OVERVIEW OF THE ROBOTIC REHABILITATION SYSTEMS FOR UPPER LIMB REHABILITATION

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Abstract
The purpose of this paper is to document a review of robotic devices for upper limb rehabilitation in order to provide a comprehensive reference about existing solutions and facilitate the development of new and improved devices.

Key words: robotic rehabilitation, degrees of freedom, end-effector, exoskeleton

INTRODUCTION
A description of the specific field of application for upper limb rehabilitation devices often determines solutions for which the device itself may be applied. Upper-extremity rehabilitation involves actions that stimulate patients’ independence and quality of life. Two main application fields of robotic devices stand out:

- support to perform some activities of daily living (e.g. by power assistance or tremor suppression) and
- providing physical training (therapy).

Second group of the robotic devices used for rehabilitation purposes is much bigger than the group of devices supporting basic activities of daily living. These may be designed for either specialized therapeutic institutes or home-based conditions. A vast majority of these devices may be used only at therapeutic institutes since they require supervised assistance from qualified personnel. Their price is often prohibitive for personal use due to their complexity.

Basic division of robotic rehabilitation devices for upper limb
Devices for upper limb rehabilitation may provide different types of motion assistance:

- active
- passive

Active devices provide active motion assistance and possess at least one actuator, thus they are able to produce movement of the upper-extremity. Such assistance of movements is required if patient is too weak to perform specific exercises. However, even with active devices, an exercise is considered passive when a patient’s effort is not required. For example, devices providing continuous passive motion exercises are active, but those exercises are categorized as passive because the subject remains inactive while the device actively moves the joint through a controlled range of motion. It is not necessary to apply active assistance to resist patient’s movement, to increase patient’s force or to ensure the patient is following the desired trajectory.

Instead, passive devices may be applied that are equipped with actuators providing resistive force only (i.e. brakes). Such actuators consume less energy and are cheaper than the heavier actuators for active assistance. Devices using only resistive actuators include both devices for physical therapy and systems for tremor suppression.

When comparing the mechanical structure of robotic devices for movement rehabilitation two categories of devices are considered:

- end-effector-based,
- exoskeleton-based.

The difference between the two categories is how the movement is transferred from the device to the patient’s upper extremity.

End-effector-based devices
End-effector-based devices contact the patient’s limb only at its most distal part that is attached to patient’s upper extremity (i.e. end effector). Movements of the end effector change the position of the upper limb to which it is attached. However, segments of the upper extremity create a mechanical chain. Thus, movements of the end effector also indirectly change the position of other segments of the patient’s body as well. The advantage of the end-effector-based systems is their simpler structure and thus less complicated control algorithms. However, it is difficult to isolate specific movements of a particular joint because these systems produce complex movements. The manipulator allows up to six unique movements (i.e. 3 rotations and 3 translations). Control of the movements of the patients upper limb is possible only if the sum of possible anatomical movements of patient arm in all assisted joints is limited to six. Increasing the number of defined movements for the same position of the end-point of the manipulator results in redundant configurations of the patient’s arm, thus inducing risk of injuries and complicated control algorithms.

The typical end-effector-based systems include serial manipulators e.g. MIT Manus [1] – fig 1, and cable-driven robots e.g. NeReBot [2] – Fig. 2. Into this group can be included also MIME system (fig. 3) for shoulder and elbow rehabilitation.
The most clinically studied upper limb robotic rehabilitation device is the MIT-MANUS (fig. 1), or its commercial version, InMotion2 (Interactive Motion Technologies, Cambridge, MA). This robot has two degrees of freedom (DoF). The user’s paretic forearm is placed in a supporting trough, which is then attached to an end-effector. The user moves the handle in the transverse plane, performing goal-directed tasks which focus on shoulder and elbow movement. A monitor displays user targets and provides visual feedback. The MIT-MANUS has developed over the years to include modular components that allow a one DoF vertical movement and a three DoF wrist movement as well as a grasp sensor. The MIT-MANUS has three modes for the user: resisted, where the robot gives the user resistance in the opposite direction the user is moving; active, where the robot magnifies the user’s actions in the direction the user is moving; and assisted movement, where the robot does all the moving and the paretic arm is passively moved. The MIT-MANUS is able to generate more or less assistance depending on the user’s ability.

