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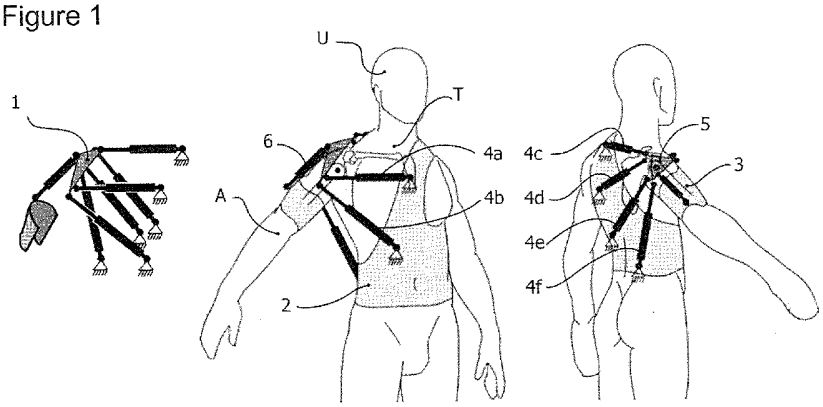
(54) Title: UPPER LIMB EXOSKELETON

Figure 1




(57) Abstract: The present invention relates a wearable exoskeleton for a user having a torso with an upper limb to support motion of the said upper limb. The wearable exoskeleton comprises a first fixed frame mountable to the torso, an upper arm brace and a first group of actuators for moving the upper arm brace relative to the first fixed frame. In an example the present invention is for use in post-stroke therapy.

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# Upper limb exoskeleton

The present invention relates a wearable exoskeleton for a user having a torso with an upper limb to support motion of the said upper limb. The wearable exoskeleton comprises a first fixed frame mountable to the torso, an upper arm brace and a first group of actuators for moving the upper arm brace relative to the first fixed frame.

The human shoulder is complex and permits an exceptionally wide range of movements compared to any other point of articulation of a human body. It is made up of three bones: the clavicle (collarbone), the scapula (shoulder blade), and the humerus (upper arm bone) as well as associated muscles, ligaments and tendons. The articulations between the bones of the shoulder make up the shoulder joints. "Shoulder joint" typically refers to the glenohumeral joint, which is the major ball and socket joint of the shoulder, although this can more broadly include the acromioclavicular joint, the Sternoclavicular joint ant the scapulothoracic joint.

Wearable exoskeletons for an upper limb are known from the prior art. As an example reference is made to the European patent application EP 1 609 451 which teaches an exoskeleton having a torso frame which is worn by the upper part of the human body (the torso) and which drives a shoulder joint portion and an elbow joint portion. The body and the upper arm are connected by a shoulder joint portion, and the upper arm and the forearm are connected by an elbow joint portion. The upper arm is placed in an upper arm frame, and a shoulder frame is applied to the shoulder as a rotation support member for said upper arm frame, wherein the shoulder frame is rotatably connected to the torso frame through a connecting portion. Further between the torso frame and the upper arm frame there is provided a tubular first actuator for rotating the upper arm frame relative to the torso frame. A second tubular actuator is provided between the shoulder frame and the upper arm frame for attracting the upper arm frame to the shoulder frame. A third tubular actuator is pro-

vided between the torso frame and the shoulder frame for rotating the shoulder frame relative to the torso frame. Fourth and fifth actuators are provided between the upper arm frame and the forearm frame for rotating the forearm relative to the upper arm frame. In EP 1 609 451 all frames are interconnected and not floating.

As a further example, Morizono et al., 2005 IEEE International Workshop on Robots and Human Interactive Communication, pp 259-266, recite a six degree of freedom mechanism for a shoulder joint of a wearable robot. Morizono does however not apply a second floating frame to which the upper arm brace is connected, and which second floating frame is supported by the first fixed frame.

