A short overview of upper limb rehabilitation devices

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Abstract. As some studies show, the number of people over 65 years old increases constantly, leading to the need of solution to provide services regarding patient mobility. Diseases, accidents and neurologic problems affect hundreds of people every day, causing pain and lost of motor functions. The ability of using the upper limb is indispensable for a human being in everyday activities, making easy tasks like drinking a glass of water a real challenge. We can agree that physiotherapy promotes recovery, but not at an optimal level, due to limited financial and human resources. Hence, the need of robot-assisted rehabilitation emerges. A robot for upper-limb exercises should have a design that can accurately control interaction forces and progressively adapt assistance to the patients' abilities and also to record the patient's motion and evolution. In this paper a short overview of upper limb rehabilitation devices is presented. Our goal is to find the shortcomings of the current developed devices in terms of utility, ease of use and costs, for future development of a mechatronic system for upper limb rehabilitation.

1. Introduction

The upper limb is an important part of the human body, which is very mobile and has a role in gripping different objects, transporting, moving and touching them. This limb has three major joints: shoulder, elbow and wrist. The shoulder is the junction of the trunk with the upper limbs, ensuring high amplitude movements of the arms. The elbow joint has a single degree of freedom and has a role in flexion/extension movement of the forearm on the arm. The hand is the most complicated segment of the body. The main role of the hand is to grasp and sustain objects combined with an important tactile role.

Every year millions of people worldwide suffer from injuries of the upper limb, such as contusions, inflammations or fractures. The most frequent accidents are produced at the extremities level (fingers, hand), followed by those at elbow level. The age that is most prone to fractures is between 20 and 40 years, people being exposed to these traumas due to their activities. The second period with increased trauma incidence is after 60/70 years old, when the bone strength is low. Children are less prone to trauma due to their bones elasticity [1].

As part of the recovery process a patient is required to execute exercises, which aim to fully recover the joint mobility. The integration of new technologies in rehabilitation therapies led to the development of active and passive devices for upper limb rehabilitation, classified as follows: exoskeletons, haptic interface systems, simple rehabilitation systems. In this paper a short overview of upper limb rehabilitation devices is presented.

2. Exoskeletons

A robotic arm used for rehabilitation was developed with the help of artificial muscle actuation [2]. The system is an exoskeleton with seven degrees of freedom (figure 1.a). Three degrees of freedom are situated on the shoulder level, two on the elbow and two on the hand. The axes of robot joints must be identical with the axes of human joints, thus the length of the robot arms is adjustable. Every joint is driven by a pair of artificial muscles that are antagonist aligned. The muscles are placed on the outside of the device, on a mobile frame. Movement transmission between actuators and joints is achieved by transmission components (cables) connected to a pulley system, located in the robot's joints. At the beginning of the rehabilitation procedure the member is in vertical neutral position. Then the robot begins to slightly bend the limb from elbow joint and, after reaching the final position, it is slowly returning to the start position.

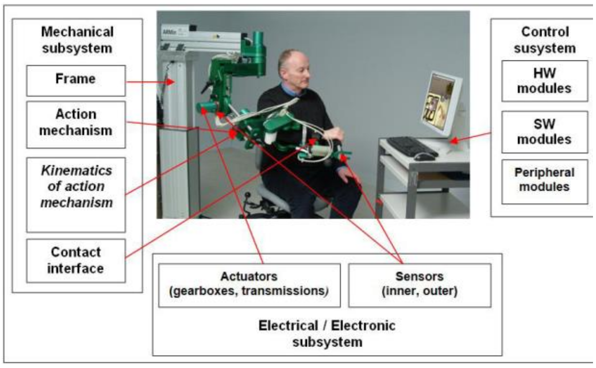

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Figure 1. Exoskeletons: a) exoskeleton with artificial muscles [2]; b) exoskeleton arm [3].

A horizontal exoskeleton was conceived with the following components: base, three links, two actuated joints, one passive joint and three digital encoders [3]. The base moves the robot arm, built from rectangular aluminium frames (figure 1.b). The two active joints are actuated by means of a continuous current electric motor with the help of a gear train. All joints are equipped with digital rotary encoders to measure angular displacement. The device is able to achieve full flexion/extension movement but it is not able to achieve the abduction movement. Therefore further research is required to obtain three degrees of freedom.