The MIME - Mirror-Image Motion Enabler (fig. 2) is based on the principle of bilateral movement, where stroke recovery is affected by corticospinal ipsilateral pathways. These pathways are active in healthy bilateral movement. The hypothesis is that bilateral symmetrical exercise will stimulate these pathways and assist in stroke recovery. The MIME consists of a six DoF end effector for the paretic arm, which has actuators to apply forces in goal-directed movements. The arm is strapped to the end effector, which restricts wrist and hand movement.

The NeReBot - Neuro-Rehabilitation-Robot is a three DoF wire based robot (fig. 3). It supports the arm through cables attached to overhead arms which are attached to a transportable C-frame. It is powered by three direct current motors at the top of the device. The NeReBot simulates hand-over-hand therapy by learning movements from therapists and then repeating these movements with clients. NeReBot has visual feedback through a monitor. Although much of the movement is passive, users can contribute to the movement by pushing or pulling. Therapists set the angular and linear position of the links according to the patient and exercise. There is an emergency stop that either the therapist or patient can use.

Exoskeleton-based devices

Exoskeleton-based devices have a mechanical structure that mirrors the skeletal structure of patient’s limb. Therefore movement in the particular joint of the device directly produces a movement of the specific joint of the limb. Application of the exoskeleton-based approach allows for independent and concurrent control of particular movement of patient’s arm in many joints, even if the overall number of assisted movements is higher than six. However, in order to avoid patient injury, it is necessary to adjust lengths of particular segments of the manipulator to the lengths of the segments of the patient arm. Therefore setting-up such device for a particular patient, especially if the device has many segments, may take a significant amount of time. Furthermore, the position of the center of rotation of many joints of human body, especially of the shoulder complex may change significantly during movement. Special mechanisms are necessary to
ensure patient safety and comfort when an exoskeleton-based robot assists the movements of these joints [3]. For this reason, the mechanical and control algorithm complexity of such devices is usually significantly higher than of the end-effector-based devices. The complexity escalates as the number of DOF increases.

The typical exoskeleton based devices are ARMin - fig. 4, WOTAS - fig. 5, MULOS - fig. 6.

The ARMin is a 6 DoF exoskeleton developed at the Swiss Federal Institute of Technology in Zurich (fig. 4). It is specifically designed for neurological rehabilitation; as a device-therapy medium as well as a tool to test existing rehabilitation strategies and find the best rehabilitation practice. ARMin is a semi-exoskeleton solution in the sense that its structure is fixed on the wall via an aluminium frame and the patient’s wheelchair can be placed beneath. The exoskeleton has 3 DoF at the shoulder permitting horizontal, vertical and internal/external shoulder rotation, 1 DoF for elbow flexion/extension, 1 DoF for forearm pronation/supination and finally, 1 DoF for wrist flexion/extension.

Impedance control is used to ensure compliant behaviour and many safety features have been incorporated in order not pose danger to the patient in case of malfunction.

Wearable Orthosis for Tremor Assessment and Suppression – WOTAS, fig. 5 is an upper limb exoskeleton specifically designed to measure and compensate for movement disorders such as tremor. It is actuated by electric motors at the wrist and elbow and its sensory system comprises of chip gyroscopes (which measure tremor force constantly) and kinetic sensors. The total weight of the system is roughly 850 gr. Impedance control strategy is used and real-time filtering algorithms distinguish between intended motion and tremor. Tremor is suppressed with the means of an actuator based on magneto-rheological fluids (whose viscosity can change by applying a magnetic field and therefore act as an effective damper).

MULOS - Motorized Upper Limb Orthotic System, fig. 6 was developed under a project funded by the Technology Initiative for Disabled and Elderly (TIDE) program of the Commission of European Communities and it was intended as stroke rehabilitation as well as an assistive. MULOS is a 5 DoF powered orthosis for the upper limb which allows the movement of the shoulder (3 DoF), the elbow and the forearm. It was designed to provide single joint exercise and operates in 3 modes. The shoulder structure is a 3 DoF mechanism having intersecting axes to allow it to behave as a spherical joint with a centre approximate coincident with that of the user’s shoulder. The structure has sufficient compliance to allow a full range of motion at the shoulder. The joints are powered by cable drives in such a way as to keep the electric motors as close to the first joint as possible and thus, keep required torques to a minimum.
CONCLUSION

In this paper there were presented an overview of the robotic rehabilitation devices for upper limb rehabilitation. The presented robotic rehabilitation systems are the most famous and utilized in robotic rehabilitation practice.

Reference

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