WO2008/031023 teaches a wearable exoskeleton for a user having a torso with an upper limb to support motion of the said upper limb, the wearable exoskeleton comprising a first fixed frame (a vest) mountable to the torso, an upper arm brace and a first group of actuators for moving the upper arm brace relative to the vest, wherein the wearable exoskeleton further comprises a second floating frame (a shoulder joint mechanism) to which the upper arm brace is connected, and which second floating frame is supported by the vest. This exoskeleton has several drawbacks that relate to the construction that the upper arm brace is connected to the vest by said shoulder joint mechanism embodied as three sets of spherical linkage chains, each of which has three revolute joints. The spherical mechanisms are thus designed with linkages wherein all axes of the revolute joints need to align to the center of rotation of the shoulder. This results in four degrees of freedom of the exoskeleton, notably one at the elbow and three at the shoulder.

Disadvantages of wearable exoskeletons for upper limbs of the prior art are that they are neither able to realise nor support the full range of motion of the human shoulder.

It is an object of the present invention to overcome disadvantages of wearable exoskeletons for an upper limb of the prior art and to provide a wearable exoskeleton that is

able to support full motion of an upper limb, such as for post-stroke therapy.

Accordingly, the present invention relates to a wearable exoskeleton for a user having a torso with an upper limb to support motion of the said upper limb, the wearable exoskeleton comprising a first fixed frame mountable to the torso, an upper arm brace and a first group of actuators for moving the upper arm brace relative to the first fixed frame, wherein the wearable exoskeleton further comprises a second floating frame to which the upper arm brace is connected, and which second floating frame is supported by the first fixed frame, and wherein the first group of actuators comprises at least six actuators configured to provide at least six degrees of freedom of movement configured to support elevation, rotation, protraction and their antagonistic motions of a shoulder girdle of a user and abduction, flexion, rotation and their antagonistic motions of the glenohumeral joint of the user, wherein the wearable exoskeleton further comprises a second group of actuators, the second group of actuators providing a connection of the second floating frame to the upper arm brace.

By providing a second floating frame the orientation of the parts of the wearable exoskeleton and a centre of rotation of the wearable exoskeleton can adapt to the orientation of the upper limb.

A further advantage of providing a second floating frame is that it makes possible to provide a virtual centre of rotation of the wearable exoskeleton that, with the wearable exoskeleton in use, is coincident with a corresponding human joint, e.g. a glenohumeral joint of a user, such that the wearable exoskeleton is able to support motion of an upper limb of a user without putting significant burden on the human (glenohumeral) joint. It is noted that a number of wearable exoskeletons for upper limbs of the prior art, rotate about the, e.g. glenohumeral, joint itself and as such put the joint under unwanted stress. In the exoskeleton with the features of the invention however it is possible to change the orientation and the position of the glenohumeral

joint in order to support natural motion of the shoulder complex by means of the actuator configuration of the first group of actuators, which is completed with the seventh actuator degree of freedom by the second group of actuators providing support for the full motion envelope of the shoulder complex. In particular it may be beneficial that the second group of actuators is configured to further support the motions that are principally enabled by the first group of actuators and are aimed at abduction and adduction, and/or inward rotation and outward rotation.

The advantages of the invention are thus particularly promoted by arranging that the exoskeleton comprises the following features:

- the first group of actuators connect the first fixed frame to the second floating frame [This enables the device to be easily fitted to the shoulder width of a user. Moreover, being able to adjust the position of the second floating frame with the first group of actuators enables positioning of the second floating frame to the anthropometric measures and motion envelope of the user];
- the second floating frame is positioned relative to the first fixed frame and the upper arm brace such that in use it is adjacent to a glenohumeral joint of a user;
- the first group of actuators comprises at least six actuators configured to provide at least six degrees of freedom of movement configured to support elevation, rotation, protraction and their antagonistic motions of a shoulder girdle of a user and abduction, flexion, rotation and their antagonistic motions of the glenohumeral joint of the user, wherein the wearable exoskeleton further comprises a second group of actuators, the second group of actuators providing a connection of the second floating frame to the upper arm brace;
- the second group of actuators is configured to provide at least one more degree of freedom of movement additional to or supportive of those provided by the first group of actuators; and,

- the second group of actuators are configured to at least support full flexion and extension of a user's glenohumeral joint. As mentioned the second group of actuators may also be supportive of the movement faculties provided by the first group of actuators in that they further support abduction and adduction, and/or inward rotation and outward rotation of the user's shoulder girdle.

