DEVELOPMENT OF A FUNCTIONAL HAND ORTHOSIS

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Abstract:

The hand is a complex structure and its dysfunction can occur from different ethiologies. Efforts to restore the hand functionality, such as surgical interventions, hand and wrist splint/orthosis and electric stimulation, have limited success. Devices available today are reported to exhibit difficulty of control, small functionality and poor aesthetics. It is clear the need of new rehabilitation devices to overcome these drawbacks. The aim of the present paper is to develop a functional hand orthosis capable of performing prehensile movements by using the patient myoelectrical signal as input of the orthosis activation. The functional characteristic of the orthosis is achieved by using a glove specially designed to allow the patient her/himself control its activation by the surface electrodes located in a selected muscle. The hand prehensile movements are performed by artificial tendons installed in the dorsal and in the ventral surface of the glove to connect the fingers to the electromechanical device (DC motor). Preliminary tests with volunteers have proved that the orthosis is efficient to hold objects of different shapes, weights and sizes. Volunteers reported its simple control, easy to handle and aesthetics characteristics. Additional work is required to allow the patient to control the force imparted to the orhtosis.

Keywords*: Bioengineering, Hand Orthosis, Electromechanical Artificial Muscle*

1. Introduction

Hand is a complex structure, capable of performing not only a great number of complex movements but also of transmitting sensorial information about temperature, shape and texture of the objects to the brain. A variety of causes can lead to the loss of hand and upper limb function. The number of people with lesion is increasing markedly in the last decades, mainly due to trauma (80%) caused by gun shot wounds, car and motorcycle accidents, sports and falls (Freed, 1984; Barros Filho, 1990; Solino, 1990; Lianza, 2001). Among the lesions of other causes (20%) there are tumors, infections, vascular and degenerative conditions (Lianza 2001).

The majority of the disabilities are due to spinal cord injury, peripheral nerve injury (braquial plexus injury), degenerative diseases (amiotrophic lateral sclerosis), making it difficult to estimate the number of people that present these problems. It is estimated that about 0.2% to 0.6% of the world population has some degree of incapacity. The lesions have severe implications in the familiar, professional and life quality of the individuals hampering daily activities such as feed, dress or take care of one self independently. These limitations are very expensive not only to the family but also to the society and government (Barros Filho, 1990, Lianza, 2001, Trombly, 2001).

Efforts to restore hand partial function have included surgical interventions, hand and wrist splints/orthosis and various systems of Functional Electric Stimulation (FES). The use of with electrodes has been applied to patients with spine lesion or stroke sequels (Cliquet Jr and Castro, 2000). One disadvantage of FES is that the adaptation of the electrodes to the skin requires specific attention, technical expertise and time, especially when the stimulation system requires the activation of various muscles and when small muscles are joined together. For hands and forearms it is difficult to adapt the electrodes surface precisely to generate smooth movements for handling objects. Furthermore, the stimulated muscles fatigue rapidly.

In the last years, the combinations of techniques, surgical reconstruction and FES implantation systems (known as neuroprosthesis) have been shown to improve individual ability to grab, hold and loose objects (Kilgore, 1989; Carroll *et al.*, 2000; Alon, 2003). These techniques have been used by tetraplegic patients. The use of FES can increase hand functions, however the equipment is very expensive and very often it is necessary a second surgical procedure to replace broken electrodes (Petroff, 2001). Furthermore, neurologic stability is necessary in order to utilize implanted systems; therefore, surgeries cannot be performed, at least, for a year after the injury. Some orthosis have been projected to improve tetraplegic hands functions, however they require that the client has wrist extension against gravity preserved (Trombly, 1995; Harvey,1996, Kilgore *et al.*, 1998, Pinto, 1999,). Some examples are *Tenodesis Splint* from the Rehabilitation Institute Chicago (RIC tenodesis splint), the Wrist-Driven Flexor Hinge Splint e o Dynamic Cable (Trombly, 1995; Harvey, 1996). Orthosis operated by electromechanical devices or by Mckibben muscles (by means of carbon dioxide), have also been described, however, historically, they have not been well accepted by the community (Redford, 1995; Trombly, 1995).

Other orthosis/neuroprosthesis are controlled by keys adjusted to the wheel chairs or in some other location easy to reach (Trombly, 1995). They are easy to handle and provide a reliable and repetitive signal. The mainly disadvantage is that it is necessary that the patient uses the opposite arm to control the mechanical arm. This usually means that the tasks have to be performed with only one hand. Also, it can be difficult to fix the keys at places always accessible to the patients. One example is Ratchet wrist-Hand Orthosis (Trombly, 1995) which can be used by patients with weak wrist or fingers; however it has to be handled with the patient’s opposite hand. Another problem with the available orthosis is that they are very often awkward, poor aesthetically, limited functions. In addition, usually these equipment are highly expensive and complex in terms of mechanics and control. (Romilly, 1994; Petroff, 2001).