For recovery after a stroke a hand exoskeleton was developed [4]. The concept of the device is that the patient must obtain control of the affected limb with the help of the other limb. Thus, the device is divided in three sections: first section contains the exoskeleton that will hold the hand that requires rehabilitation, the second section is the control glove, and the third section is represented by the control system (figure 2a). Four fingers (without the thumb- this finger requires a different mechanism) are executing the same flexion/extension movements with the help of four identical mechanisms. For the index finger, for example, the mechanism consists in three support structures, for proximal, middle and distal phalanges. Also two rods are connecting these structures, two by two. The control glove is a standard glove available in commerce. It has sensors in every finger to exactly determine the fingers position. Based on the values that these sensors record, the microcontroller will decide the movement of the linear actuators. The prototype executes the flexion/extension movement of the left hand based on the movements of the right hand. The material chosen for the construction of the exoskeleton is aluminium, due to low weight.

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Figure 2. Exoskeletons: a) exoskeleton control glove [4]; b) PAFEx [5].

PAFEx (Pneumatic Actuated Finger Exoskeleton) is a device developed at Teknologi University, Malaysia [5]. The device is conceived to help the patients that can move their hand, but have problems with grasping objects. This system has a pneumatic actuator that helps the middle phalange of the thumb and the middle and proximal phalange of the (figure 2.b). To transform the rotary motion into linear motion a cam mechanism is used. The device is attached to a glove, which has flexible sensors that measure the angular displacements of the joint. The system was only tested on healthy subjects, presenting a real potential for hand rehabilitation.

3. Haptic interface systems

Compact Rehabilitation Robot (CR2) is a robot developed by Khor et al. [6] for rehabilitation of the upper limb, as well as for the lower limb (figure 3). The robot has a virtual rehabilitation system, with LED monitor and boxes, which shows different games, while the patient is working his forearm. The game is structured on 9 levels of difficulty and it can be adjusted to the patient's needs. At the same time the position and force used to achieve the movement are recorded. This robot can be adjusted for different required movements. For example, it can be programmed to recover the horizontal movement of the arm, movement that is used to open windows. Also, by adjusting the height of the platform one can execute lifting exercises of an object during orthostatic position. To prevent a patient to compensate the movement it was developed a system for monitoring the position. The patient's chair has two limiters sensors and one flexible sensor. The flexible sensor detects when a person sits on the chair and the others verify that the position of the patient is correct, lean on the seatback, assuring a proper recovery.

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Figure 3. Haptic interface systems: a) Compact Rehabilitation Robot [6]; b) simple haptic system [7].

A simple haptic system for rehabilitation of the pronation/supination movements was designed by Rahman [7]. The system uses a knob as end-effector but it can be replaced with other shapes, to practice some daily activities (figure 3.b). To achieve the motion a DC motor it's used, equipped with an encoder, firmly attached to the base. The other components are also attached to the base allowing a small design. The program interface allows feedback for the user using different levels of exercises.

HapticKnob is a robotic device with two DOF used for training catch movements in the same time with the pronation/supination movement of the forearm [8]. These functions are crucial for object manipulation, for example open a door, pouring a glass of water. The device's design is based on end-effector approach where the robot interacts with the user at hand level (figure 4.a). It can generate resistive or assistive forces up to 50N for open and close the hand and a torque up to 15Nm for the pronation/supination movement. These values are far from the normal values that a healthy person can achieve, but they are enough for the patients with disabilities. Different accessories can be attached to train different functions of the hand. In front of the robot we have a support for the forearm. The device is controlled through a computer and programmed in LabView. One can perform different exercises like open and close the hand, pronation and supination and combination of these, offering a visual feedback.

