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40

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CONTENTS

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MEDICAL RECOVERY SYSTEM OF THE UPPER LIMB MUSCLES

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Abstract. Starting from the study of arm and forearm biomechanics the paper presents a device for mobilization and rehabilitation of the upper limb muscles, conceived for patients with a reduced mobility of this limb requiring repetitive motions along the same path but with various intensities.

The actuation of this equipment is achieved by linear pneumatic muscles, thus ensuring compliant and selfadaptive behaviour, characteristics due to air compressibility. The equipment described in this paper allows rehabilitation of patients with deficiencies of the upper limb, as well as training of competitive athletes. Due to its simple and cost-efficient construction the equipment is widely affordable and can be used for home exercising, not requiring the presence of a physical therapist.

Keywords: muscle rehabilitation, pneumatic muscle, self adaptability

1. Introduction

International studies have revealed that each year worldwide about 15 million individuals are affected by strokes, 5 million of whom retain a permanent invalidity of the upper and/or lower limbs. In a large part of these cases the functional utilization of the limbs cannot be achieved even following prolonged rehabilitation treatment [1].

Under these circumstances, worldwide medical recovery institutions are assaulted by requests for neuro-rehabilitation services, complementary to surgical and pharmaceutical treatment.

Traditionally the rehabilitation of the upper and lower paretic limbs requires their mobilization and manipulation by a physical therapist. The rehabilitation treatment is planned following an *ex ante* evaluation of the residual abilities of each subject and can last several hours daily: thus it often proves a long and tiresome exercise, for both patient and therapist. Furthermore, therapeutic treatments can extend over several months, requiring the patients to be taken every day to the rehabilitation clinic, entailing discomfort and significant costs.

The minimization of the discomfort and expenditure caused by rehabilitation exercises can be achieved by conducting the exercises at the patients' home. This option has become possible by the development of several variants of robotic systems for the recovery of the upper and lower limbs, thus partially replacing the therapist's work. A particularly important advantage of robotic rehabilitation systems is that they allow the patient to conduct rehabilitation sessions in a semi-autonomous manner, thus reducing the necessity of engaging the services of a physical therapist on a permanent basis. The equipment deployed in robotic rehabilitation accepts and if necessary completes the motion carried out by the patients in accordance with their residual mobility (the so-called "assisted as needed" control strategy) [2].

The rehabilitation equipment currently available on the marketplace includes mechatronic systems capable of supporting the therapist while applying programmable and customizable recovery programmes. These systems include one or more actuation modules, energy supply modules, proprioceptive and extroceptive sensors necessary for providing information on the device status and the machine – environment interaction, a microcontroller for the processing of the data received from the sensors and the issuing of control commands to the motors, as well as a dedicated man-machine interface.

Over the last decade innovative robotic systems have appeared on the marketplace, capable of allowing patients to carry out repetitive and result-oriented motions. Such systems can offer a safe and intensive exercising programme, thus improving the planning and utilization of medical assistance resources. The clinical potential of these machines is obvious, as such equipment on one hand assist the therapist in administering patient-specific physical treatment, accurate and repeatable, typical for robotic systems, and on the other provides quantitative and qualitative data regarding patient status.

The rehabilitation of the upper limbs requires the development of specific dedicated equipment. The paper presents and analyses such equipment developed for patients with reduced mobility of the arm and forearm and who require repetitive motion along the same path, at various intensities. It has been experimentally established that repetitive motion can improve muscle force and motor coordination in patients with neurological lesions.

2. State of the art of upper limb rehabilitation equipment

Designing rehabilitation equipment cannot be achieved without detailed knowledge of the motions conducted by various parts of the human body. Biomechanics is the science studying the effect of mechanical forces on the human functional structure in relation to bone, joint and muscle architecture as motion determining factors. Another science of interest if kinetic therapy where motion is regarded and utilized as the main means of recovery or rehabilitation subsequent to trauma, locomotion affections, etc. Correct application of biomechanical knowledge in kinetic therapy can shorten the duration and improve the quality of recovery or rehabilitation subsequent to various suffered traumas, accidents, surgical interventions or can reduce the invalidity complex.

In the field of recovery activities, knowing and studying from the biomechanical viewpoint of the generation of various accidents, lesions, muscle ruptures and fractures are paramount for their prevention. Recovery and therapy in such cases are significantly improved if not only the biomechanical causes of the accidents are known, but also the effects of certain temporarily motion inhibiting recovery solutions (like prostheses, casts, fixing or stretching devices) [3].

