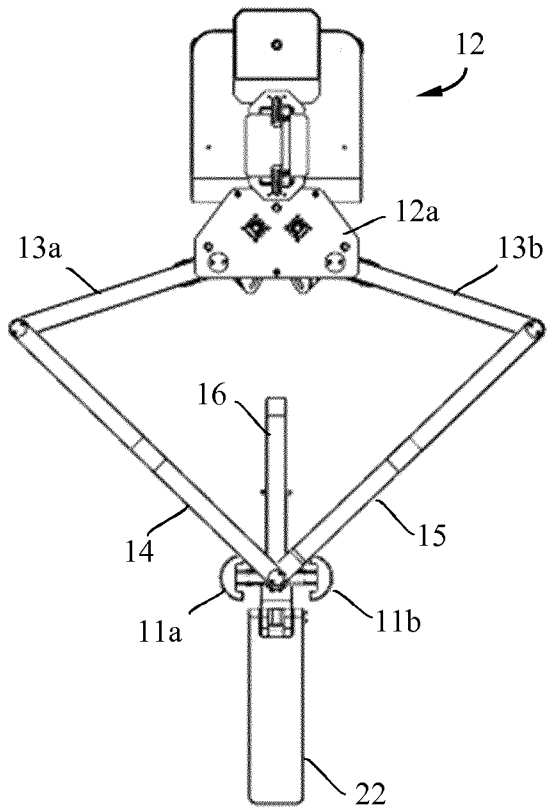
**FIG. 5b**



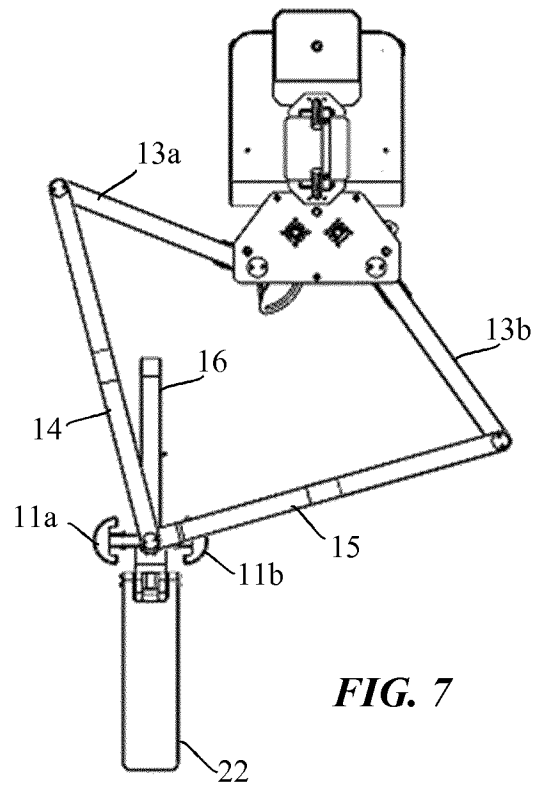
**FIG. 5c**



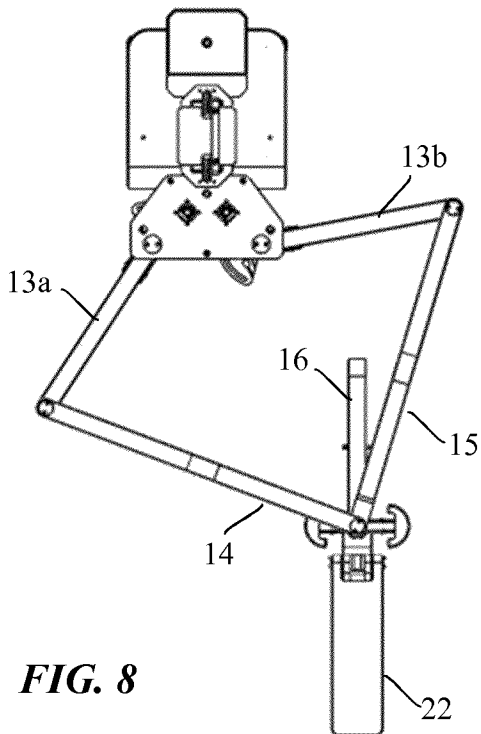
**FIG. 5d**



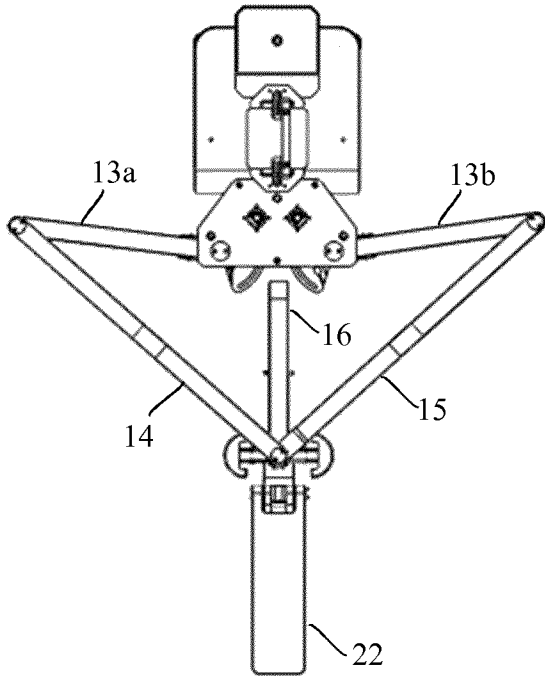
**FIG. 6**



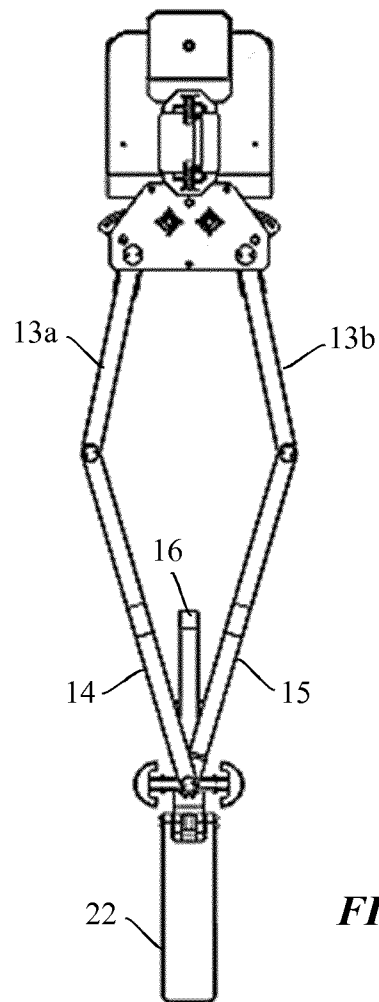
**FIG. 7**



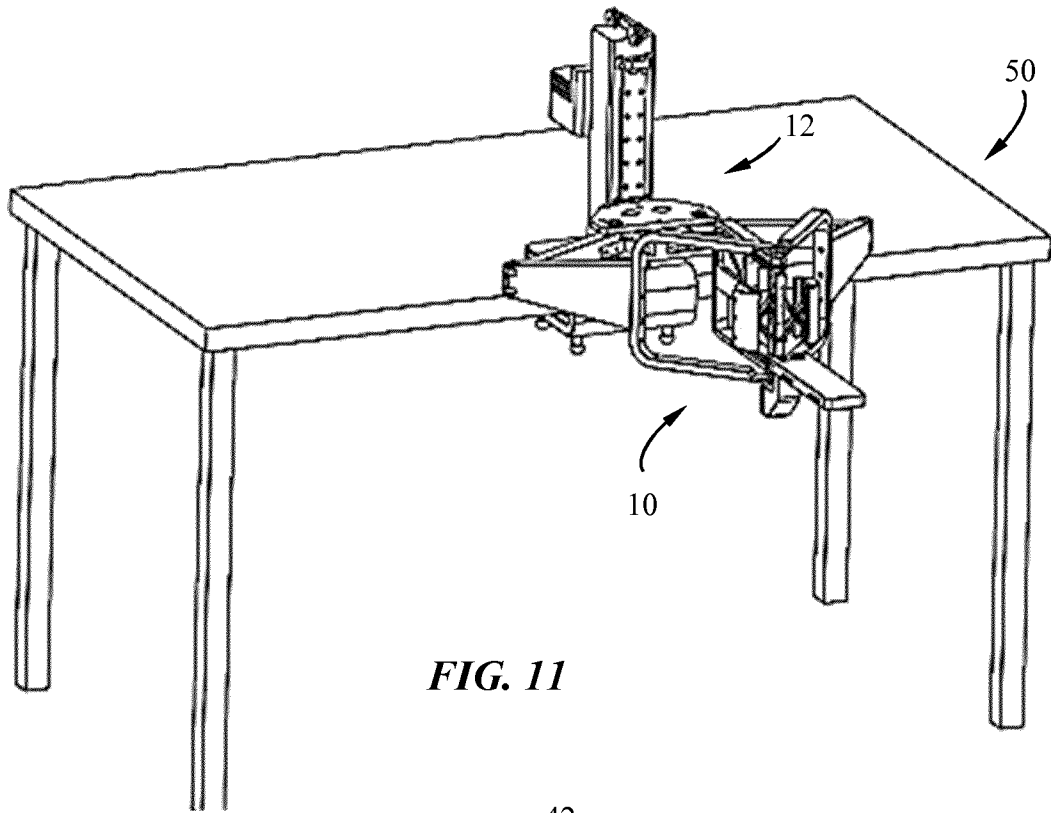
**FIG. 8**



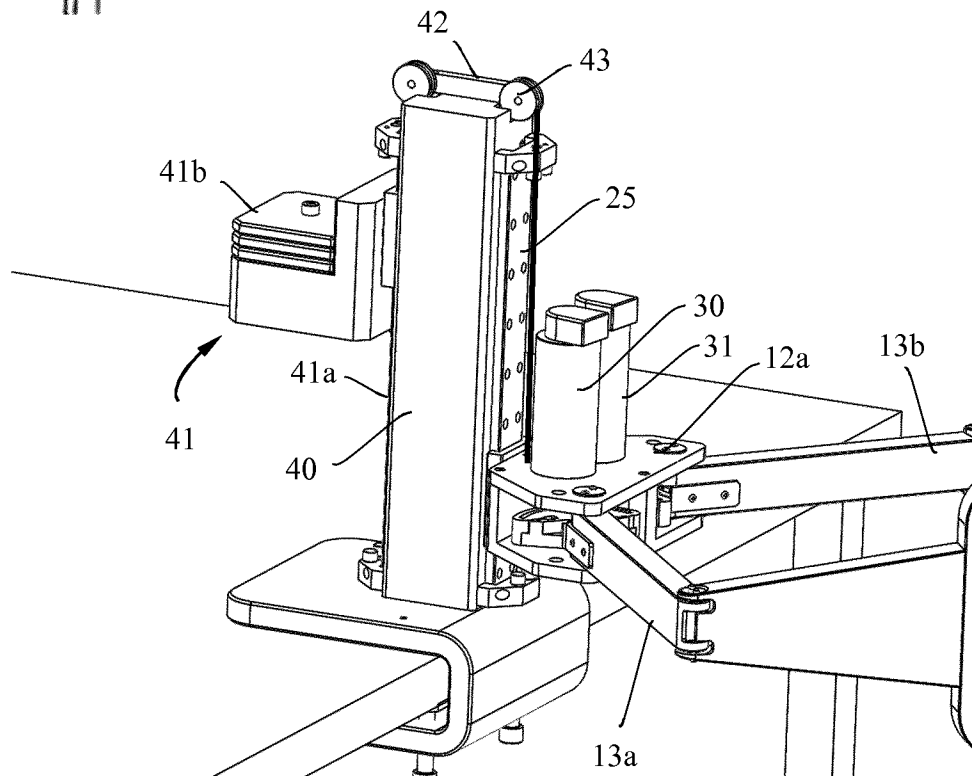
**FIG. 9**



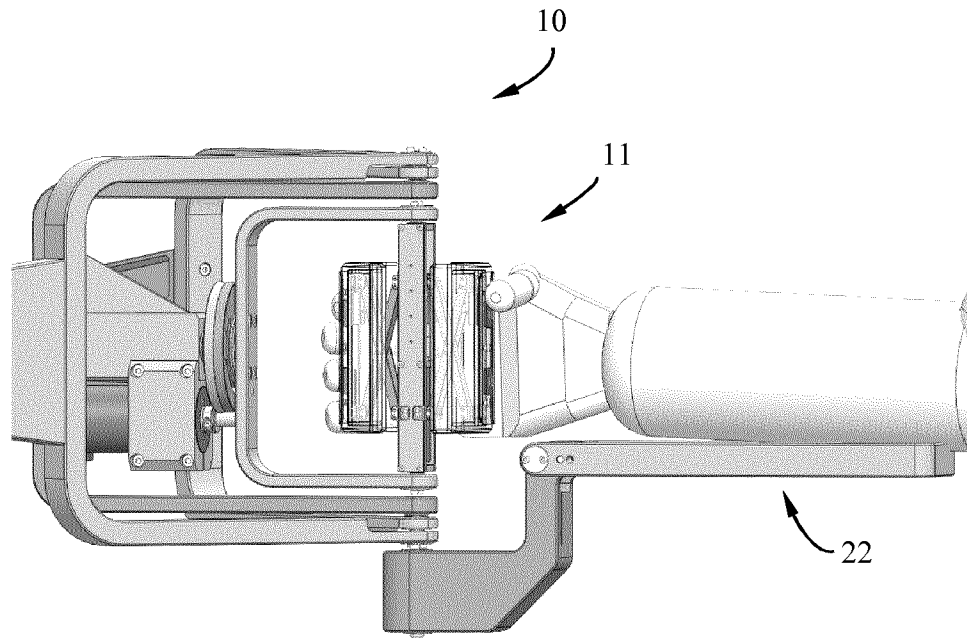
**FIG. 10**



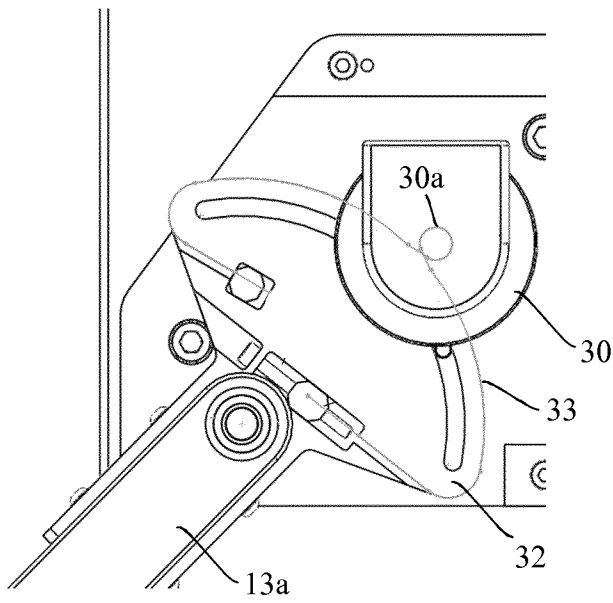
**FIG. 11**



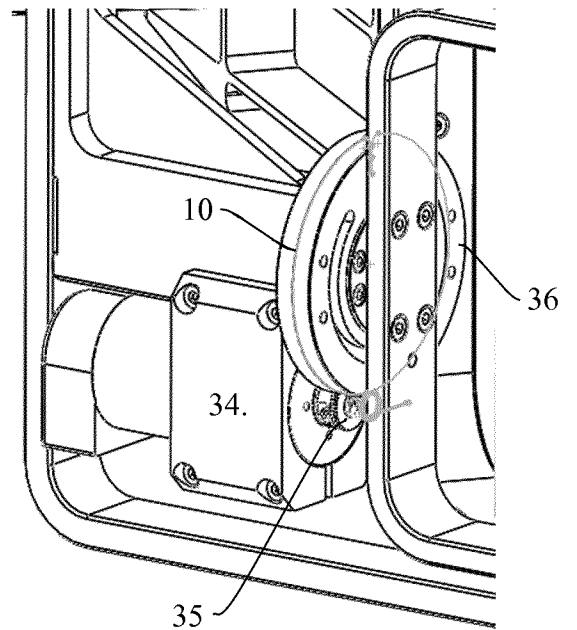
**FIG. 12**



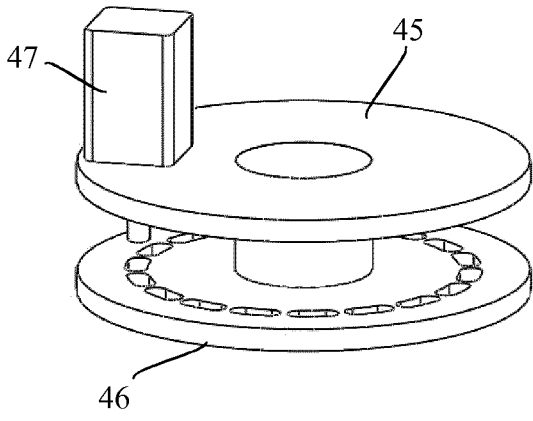