The objective of this work is to develop a functional orthosis capable of restoring the hand prehension movement as a solution to various problems mentioned above.

2. Materials and Methods

The orthosis is composed of anatomical gloves equipped with an electromechanical actuator. The actuator imposes movement to artificial tendons (wire or stick). The actuator is a continuous current electric machine, PT03002 model, HC 313MG series, trade mark Johnson Electric. The machine is connected to planetary gears with 70 fold reduction whose axis is fixed to ventral artificial tendons. The fingers flexion movements will occur when the electric machine is turned on in one direction. When turned on the opposite direction fingers extension occurs by means of a spring connected to the dorsal part of the gloves. By keeping the wrist in extension (approximately 20^o), the orthosis allows flexion and extension of metacarpophalangeal movements (MCP) and interphalangeal (IF) of the fingers 2^o to 5^o while the thumb is immobilized in adduction and semi-flexion of the MCP articulation, allowing that the hand adapts itself to objects of various shapes and sizes.

2.1. Activation Method

The orthosis may be controlled by the person him/herself by means of myoelectric signals, detected through surface electrodes placed on the motor point. In myoelectrical detection system, the myoelectrical signals of a preserved muscle or muscle group are used to activate the orthosis. The muscle contraction must be enough to be interpreted by the circuit as an activation signal, and the person should be able to realize contraction repeatedly without fatigue. The motor will operate in a constant velocity, independent of the applied muscle force. In Figure 1 is shown a block diagram from activation system.

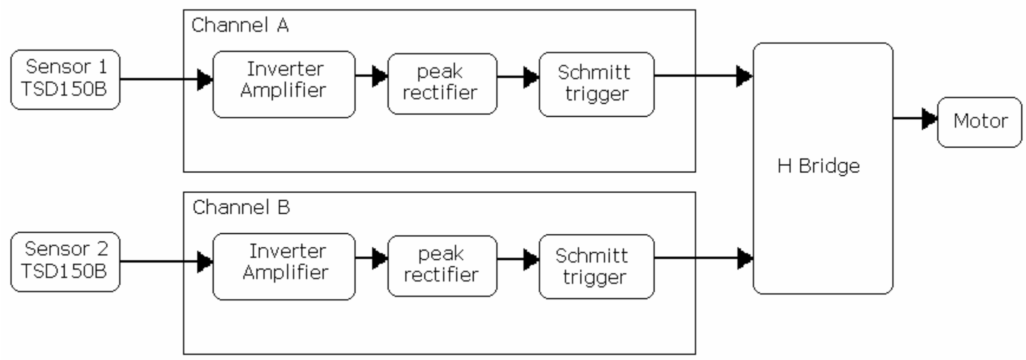

Figure 1. Block Diagram from activation system

2.1.1. Myoelectric Sensor

It is used the **TSD150B** sensor from Biopack. This sensor amplifies and filters the detected myoelectric signal using a differential amplifier. The filter is an analog low-pass kind, with cut frequency tuned to 500Hz, because signals with greater frequency are not considered physiological signals. The sensor output signal has the range about 100mV to myoelectric signal from healthy muscles, it passes through treatment channels that interpret the signal and transmit the commands to the motor.

2.1.2. Channels A and B

The signal caught by the sensors passes through an inverter amplifier and it is amplified 100 times. The choice of this kind of amplifier was given because the simplicity of the circuit and the fact that a phase inversion does not interfere with the interpretation of the signal. The amplitude of the block output signal during muscle contraction is approximately 10Volts.

The signal passes through the peak rectifier and after that through the Schmitt trigger block. This one determines the minimum amplitude of the signal should have so that a muscular contraction could be detected. Otherwise a muscular relaxation is interpreted. This interpretation is send to the H bridge block.

2.1.2. H Bridge and Motor

The H Bridge receives the signal from the channels A and B and puts the motor in motion. According to the channels interpretation, the motor is driven back or forward.

Once the motor is the main power consumer of the system, it uses an independent rechargeable power source. This is the simplest way to maintain the proper motor source and does not cause noise in the power source of the rest of the system.

3. Tests and results:

To perform the tests, the artificial hand was manufactured based on human hand skeleton model.

Test 1: Determine the traction force in the flexion tendons (ventral) necessary to maximum closure of the set orthosis/artificial hand. One spring dynamometer (1N resolution) was connected to the ventral artificial tendons. A force was applied to the dynamometer in order to verify the amount of force necessary for the orthosis closure. This force represents the human hand mechanical resistance (simulated by artificial hand), the orthosis mechanical resistance and the force applied by the spring. Ten measures were performed, with an average of 29N and standard deviation of 0.7N.

