FUNCTIONAL HAND ORTHOSIS: CONTROL UNIT DESIGN AND APPLICATION

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Abstract. *Hand orthosis are useful for patients with central or peripheral nervous system injury affecting hand function and dexterity. This paper describes a control module design of the hand orthosis developed at the Laboratory of Bioengineering (LabBio) of the Federal University of Minas Gerais (UFMG). The functional hand orthosis is divided in three parts: glove, electromechanical artificial muscle and control module. The glove was constructed using antiallergic elastic material to provide comfort and accommodation during its use on the patient's hand. The glove biomechanical action is performed by artificial tendons with high mechanical resistance, low weight and a small diameter, disposed in a net form. Additionally, a servomotor was attached to tendons structure acting in the glove movements. The control module performs EMG signal processing, and generates a resultant electrical signal to control the orthosis. The control strategy was based on EMG signal aquisition from two auxiliary healthy muscles groups, which were stimulated consciously by patients. The groups were chosen so that one was responsible by the opening command and the other by the closing command of the orthosis. The muscle groups were previously chosen through a clinical review performed on the patient by a physiotherapist. The functional hand orthosis was assembled and tested on patients who had hand movement paralysis. The design incorporated aspects of low cost and weight, low power consumption, usability, high autonomy of functioning, ergonomics and more.*

Keywords*: Hand Orthosis, Myoelectric Signal, Bioengineering, Control Module*

1. INTRODUCTION

The loss of hand function and dexterity can be potentially devastating. Injuries result in lack of hand, arm and, sometimes, wrist control, beside loss of sensitivity in the arm or hand. In addition, generally the loss of functionality and decrease in capacity to carry out large proportion of daily tasks causes psychological problems (Petroff *et al*, 2001).

Functional hand orthosis assist in hand movements and restore partially its function. However, the current orthosis designs are often cumbersome, not aesthetically pleasing, and provide restrictive hand functions (Benjuya and Kenney, 1990; Slack and Berbrayer, 1992; Trombly and Liden, 1995; Prochazka *et al*, 1997; Alon and Mcbride, 2003). In addition, these equipments usually are highly expensive and complex in terms of mechanics and control. Most of them have been used only to decrease pain, deformity, and to place statically the upper limb extremity, but do not have functionality (Romilly *et al*, 1994; Kohlmeyer *et al*, 1990).

This paper describes the implementation of a control module of a hand orthosis developed in the Bioengineering Laboratory (LabBio) of Federal University of Minas Gerais (UFMG). The hand orthosis was developed in three parts: a functional glove, an electromechanical artificial muscle and the control module. The control strategy was based in the acquisition of the electromyographic (EMG) signal from two auxiliary healthy muscles groups, which are stimulated consciously by patients, where one of them was responsible by the opening command and the other by the closing command of the orthosis.

2. MATERIAL AND METHODS

2.1. The Glove

The glove was constructed using anti-allergic elastic material to provide comfort and accommodation during its use on a patient's hand (Fig. 1a). It allows the fingers move with exception of the thumb and the wrist that are stabilized by a static orthosis (Fig. 1b).

(a) (b)

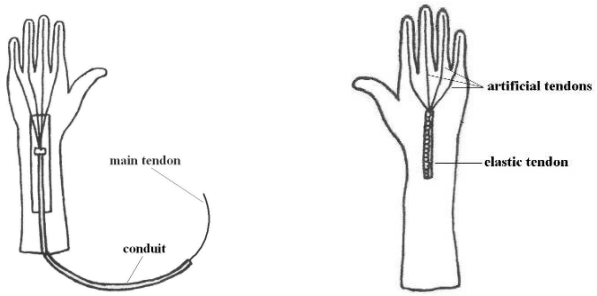
Figure 1. (a) Glove; (b) Static Orthosis

2.2. Electromechanical Artificial Muscle

The biomechanical system employed for the glove construction is based on two distinct artificial tendons set with high mechanical resistance, low weight and a small diameter. One set acts in the closing of the glove and is composed by artificial individual tendons that connect the glove fingertips of the palmar face to a artificial main tendon (Fig. 2a), guided through a conduit connected to the actuator. The other set is constituted by individual tendons that connect the glove fingertips dorsal face to the elastic tendons fixed in the forearm portion of the glove (Fig. 2b). This elastic tendon is responsible for the opening operation of the glove.

A high-torque and compact servomotor (Futaba DS8711) was used as the actuator. A pulley was attached to the servomotor to connect it to the artificial main tendon.