The additional degree or degrees of freedom of movement provided by the second group of actuators is particularly supportive in realizing that the centre of rotation of the wearable exoskeleton is able to adapt without restriction to the orientation of the upper limb.

In a further preferred embodiment, the wearable exoskeleton further comprises programmable control means for registering and/or controlling the first and/or second groups of actuators. This not only assists in easily programming the control means in a manner of "learning by doing" when it is in the registration mode and the skeleton is moved by external forces to 'program' for the users subsequent exercises with the exoskeleton. It thus facilitates the ease of use of the exoskeleton in rehabilitation of post-stroke patients and helps them to regain mobility of their upper limbs.

The present invention is further elucidated with reference to the Drawing of Figures 1. The drawings are provided for illustrative purposes only and are not to be considered to limit the invention.

Figure 1 shows a preferred embodiment of the wearable exoskeleton of the invention.

With reference to Figure 1, a wearable exoskeleton 1 is shown for a user U having a torso T with an upper limb A to support motion of the said upper limb A, the wearable exoskeleton 1 comprising a first fixed frame 2 mountable to the torso T, an upper arm brace 3 and a first group of actuators 4 for moving the upper arm brace 3 relative to the first fixed frame 2. The wearable exoskeleton 1 further comprises a second floating frame 5 to which the upper arm brace 3 is connected, and which second floating frame 5 is supported by

the first fixed frame 2.

The first group of actuators 4 connect the first fixed frame 2 to the second floating frame 5, which said second floating frame 5 is positioned relative to the first fixed frame 2 and the upper arm brace 3 such that in use it is adjacent to a glenohumeral joint of a user U.

The first group of actuators 4 comprises six actuators (4a-f) configured to provide six degrees of freedom of movement configured to support elevation, rotation, protraction and their antagonistic motions of a shoul-der girdle (not shown) of a user and abduction, flexion, rotation and their antagonistic motions of the glenohumeral joint (not shown) of the user U.

The wearable exoskeleton further comprises a second group of actuators 6, the second group of actuators 6 providing a connection of the second floating frame 5 to the upper arm brace 3. The second group of actuators 6 is configured to provide a degree of freedom of movement additional to those provided by the first group of actuators 4. Specifically, the second group of actuators 6 are configured to support full flexion and extension of a user's U glenohumeral joint.

The wearable exoskeleton 1 further preferably comprises programmable control means (not shown) for registering and controlling the first- and second- groups of actuators 4, 6.

## CLAIMS

1. A wearable exoskeleton (1) for a user (U) having a torso (T) with an upper limb (A) to support motion of the said upper limb (A), the wearable exoskeleton (1) comprising a first fixed frame (2) mountable to the torso (T), an upper arm brace (3) and a first group of actuators (4) for moving the upper arm brace (3) relative to the first fixed frame (2), wherein the wearable exoskeleton (1) further comprises a second floating frame (5) to which the upper arm brace (3) is connected, and which second floating frame (5) is supported by the first fixed frame (2), **characterised in that** the first group of actuators (4) comprises at least six actuators (4a-f) configured to provide at least six degrees of freedom of movement configured to support elevation, rotation, protraction and their antagonistic motions of a shoulder girdle of a user (U) and abduction, flexion, rotation and their antagonistic motions of the glenohumeral joint of the user, and that the wearable exoskeleton (1) further comprises a second group of actuators (6), the second group of actuators (6) providing a connection of the second floating frame (5) to the upper arm brace (3).

2. A wearable exoskeleton (1) according to claim 1, **characterised in that** the first group of actuators (4) connect the first fixed frame (2) to the second floating frame (5).

3. A wearable exoskeleton (1) according to one or more of the preceding claims, **characterised in that** the second floating frame (5) is positioned relative to the first fixed frame (2) and the upper arm brace (3) such that in use it is adjacent to a glenohumeral joint of a user.

4. A wearable exoskeleton (1) according to any one of claims 1 - 3, **characterised in that** the second group of actuators (6) is configured to provide at least one more degree of freedom of movement additional to those provided by the first group of actuators (4).