Starting from detailed knowledge of the upper limb biomechanics, a number of robotic systems with up to three degrees of freedom have emerged on the marketplace, developed for the recovery of the shoulder, elbow and wrist joints. Some of these are presented below.

An innovative solution of home rehabilitation equipment for patients with upper limb neuromotor disabilities is the one called Tailwind Arm Rehabilitation Device (Figure 1) developed by the University of Maryland, Baltimore (UMB) together with Encore Path Inc. of Baltimore [4].

The system is aimed at mobilizing both hands, simultaneously or individually. The patient, sitting on a chair, pushes or pulls one or both levers, the resistance opposed by the device being adjustable within a wide range, according to the patient's degree of disability.

Figure 1. Tailwind Arm Rehabilitation Device [4]

Another interactive constructive solution based on haptic robotic technology has been developed by the Canadian Quanser Inc. in partnership with the University of Toronto and the Toronto Rehabilitation Institute (Figure 2) [5].

Figure 2. Quanser Autonomous Upper-Limb Stroke Rehabilitation Device [5]

This equipment allows patients to conduct rehabilitation exercises at home by pushing on the robotic arm, feeling resistance and watching results on a video monitor.

Other upper limb rehabilitation equipment are those manufactured by Rehab Dynamics (USA) (Figure 3) [6] or the one known as PUPArm developed by Miguel Hernandez from the Universitad de Elche, Spain (Figure 4) [7].

PUPArm is a planar device with two degrees of freedom. PUPArm is moved by pneumatic actuators and it is intrinsically safe. PUPArm system integrates heart pulse sensor for measurement of the patient state.

In most cases the presented pieces of equipment are actuated electrically or mechanically, thus yielding a high rigidity of the entire construction and a very good positioning and position repeatability of the effector element. Increased rigidity, however, renders these robots less adequate for medical rehabilitation activities, or in general, for operation in the proximity of humans, as rigid behaviour may cause undesired accidents within the operating range.

Figure 3. Circular motion based rehabilitation equipment [6]

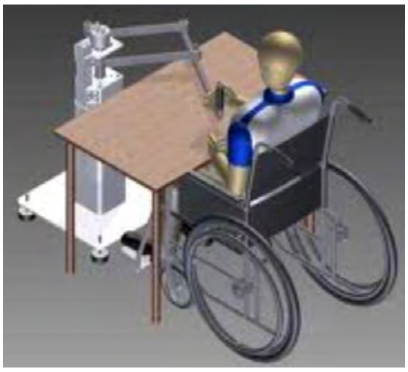

Figure 4. The PUPArm device [7]

In order to be able to work in the vicinity of man or interact with humans, the new generations of robots need ensure safe operation, meaning the prevention of undesired man-robot collisions, or in the worst case, minimization of the effects of such.

An alternative to utilizing electric motors are pneumatic actuations. One of the most attractive aspects of pneumatic actuation is the low weight of the included components and implicitly favourable response to commands. A behaviour featuring favourable response to commands, also known as compliance, is due to air compressibility and can thus be influences by control pressure adjustment.

Research conducted over the last years at the Transilvania University of Braşov has revealed the advantages of deploying pneumatic muscle type actuators in robotics. The paper presents and discusses the utilization of pneumatic muscles as part of a device developed for the mobilization and rehabilitation of arm and forearm muscles.

3. Device description

The rehabilitation device discussed in this paper is based on the utilization of pneumatic muscles as driving elements of the upper limb. Figure 5 presents the constructive solution of this equipment.

Similarly to Skandenberg type motions, the patient's hand tries to rotate a lever by its joint. This motion is opposed by the force developed by two pneumatic muscles joined at their free ends. Thus the two muscles work in tandem (while one is inflated and shortens, the other one is deflated and elongated, and vice versa). The displacement of the joined free ends of the muscles is monitored by a position transducer.