The fingers flexion occurs when the main tendon is pulled by the servomotor during its rotation in the clockwise direction. The finger extension is performed when the servomotor rotates in the opposite direction.



(a) (b)

Figure 2. (a) Palmar view; (b) Dorsal view

2.3. The control module

The control module is composed by: *signals acquisition interface*, amplifier, filter, rectifier, level comparator and processing (Fig. 3). The channels A and B refer to the EMG signal from each muscle groups.

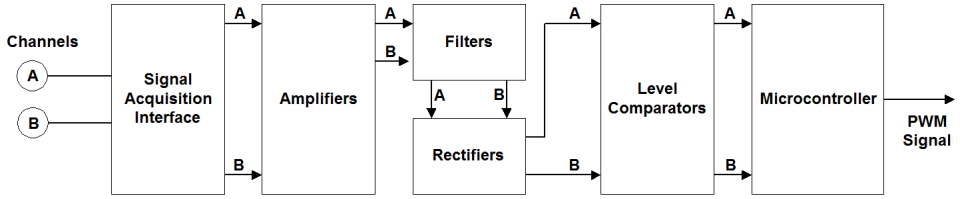


Figure 3. Control module blocks diagram

The EMG acquisition from muscle groups of the patient is accomplished through of a *signals acquisition interface*. Each muscle group from the patient is connected to a pair of passive and dispose electrodes for EMG differential acquisition placed according to the orientation of muscle fibers in order to obtain greater range and reduction of crosstalk. Additionally, a ground reference electrode ensures better signal/noise and stability of signals. Figure 4 illustrates the electrodes positioning on the muscle groups.

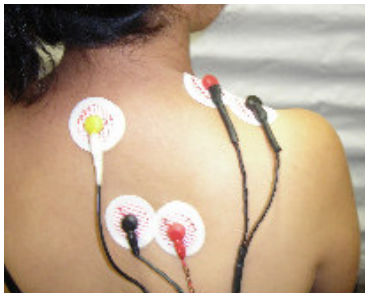


Figure 4. Electrodes positioning

The amplifier provides two balanced and independent external input EMGs acquisition, one reference ground output and one shielding ground output to the cable mesh of electrodes. Each signal input implements an amplification and signal conditioning stage. To implement these functions, instrumentation amplifiers INA118A (Texas Instruments part number) and operational amplifiers OPA27 (Burr Brown part number) were used - both have reduced supply voltage range, low internal noise and high CMRR (Common Mode Rejection Ratio). The EMG signal is connected to these inputs through the *signals acquisition interface*.

The spectral analysis of EMG signals from patients during the clinical test identified the distribution of relevant frequencies from 0 to 300Hz range (Fig. 5).

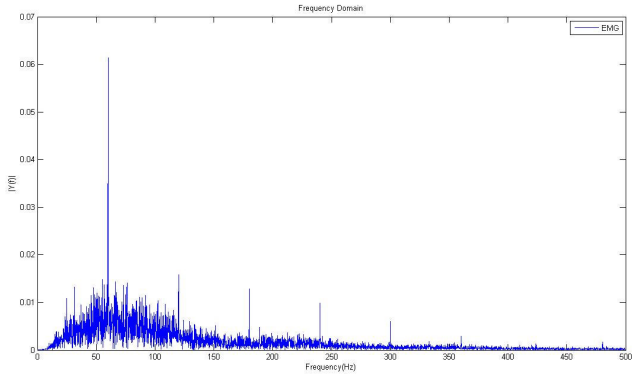


Figure 5. Spectral analysis of EMG signals

Considering that the 60Hz frequency is nominal AC power line signal, it represents a strong source of noise that is harmful to electronics interfering in the EMG processing. To minimize this interference, a 2nd order analog high-pass filter with 60Hz cutoff frequency and a 2nd order analog low-pass filter with 300Hz cutoff frequency were implemented, associated to each output of the amplifiers. The cutoff frequency of the filter is within the range of EMG signal, thus causes a loss of spectral information and define a new range of evaluation for the EMG signal between 60 and 300Hz. Analyzing the acquired signal (Fig. 6a) and the filtered signal (Fig. 6b), it can be demonstrated that, despite a spectral loss inferior to 60Hz and upper to 300Hz, a range of evaluation contains information acceptable to execute the control, since this will be based on a time domain, and not on a frequency domain.

The rectifier was implemented to obtain the module of the filtered EMG signal. Thus, in the output of each rectifier, all voltage amplitudes relative to EMG are only positive.