**FIG. 13**



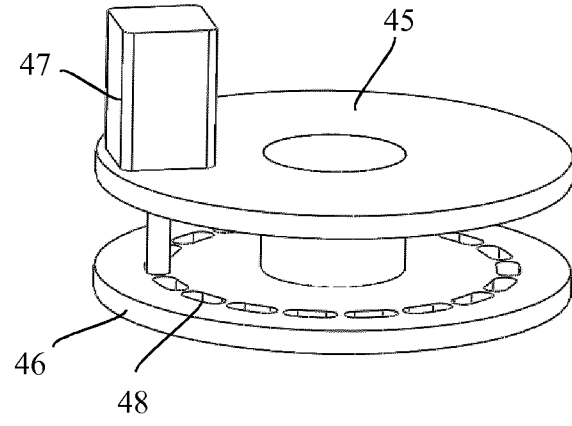
**FIG. 14a**



**FIG. 14b**



**FIG. 15a**



**FIG. 15b**

INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2015/068104

A. CLASSIFICATION OF SUBJECT MATTER					
INV.	A63B71/00	A47G29/087	A63B71/06	A61H1/02	A63B21/005
	A63B21/00	A63B21/16	A63B23/12	A63B23/14	A63B23/16
	A63B24/00				
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) A63B A47G A61H

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)  
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 755 645 A (MILLER LARRY C [US] ET AL) 26 May 1998 (1998-05-26) column 4, line 4 - line 17 column 8, line 6 - line 25; figures -----	1-10
