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ELECTROMECHANIC UPPER LIMB DYNAMIC ORTHOSIS FOR REHABILITATION OF HAND AND ELBOW

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Abstract. *People with some kind of upper limbs motor impairment show have several limitations that interfere with the ability to do regular activities independently, affecting social participation and life quality. One possible way for rehabilitation is the robot-assisted therapy, an approach that uses an intensive, repetitive, interactive and individualized practice (Sivan et al., 2011; Brewer et al., 2007). This paper consists in the project, development and validation of an upper limb dynamic orthosis to be used for robot assisted therapy.*

Keywords: *upper limb dynamic orthosis, rehabilitation, assistive technology, robot-assisted therapy.*

1. INTRODUCTION

Mostly devices used for robot assisted therapy are robust, heavy, untransportable and expensive (Araujo, 2011). To help this situation, the Laboratory de Bioengineering (LABBIO) of the Department of Mechanical Engineering of the Federal University of Minas Gerais developed an upper limb dynamic orthosis to eliminate this limitations and help to improve the life quality of people with some kind of upper limbs motor impairment, mostly caused by stroke (cerebrovascular accident).

2. EXPERIMENTAL PROCEDURE

The electromechanic upper limb dynamic orthosis for rehabilitation of hand and elbow (Figure 1) is an innovative concept by presenting an electromechanic solution with modular and adjustable structure, in a light, resistant and low cost material.

Figure 1. Upper limb dynamic orthosis prototype

2.1 Orthosis biomechanics

Considering the anatomy and sensibility of the human arm it was projected a prototype (Figure 2). To simplify the project, the orthosis has just two degrees of freedom: the elbow extends and contracts; and the hand opens and closes. This was necessary because for each degree of freedom, it is necessary an actuator. Increasing the number of actuators increases the weight of the device and the energy consumption (an obstacle for a future portable device). Furthermore, this two movements, assisted by a small shoulder movement, comprehend a large amount of the movement range used in daily functions.

The elbow extension and flexion are done by a DC electric motor. The hand extension is done by a servo motor. However, the hand flexion in this orthosis is passive, due the hand spasticity (an increase of muscular tonus, which tends to close the hand), a characteristic of the stroke patient, the focus of this project.

It was made an exploratory study to validate the prototype in order to verify the correct functioning of the biomechanical part of the orthosis, to ensure the users the safety of the equipment. The bench tests with the orthosis were done at the Laboratory of Bioengineering of the Engineering School, in the Federal University of Minas Gerais.

2.2 Materials

Most of the mechanical parts of the orthosis were made by rapid prototyping, using filaments of PLA (Polylactic acid). The low cost, low crating time and low weight were the main factor for choosing this technology. The attachment parts were made of thermoplastic and fabric (polypropylene sheets and neoprene, respectively). This materials are widely used for static orthosis in the occupational therapy and physiotherapy industry.

2.3 Orthosis modules

The orthosis was projected in three modules: hand module, elbow module and control/actuation module. This division made possible the development of the orthosis by three groups simultaneously. Moreover, this facilitates the maintenance and improvement of the orthosis.

The hand module (Figure 2) consist of a static orthosis attached to the forearm, positioning the thumb and the palm, a back hand piece to positioning the strings and four finger cots. On the back of each finger cot, there are two pipes aligned and a string passing through both. The four string are attached to a ring inside the back hand piece, that is attached to the string connected to the actuators.

Figure 2. Hand module

The elbow module (Figure 3) is composed by a static orthosis attached to the arm, a groove (connected to the static orthosis of the forearm), two bars (one is connected to the static orthosis of the arm and the other is inserted inside the groove) and a sheave (connecting the two bars). The sheave is aligned to the elbow joint, but this joint is so complex that a groove was necessary, adding a passive degree of freedom, protecting the patient arm from any misalignment. In the sheave, two strings are attached (one in each direction), allowing the actuator to extend and flexion the elbow.

Figure 3. Elbow module

The control and actuation module (Figure 4) is composed by an Arduino Nano, a 12 volts power source, a H bridge (connected to the DC motor), a Bluetooth module, a DC motor (actuator that moves the elbow), an servo motor (actuator that moves the hand), two sheaves (one attached to each actuator), an potentiometer (connected to the DC motor to measure the angulation), two limit switches (to protect the patient arm in case of some error), two clips (connected to the strings) to activate the limit switches, and three conduits where the strings, connected to the hand module and elbow module, pass thought. This is the only module that is not attached to the arm. The main reason is that stroke patients have a balance deficit, and the weight of this module in the arm can be a great problem for them.