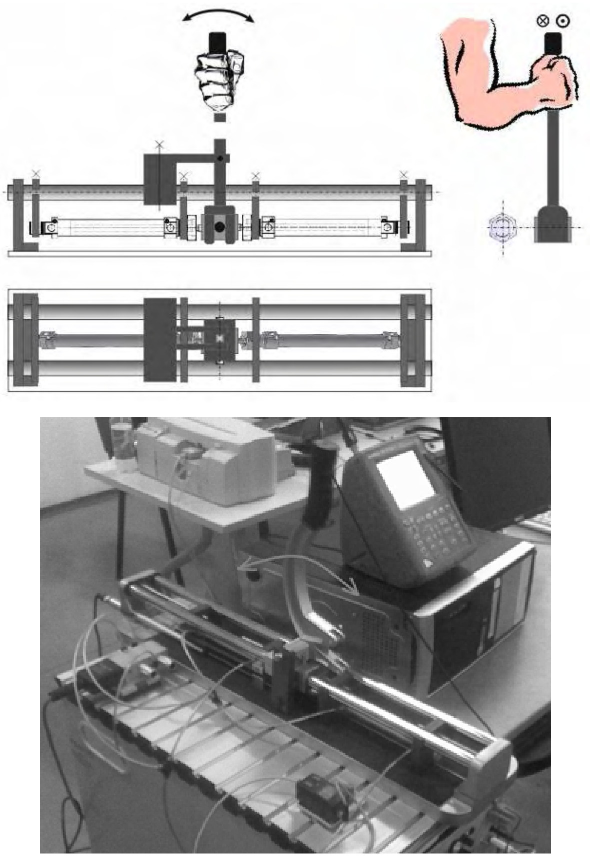

Figure 5. Upper limb muscle mobilization and rehabilitation device

The pneumatic diagram features an analogue pressure sensor, the role of which is to provide a realistic sensory feedback for the patient, while also enabling the system to sense how to accurately respond to each patient.

The control system of the equipment includes a proportional moduledestined for setting the reference values, connected to PID controller. This, on its turn feeds a signal to a 5/3-way proportional valve that controls the pressure in the muscle. The output of the resistive displacement transducer is also connected to the PID-controller input, supplying the feedback quantity of the automatic control system. The actual value of the displacement transducer electric resistance is directly proportional with the rotation of the lever related to the point of reference, what allows control of the pneumatic muscles so that the resistive force of the system returns the lever to its (vertical) position of equilibrium

The entire system operates by a „sense – think - act" type sequence, as follows:

Sense: the position of the patient hand (of the lever of the device) is sensed by the position transducer, that feeds this information to the PID-controller;

Think: based on the received information the PID-controller calculates the next motion;

Act: the corrective action decided by the PID (namely of returning the lever to its initial, vertical position) is transmitted via the 5/3-way proportional valve to the pneumatic muscles.

The information provided by the pressure transducer is transmitted to a computer via a data acquisition card. The pressure variations recorded during utilization of the equipment are converted by a specially developed software application into modifications of the expression of the human face. The functioning of the application consists in receiving the value of the pressure from the data acquisition card. . This pressure is amplified in code and describes the dynamics of the animation. When the pressure in the muscle is great, that is when the patient „overpowers" the device, the animation changes its expression displaying an upset face; oppositely, when the device overpowers its adversary (the patient) or when the adversary does not develop a sufficiently large force such as to overcome muscle pressure, the animation displays a cheerful face.

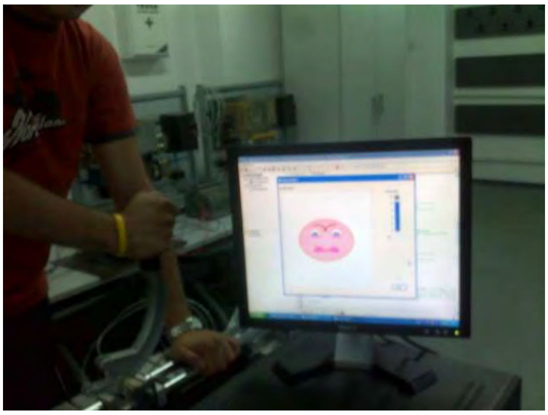

Figure 6. The patient „overpowers" the rehabilitation device

Figure 6 exemplifies the case of the patient succeeding in applying to the lever a force greater than that developed by the pneumatic muscles, what causes the „upset expression" of the computer.

4. Conclusions

The paper proposes a device with a single degree of mobility developed for the mobilization and rehabilitation of the upper limb. The proposed system is actuated by means of pneumatic muscles, benefitting from the advantage of a compliant behaviour that is of favourable response to commands, due to air compressibility.

The developed equipment, conceived to motivate and stimulate the user by means of its dynamic interface, represents a novel alternative to existing rehabilitation devices. The equipment's animation monitors pressure variation and changes its facial expression according to the pressure applied by the user to the robotic arm. To users who cannot produce sufficient force such as to overcome the robotic arm, this returns a joyful face, thus motivating them to keep trying. On the other hand, to users who have "overpowered" the device, this shows an upset expression, thus giving them the satisfaction of victory. Hence, by addressing user emotions the device offers a friendlier interface than classical kinetic therapy equipment.

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