5. A wearable exoskeleton (1) according to one or

more of claims 1 - 4, **characterised in that** the second group of actuators (6) are configured to support full flexion and extension of a user's (U) glenohumeral joint.

6. A wearable exoskeleton (1) according to claim 5, **characterised in that** the second group of actuators (6) are configured to further support the motions enabled by the first group of actuators (4) aimed at abduction and adduction, and/or inward rotation and outward rotation.

7. A wearable exoskeleton (1) according to one or more of the preceding claims 1 - 6, **characterised in that** the wearable exoskeleton (1) further comprises programmable control means for registering and/or controlling the first and/or second groups of actuators (4,6).

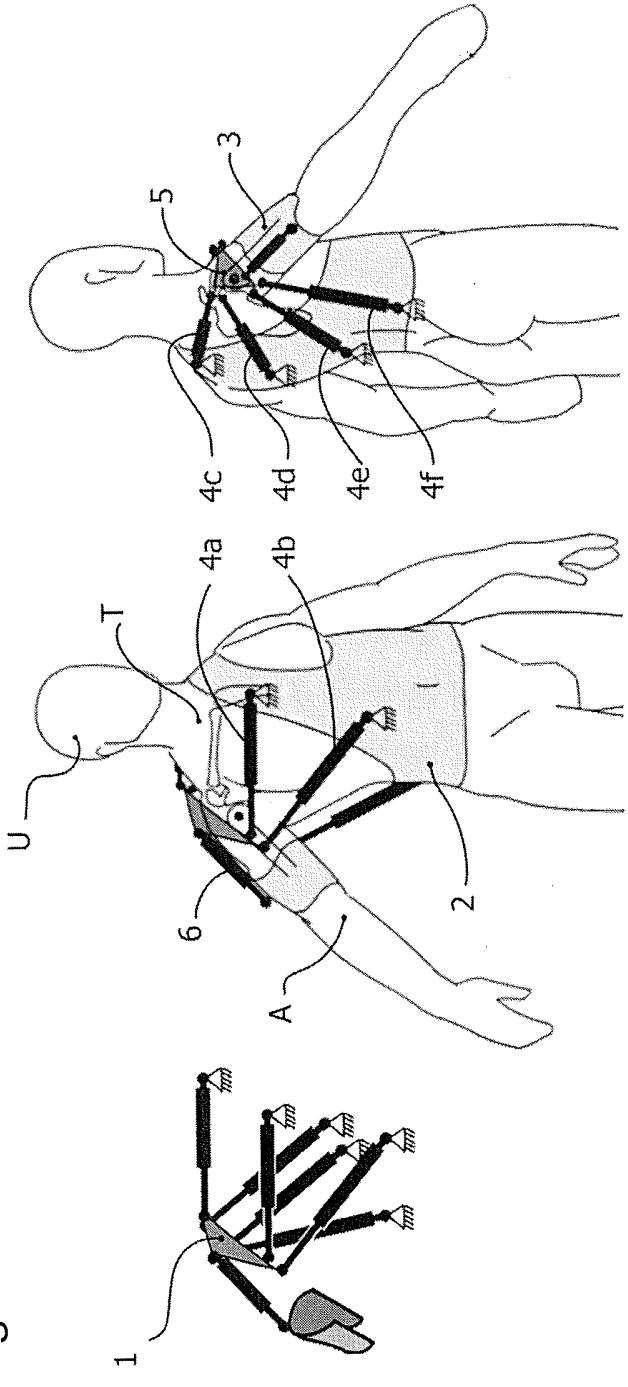


Figure 1

# INTERNATIONAL SEARCH REPORT

International application No
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**A. CLASSIFICATION OF SUBJECT MATTER**
INV. A61F5/01 A61H1/02 B25J9/00
ADD.

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)
A61F B25J 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**

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| | ----- | |
| A | DE 199 40 603 A1 (SCHAEFER CHRISTIAN [DE]) 19 April 2001 (2001-04-19) abstract; figures | 1 |
| | ----- | |
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 2 March 2015 | 06/03/2015 |

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

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International application No
PCT/NL2014/050836

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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**Information on patent family members**

International application No
PCT/NL2014/050836

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