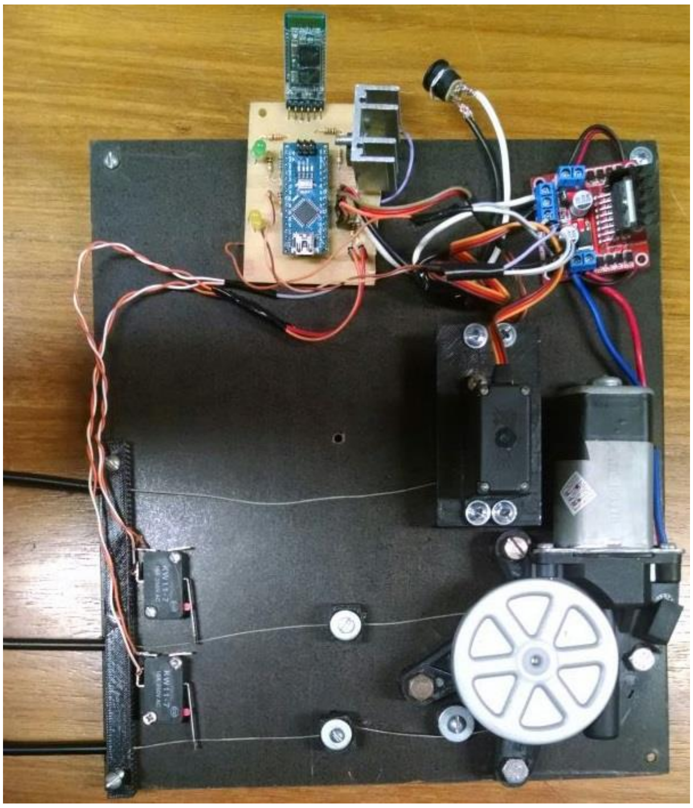

Figure 4. Control and actuation module

3. RESULTS AND DISCUSSION

There were two main focus in the orthosis project: the angulation range that the elbow should reach, respecting the elbow biomechanics; and the user interface, so the occupational therapist can control the orthosis in an effective and simple.

3.1 Orthosis elbow angulation

The maximum and minimum flexion angles of the elbow was defined considering the amplitude of movement needed to do basic day life activities, that is, activities related to self-care. According to Radomski and Lathan (2013), the zone of 10 to 140 degrees of flexion allows the accomplishment of a great number of functional activities (Table 1). Therefore, this was the chosen angulation for the orthosis, allowing an arc of free movement of 130 degrees.

Table 1. Flexion angle of the elbow for functional activities (Radomski and Latham, 2013).

	Flexion Angle (degrees)		
Activity	**Start**	**End**	**Arc**
Putting on a shirt	15.0	140.0	125.0
Using a phone	42.8	135.6	92.8
Getting up off that chair	94.5	20.3	74.2
Drinking from a glass	71.5	129.2	57.7
Opening a door	24.0	57.4	33.4
Eating with a fork	93.8	122.3	28.5
Reading a newspaper	77.0	104.3	26.4
Cutting with a knife	89.2	106.7	17.5
Pouring water out of a jar	35.6	58.3	22.7
Eating with spoon	101.2	123.2	22.0

Maximum amplitudes of flexion (0 to 150 degrees) were avoided to prevent excessive stress on the articulations and ligaments of the elbow.

3.2 User interface

To operate the orthosis, it was created an app for smartphone (android and iOS) that communicates with the Arduino Nano via Bluetooth. The app created controls the positions of the hand and elbow, speed of movement, number of repetitions and the intervals between this repetitions of movements (Figure 5). Sequences of commands can be stored to be used as functions, such as "Pick object", "Drink glass", etc.

Figure 5. Orthosis user interface screens. a – Main screen; b – Hand control; c – Elbow control; d – Training mode

It was included in the app an option to use the voice recognition software of the smartphone to select the commands (Figure 5a). Although the orthosis is to be used by the occupational therapist, not the patient, the voice recognition software can be used on possible future uses of the orthosis by patients.

At the tests with the app, the orthosis performed all the commands given, showing that it works properly. However, using the option of voice recognition software, the answer time was relatively higher (about 6 seconds), compared to the answer time without the voice recognition software (between 1 and 2 seconds).

4. CONCLUSIONS

Basing on the tests done with the dynamic orthosis prototype, it was possible to verify the applicability and the functionality of the proposed device, since it follow correctly the given commands, that is, the structure reproduced and performed the movements according to the objective of angulation expected with an adequate force. However, using the option of voice recognition software, the answer time was greatly increased, which could be a problem for a future patient self-use.

Other improvement that could be made is the reduction in weight and size of the control and actuation module and a use of a battery. This way, the module could be used as a backpack, a place where the balance deficit of stroke patients would not be important, since it is on the balance plane of the patient.

After some adjustments, future studies are fundamental to validate the equipment in patients with upper limb motor impairment, alowing them to do independently laisure, vocational and dayly activities, improving his self-steem and life quality.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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