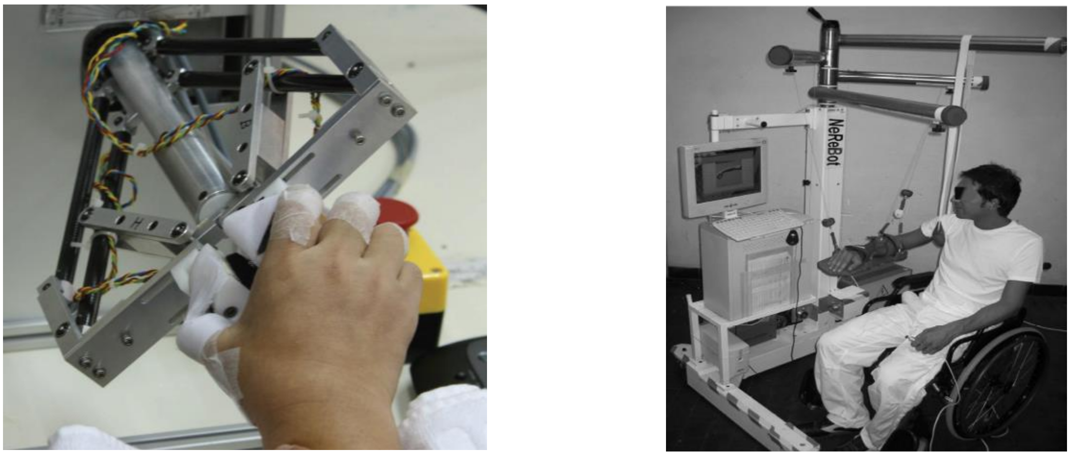

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Figure 4. Haptic interface systems: a) HapticKnob [8]; b) NeReBot [9].

NeReBot is a three degrees of freedom robot used to rehabilitate the upper limb [9]. The robot frame is shaped like C letter with support rollers and a square central column (figure 4.b). At the high end of the column, three aluminium studs sustain three nylon thread connected to corresponding DC motors. The other ends of the threads are connected to patient's arm with the help of a rigid orthosis. NeReBot is programmed to perform repetitive movements (flexion and extension, adduction and abduction, pronation and supination) of the upper limb. The therapist is moving the arm of the patient in the desired positions, recording the points that the robot must reach. Once these points are recorded, the control system interpolates the recorded position so that the trajectory is generated. Using these trajectories, a linear motion is produces for the patient's arm. A safety button is connected to this system that can be activated by the operator or by the patient. During the rehabilitation process the program offers acoustic and visual feedback (a 3D image of an upper limb with three arrows that point the direction of movement to the patient).

4. Simple rehabilitation systems

A hand training robot was developed at Brussels Faculty of Engineering by Bruface Mechatronics Team Project [10]. To use the system the user must actuate a wire connected to a series of springs (figure 5.a). To offer resistance and to avoid a premature wear of the system the wire is made from

Kevlar and the four springs are connected with the help of a metal plate. Modifying the spring's elongation the difficulty of the exercises is modified. For this it is used a servomotor to extend the springs depending of the chosen level. The motor was modified to execute a free movement of 360 degrees. All the components are incorporated in a metal box, using a metallic handle to actuate the system. To create a device with multiple degrees of freedom the box is mounted on a joystick's axis, allowing the user to rotate it's wrist during exercises.

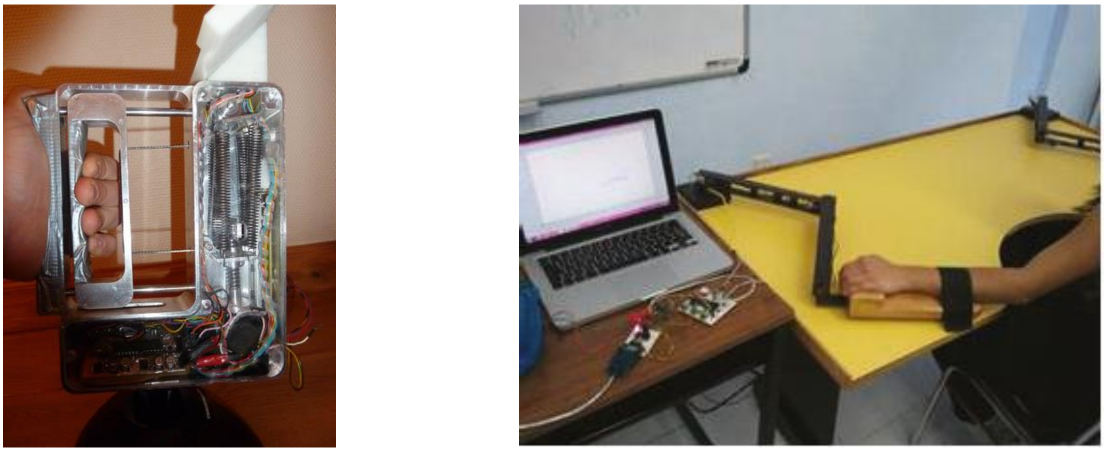

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Figure 5. Simple systems: a) hand training robot [10]; b) single-dimension workplan robot [11].