Patients have individual muscular responses and different ranges of EMG signal amplitudes. A level comparator was implemented to ensure a better adjustment to these different amplitude ranges. The level comparator performs the comparison between the rectified EMG amplitudes of each muscle group and the *reference signal*.

The *reference signal* represents the minimum value of muscular activity and establishes the threshold for the *digitalization* of analog input signals of the comparator. This *digitalization* defines two logical levels: 5V (logic level "1") corresponding to the presence of EMG at the comparator input and 0V (logic level "0") corresponding to the state of absence of EMG. The level comparators were projected adopting level of hysteresis of 100mV to ensure greater stability of its output avoiding erroneous or spurious transitions.

The level comparators were implemented adopting the LM393 (National part number) which has two independent comparators and electrical characteristics such as: small input voltage range, low consumption and good accuracy. The output signals of level comparators were connected to the digital input of microcontroller for processing and controlling the servomotor.

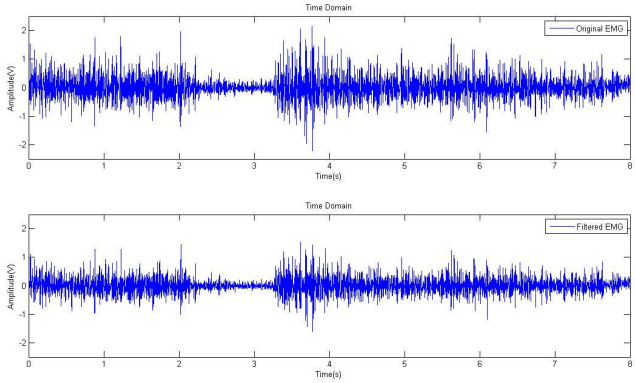


Figure 6. (a) EMG signal; (b) Filtered EMG signal

The MC68HC908QT4 microcontroller (Motorola part number) was chosen due to its characteristics of low cost, operational performance, small size and ease of recording and firmware updates. The microcontroller performs the processing of digital signals from the outputs of the comparators and generates a PWM (Pulse Width Modulation) standard output signal used to control the position of the servomotor. The direction of rotation and consequently the position of the servomotor depends on the duty cycle of the PWM signal, usually expressed in percentage.

The patient's muscle contractions detected through level comparators are processed by the microcontroller, where the implemented algorithm determines whether the glove should be open, closed or maintained in its current position.

Figure 7 shows the flowchart of the implemented algorithm. When the orthosis is started, the PWM duty cycle is set so that the orthosis is in total extension position. Later on, channels A and B are read. Each channel has two states: when the muscle group refer to the channel is contracted, its state is enabled, otherwise, its state is disabled. So, when both the channels are disabled, the PWM duty cycle maintains its current value. When only the channel A is enabled, the PWM duty cycle is incresead, causing the orthosis closing. In the same way, when only the channel B is enabled, the PWM duty cycle is decresead, causing the orthosis opening. When both channels (A and B) are enabled, the PWM duty cycle remains with its current value, maintaining the angle of the orthosis at its current position. This last configuration was implemented in order to ensure the users safety.

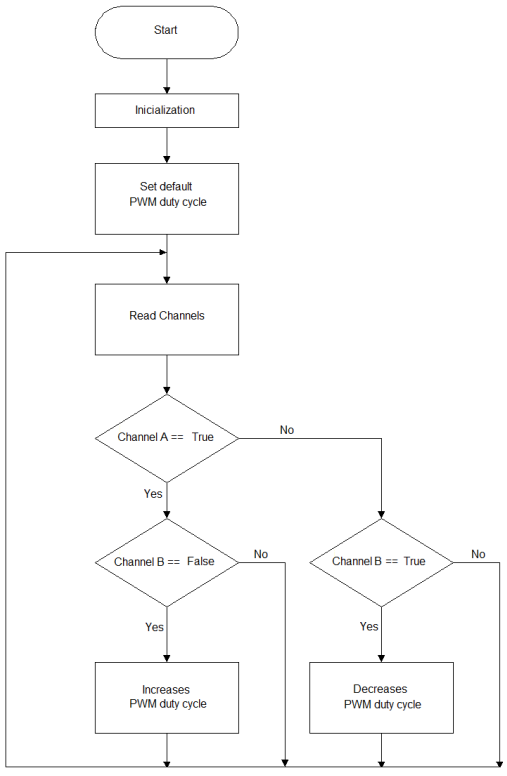


Figure 7. Flowchart of the implemented algorithm

2.4. Clinical tests

This research was approved by Ethical Comite of UFMG (ETIC 368/06) and City of Belo Horizonte Health Office (016/2007).