Test 2: Determine the force necessary to hold objects.
Objects with different shapes and weight representing those utilized daily were selected. The orthosis was held in place with the forearm in neutral position (between pronation and supination) in such a way that the objects remained hung. The objects were put in the palm of the set orthosis/artificial hand with the dynamometer held to the ventral tendons in order to measure the necessary force to hold the objects. Ten measurements were performed for each object. Table 1 presents the objects used with their respective weights, dimensions and the average force necessary for prehension. The orthosis was able to hold all objects for at least, 10 seconds.

Table 1: Objects, weights, dimensions and average prehension force

Object	Mass (g)	Dimensions (cm)	Average Force (N)
Wood stick	5	0.6 (diameter) x 7.6	21
Wood cube	10	2.5 x 2.5 x 2.5	10
Plastic cylinder	100	4.1(diameter) x 11.4	29
Video tape	225	20.4 x 14.5	30
Plastic cylinder	500	4.1(diameter) x 11.4	40

Test 3: Identify muscles or muscle group suitable to activate the machine.
The identification of muscles or group muscle suitable to activate the machine poses as a great challenge. Due to the paralysis, the patients have few voluntary movements that can be used as source of power. Muscle selection must be based on anatomical, kinesiological, and electromyographical studies with surface electrodes. We recommend the quest for muscles where distinct myoelectric signals could be detected between relaxation and contraction and that were of easy voluntary activation. In addition, these muscles should not interfere in the positioning of the upper limb. In order to test the circuit it was selected ipsilateral movements of shoulder lift (superior trapezius fibers) for hand closure and shoulder plate retraction (medium trapezius fibers) for opening. The electromyographic exams were performed in a health subject at the Laboratório de Performance Humana (LAPER) da Escola de Educação Física, Fisioterapia e Terapia Ocupacional da UFMG (Human Performance Laboratory- LAPER- of the Physical Education, Physiotherapy and Occupational Therapy School) and complied with the required characteristics.

Test 4: To verify whether the system was able to interpret different states of muscle relaxation and contraction, as well as the action of each muscle individually, a test was performed with a circuit represented in the diagram (Figure 2). The circuit consists of two channels for detection of myoelectric signal through surface electrodes placed on the motor point of each muscle. The myoelectric signal of the superior trapezius fibers was detected in channel A, connected to a red dyode light emission (LED). The myoelectric signal of the trapezius medium fibers was detected by channel B, connected to a green LED. When the system interprets a muscle contraction the LED is on and the absence of contraction the LED is off.

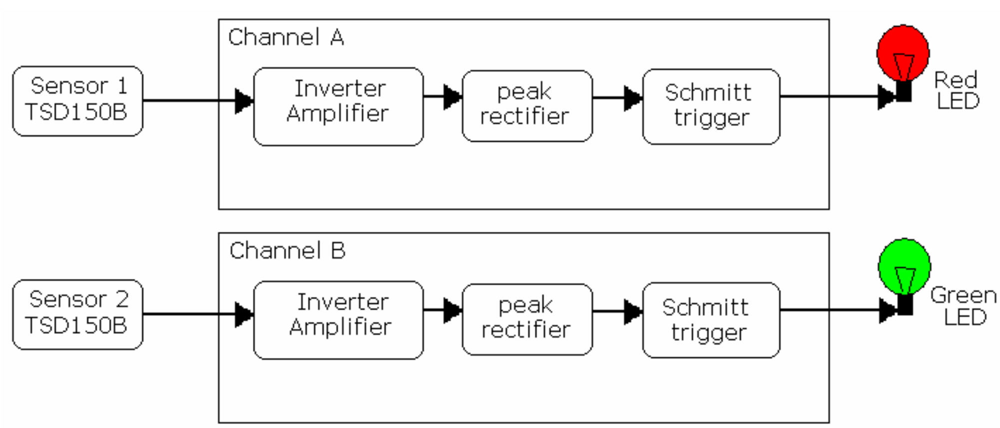

Figure 2 – Block Diagram of myoelectric signal detection

The signals of the muscles were measured using a digital oscilloscope. Figure 3 and 4 represents the muscles activity of the trapezius superior and trapezius medium, during different phases:

Phase 1 – Deactivation of the muscles trapezius superior (Fig. 3) and trapezius medium (Fig. 4);

Phase 2 – Activation of the muscles trapezius superior (Fig. 3) and trapezius medium (Fig. 4);

Phase 3a – Deactivation of the trapezius superior with the activation of the trapezius medium (Fig. 3)

Phase 3b - Deactivation of the trapezius medium with the activation of the trapezius superior (Fig. 4)

The analysis of the phase 3a and 3b shows that the activation signal of the muscle does not interfere in the signal measurement of the other.