A robot that has a single dimension work-plane was developed by Salas-Lopez [11] with low cost, to rehabilitate the upper limb. The system will help the patients to speed up the recovery time using vibro-tactile feed-back and will help the therapists to obtain relevant information about the patient's evolution. The main feature of this device is the vibro-tactile system that will offer to the patient a vibro-tactile stimulus in real time, to correct the trajectory and position of the upper limb. The robot is presented in figure 4.b together with the operating space. It has two links with joints to both ends. The end effector is defined by the pad on which the patient's arm is resting. The sensors used to measure angular position in each link are potentiometers with a resistive value of 10 KOhm, that send information a PIC microcontroller. Four vibrating motors are used to send vibro-tactile stimulus to the patient, correcting the trajectory of the arm during rehabilitation exercises. So, if the patient is following a bad trajectory, the system is verifying it in real time, and function of the error, generates stimulus in one of the four motors to motivate the patient to execute the correct trajectory.

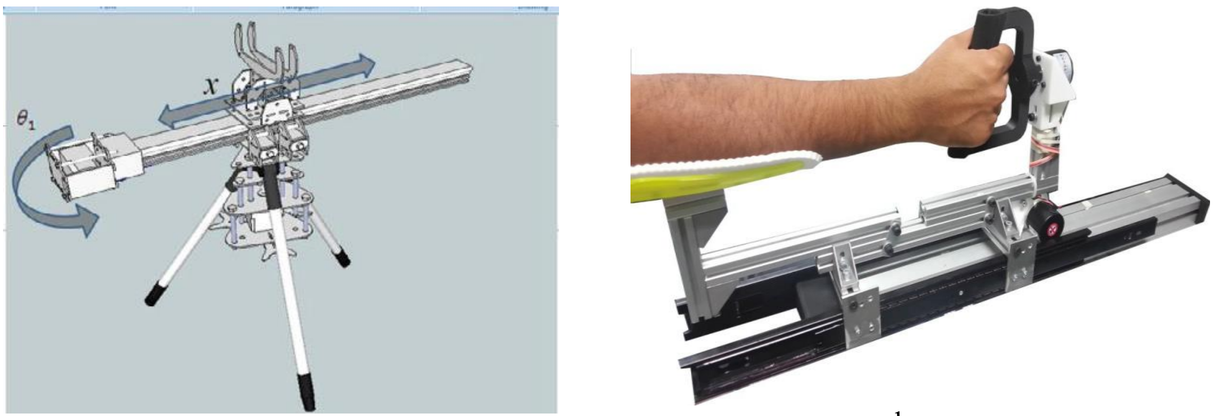

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Figure 6. Simple systems: a) robotic platform [12]; b) amplitude measurement system [13].

A robotic platform for assisted rehabilitation was developed by University Tun Hussein Onn Malaysia [12], which is presented in figure 6.a. The system has two DOF allowing guidance to the arm after a longitudinal trajectory, allowing a rotation around z axis. The control method is based on the Chedoke-McMaster Stroke Assessment procedure that helps the patients forearm.

To measure the amplitude of recovery motions a passive device was developed [13]. The system is not actuated and it can be used both for recovery and for finding correlations between the conventional measurement scales of movement's amplitudes (figure 6.b). The system allows the extension of the forearm and the execution of pronation/supination movements. It is equipped with two optic encoders to record the position of the arm during motion. The handles can be easily switched to perform different games for patient's motivation and execution. The system has an aluminium frame connected to the base with three gliders to generate free linear motion. The handle was build using a3D printer as such way that the encoder's axis is perpendicular on the forearm axis (thus a 16 degrees angle between the gripping part and the encoder).

5. Commercial systems

To rehabilitate the upper limb one can acquire equipments offered by Interactive Motion Technologies [14]. Their products are for a large range of patients, even to those with reduced mobility. InMotion Arm (figure 7.a) is an interactive intelligent system that is capable to continuously adapt to every patient's needs. The system has two DOF and allows elbow flexion/extension and also internal/external rotation and abduction/adduction of the shoulder. The weight of the system is 271 kg and includes therapeutic exercises for hand-eye coordination, attention, motor planning and so forth. InMotion Hand (figure 7.b) is an optional module of the previous system that helps recovery hand movements. It has force sensors and offers assistance as needed, constantly adapting to patient's needs.