Three patients with wrist and hand paralysis were selected. For each patient an orthosis was made taking into consideration their characteristics and individuals necessity. The identification of the muscle groups used for myoeletric control was also performed.

2.4.1. Test Protocol

Unimanual and Bimanual tests were achieved with patient using the orthosis in order to evaluate the agility and dexterity of the hand, and their performance in the daily activities. The Unimanual test was performed to evaluate the capacity of objects prehension. This test was an adaptation of "*Grasp Release Test*" (Wuolle *et al.*, 1994), which solicits the individual to grasp, hold and release objects of various sizes, shapes and weights. At the Bimanual test, the orthosis is used as an auxiliary hand to stabilize and place objects of various shapes and allow the manipulation of the dominant hand (preserved hand). This test included tasks such as: to get an empty glass and fill it with water, put a spoon of sugar and stir; to hold a paper and cut it with scissors.

3. RESULTS AND DISCUSSION

A prototype of the control module was constructed, where the functioning test, refining and adjustment of electronic design and firmware was achieved(Fig. 8). All electronic components used are of the type PTH (Pin Through Hole), in order to facilitate the maintenance, management and commercial acquisition. An important operational parameter for the selection of electronic components was the low energy consumption, since the module requires the use of power supply by batteries. Even using a technology of prototype construction, the module was compact, lightweight, functional and easy to adapt to the body of the patient.

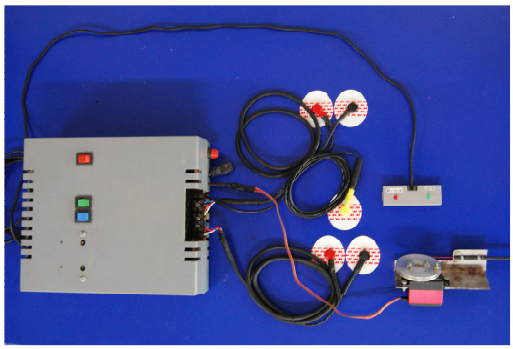
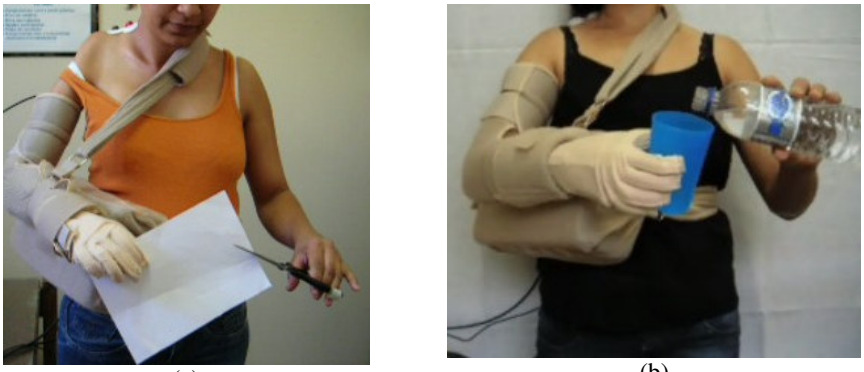


Figure 8. Prototype of the control module

The results of the Unimanual and Bimanual clinical tests show that the patients could control the flexion and extension of the orthosis fingers using EMG signals acquire by surface electrodes, which were placed on the selected muscles. They were able to grasp objects and perform the specified tasks, such as: to cut a paper (Fig. 9a) and to fill a glass of water (Fig. 9b).



(a) (b)

Figure 9. (a) Patient cutting a paper; (b) Patients filling a glass of water

4. CONCLUSION

As general aspects, it was found that reducing the spectral range of the EMG signal caused by activity of the filters didn't impair the control.

In regards to the *signals acquisition interface* it was verified the importance of choosing the model and manufacturer of auto-adhesive passive electrodes due to the problems observed on the difficulty to fix it to the body of the patient and its time of fixation. During the tests some models of passive electrodes did not show good adhesion, causing capture errors of EMG signals, noises and bad function of the orthosis.

Patients who participated in clinical tests managed to operate successfully the orthosis. The protocol used for testing showed that the control module operated properly, and that the adjustment of the level comparators that were implemented allowed greater versatility and adaptability of the control module to different levels of amplitudes of EMG signals from patients.

The performance of Unimanual tasks allowed the evaluation of the functioning mode of closing and opening operation of the orthosis, while the performance of Bimanual tasks allowed the evaluation of the complete functioning of the control module of the orthosis.

5. ACKNOWLEDGEMENTS

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