Y	CN 103 481 283 A (UNIV JIANGNAN) 1 January 2014 (2014-01-01) figures -----	1-10
Y	US 6 319 175 B1 (WU RACE [TW]) 20 November 2001 (2001-11-20) the whole document -----	5,6,8
X	FR 2 965 184 A1 (STEVENOT THIERRY [FR]; LUBIN MATHIAS [FR]) 30 March 2012 (2012-03-30) the whole document -----	1-4,7
	-/--	

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search	Date of mailing of the international search report
15 October 2015	26/10/2015

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  Squeri, Michele
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## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2015/068104

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/106326 A1 (KREBS HERMANO I [US] ET AL KREBS HERMANO IGO [US] ET AL) 18 May 2006 (2006-05-18)	1,3,4,7, 10
Y	page 1, paragraph 4 - page 2, paragraph 29 page 4, paragraph 41 - paragraph 43; figures	5,6,8,9
Y	----- WO 2007/131340 A1 (REHABTRONICS INC [CA]; KOWALCZEWSKI JAN [CA]; PROCHAZKA ARTHUR [CA]) 22 November 2007 (2007-11-22) page 13, last paragraph - page 14, paragraph 1; figures	5,6,8,9
A	----- JP 2013 154431 A (OKUMURA CORP) 15 August 2013 (2013-08-15) figures -----	1

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/EP2015/068104

## 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.: 11  
because they relate to subject matter not required to be searched by this Authority, namely:  
Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy
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

Information on patent family members

International application No PCT/EP2015/068104
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JP 2013154431	A	15-08-2013	NONE
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