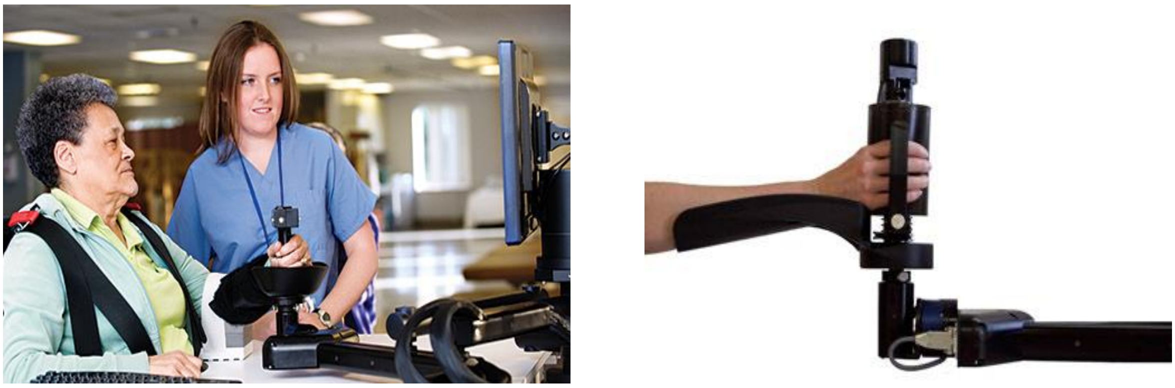

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Figure 7. Commercial systems: a) InMotion Arm [14]; b) InMotion Hand [14].

InMotion Wrist (figure 8.a) it is capable to lift the patient arm even for the paralytic patients and achieves the range of motion of the wrist used in daily activities. It can be used as a separated system or as a module for InMotion Arm, to offer progressive neuro-rehabilitation. The robot arm has 3 DOF and an universal system for the patients seat with adjustable height.

MIT-Manus is a project started in 1989 with support from Science National Fundation and it is operating since 1994 at Burke Rehabilitation Hospital [15]. This robot is a plan modulus that offers two translational degrees of freedom to move the arm and forearm. The modulus is portable and built from a SCARA-type robot. This configuration was selected because it has special characteristics like low impedance in the horizontal plane and almost infinite impedance on vertical plane. This robot can sustain easily the weight of the patient's limb. The mechanism is actuated with brushless motors with a continuous torque of 9.65 Nm and encoders that measure position and velocities. A force sensor with six DOF is mounted on the end-effector of the robot. The command system is implemented on a computer that displays tasks for both operator and patient. To support the patient's arm special systems are used on the end-effector. The robot was continuously developed with different modulus that eases the work of the operators and patients.

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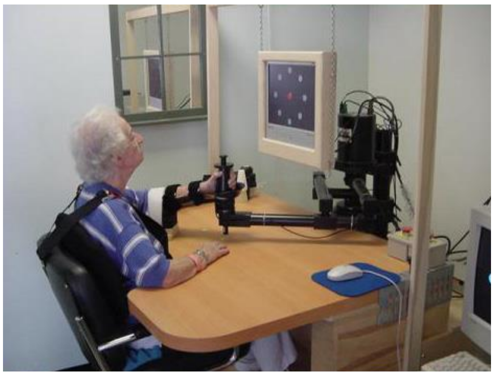

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Figure 8. Commercial systems: a) InMotion Wrist [14]; b) MIT-Manus [15].

6. Conclusion

The introduction of robotic devices in physical rehabilitation of patients has proved extremely beneficial and it is a modern alternative to classic recovery due the performance of these devices: they are capable to restore some major deficiencies, contribute to restore joint's mobility, increase muscle activity, allowing repetitive exercises and scheduled execution, monitoring and evaluation of patient's progress. Thus robotic systems facilitate the work of physiotherapists in the recovery process. Although there are a variety of systems used in the recovery of the upper limb it can be said that currently we still require a system that fully satisfies the need of the patient and does not encounter technical problems. Therefore emerges the need for easy to use mechatronic systems that facilitate optimal recovery of the patients that suffer from various disorders of the upper limb.

Based on these facts and starting from the state of art in this field, in future work we will propose and analyze new models and devices for upper limb rehabilitation.

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