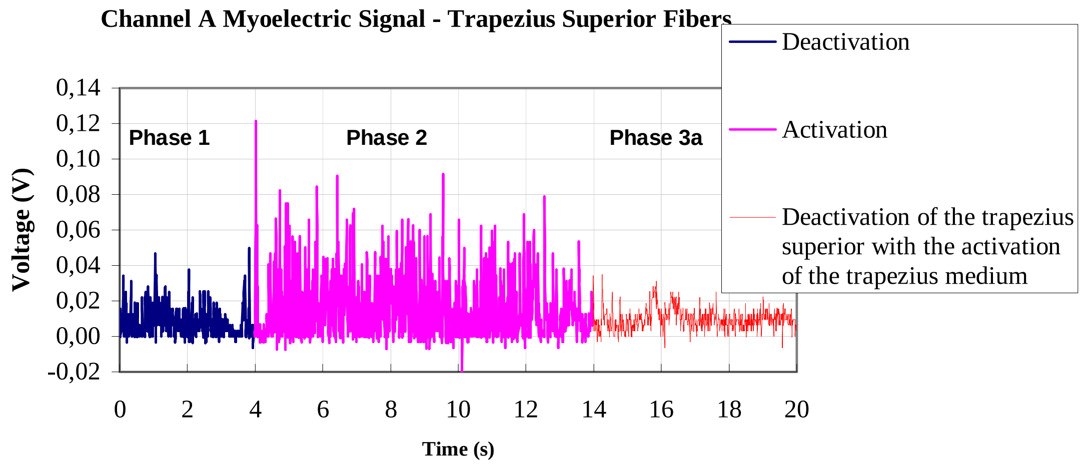

Figure 3 – Channel A myoelectrical signal – Trapezius Superior Fibers**.**

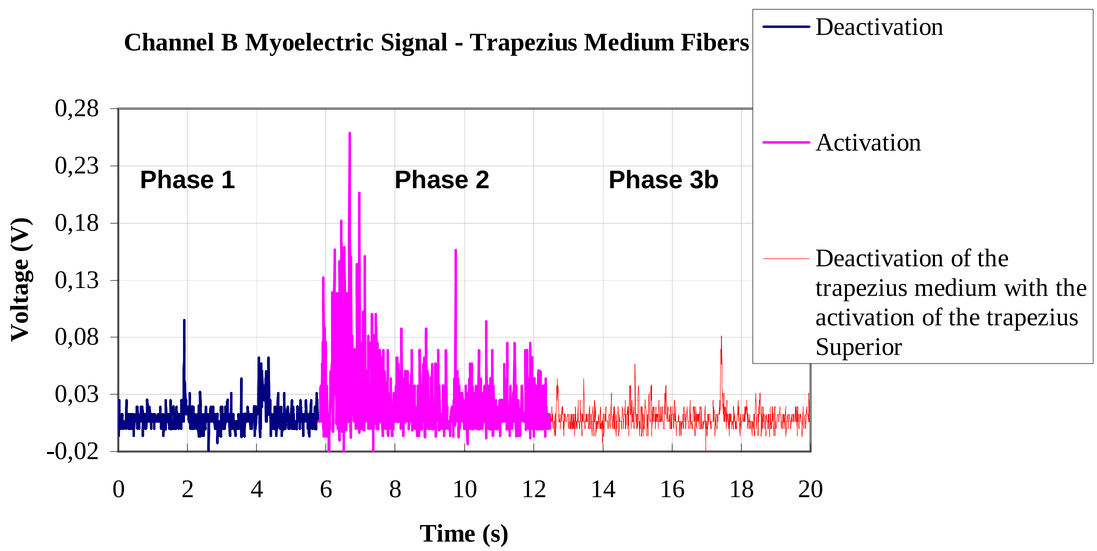

Figure 4 – Channel B myoelectrical signal – Trapezius Medium Fibers**.**

The circuit was able to differentiate the levels of amplitude during the muscle relaxation and contraction. Therefore, the system can be utilized to transmit information about muscle activity to another system that will act to activate the orthosis.

4. Conclusions:

It was devised a functional hand orthosis that allows the patient control its movements by means of myoelectrical signals captured from an higid and pre-trained muscle. In the present paper it was shown an example of activation using trapezium muscle. By doing this, the microprocessor interpreted the activation of the superior muscle fibbers (by elevation of the shoulder-blade) as a command to perform the hand closure. The volunteer achieved the hand opening by activating the medium muscle fibbers (by retracting the shoulder-blade). The control circuit was able to activate the electromechanical device by myoelectrical signals. The orthosis demonstrated to be effective to perform prehensile movements making it possible to handle objects with different shapes, weights and sizes. It was possible to achieve good functionality and aesthetics.

5. Acknowledgements

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