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Construction of an Electronic Controller for Gripper with Bioelectric Signals

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Abstract

The development of robotic structures and tools day by day is advancing by leaps and bounds, seeking to facilitate the execution of tasks or activities that require a high degree of precision, effort and inclusion that can be harmful for the integrity of the human being. This paper proposes the development of an electronic controller associated with the recognition of electromyographic signals (EMG), in order to control grip and grasp movements of an electromechanical gripper structure. The aim is to implement a control unit based on a 32-bit microcontroller, which will allow the effective detection of the electromyographic signals from the long palmar muscle and associate them to actions of the grip mechanisms, used in robotic devices in industrial, biomedical, exploration environments and any field where its implementation is necessary and feasible.

Keywords: Electromyographic signals, Grippers, Controller, EMG.

INTRODUCTION

Electromyographic signals are produced by the contraction and relaxation of any muscle, which, in spite of presenting small voltage levels, can be previously measured, having been conditioned and processed, so this type of information can be used in any human-machine interface, robotics field, automation, medicine, biomedical, clinical engineering, video games, among others. [1-2]

The use of electromyographic signals to control robotic mechanisms and prostheses is more and more frequent, because those signals provide a useful non-invasive measure of the developed muscle activity [1]. The manipulation and implementation of this type of techniques allow the control from simple elements with a single degree of freedom (basic grippers) to very complex devices (robotic arms and hands with 5 or more degrees of freedom) [3], inclusive offering the possibility of achieving assistance or functional replacement of human extremities [4].

When using controllers for biomechanical structures, [5] [6] and even some dedicated to saving energy [7], are defined two ways to use an EMG signal in this field; the first part emphasizes using the amplitude of the respective signal in steady state, by maintaining a constant force with a specific muscle chosen for monitoring. The second form refers to the temporary transient structure of the EMG activity, which can be obtained by performing rapid movements or gestures with the hands, fingers or wrist [8].

Taking into account the above, this paper establishes a proposal for the development of a real time electronic controller, which is responsible for acquiring, filtering and conditioning the respective EMG signal, in order to activate a gripper-type mechanism. It should be noted that the document also included the mechanical design of the gripper, because it was built in order to demonstrate the effectiveness of the control algorithm, allowing validation of both the functional aspect and the response times for the embedded solution (32-bit microcontroller).

METHODOLOGY

Acquisition and treatment of the EMG signal

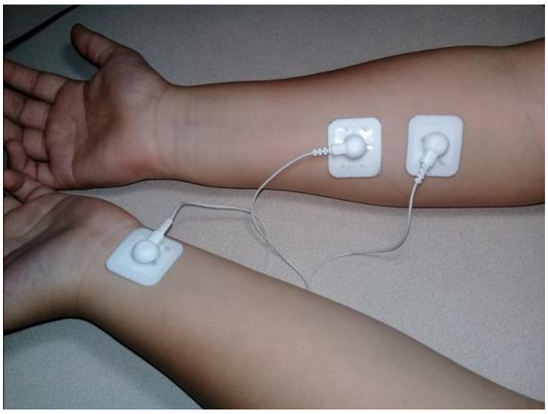

Figure 1: Location of electrodes for signal acquisition

Detecting the ionic signals of the body is a process that allows designing different applications that use the corporal movements; for the case of the proposed solution, it was decided to monitor the Palmaris Longus muscle, locating the electrodes at the beginning and end of this muscle, see Fig. 1 (this is a long, thin and superficial fusiform muscle of the forearm, responsible for the flexion of the hand, is on the medial side of the flexor carpi radialis [9]).

To reference the system, it was chosen to locate the third ground electrode on the styloid area of the opposite upper extremity of the test subject as shown in Fig. 1. Once the signal is acquired, it is amplified and filtered, in such a way that the microcontroller that will process the information will be able to identify an activation threshold, determined by a comparison process according to the level of excitation registered in the muscle.

Controller architecture

The control stage is essential for the prototype control; the proper functioning of the device depends on it, in addition to interlacing the mechanical part and electromyography or signal acquisition [10]. The control stage consists of an algorithm that allows the gripper user to adjust the attachment angles depending on the level of excitation of the monitored muscle. For this, it is necessary to know the amplitude of the action potential, in such a way that the maximum value reached during the time in which the signal is maintained above an amplitude threshold *Vth* can be obtained. This voltage threshold is set by comparing the amplified myoelectric signal with the reference voltage *Vth*, so that as long as the signal exceeds this reference value, a logical '1' is obtained in the output and otherwise it remains a logical '0'. The electronic control unit will check this digital signal to determine when to read the analog values of the myoelectric signal. Fig. 2 shows the complete architecture proposed for the electronic controller.

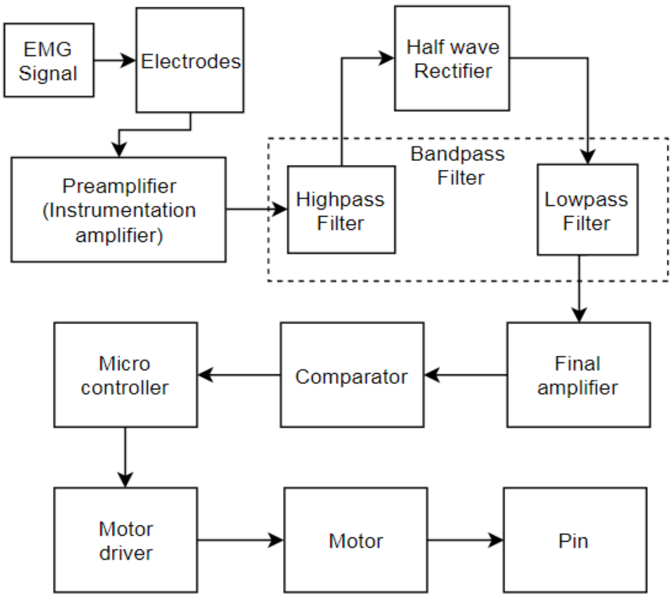

Figure 2: Electronic controller architecture

The control unit takes into account two signals; the first one is given by a digital signal which indicates the existence of a nerve signal transmitted by means of an action potential or electric impulse. The measured action potential is an electrical discharge wave that travels along the cell membrane modifying its distribution of electric charge. This signal is used since it is a rapid change of the membrane potential that quickly extends along the nerve fiber membrane and therefore allows the flexing of the Palmaris Longus muscle to be recognized. [12]

The second signal is analogical and corresponds to the instantaneous reading of the amplified myoelectric signal. Once these two signals are recognized by the unit, the algorithm makes logical decisions according to the rising or falling edges that exist in the digital input signal and the maximum value recorded in the analog signal, to subsequently generate a PWM (Pulse width modulation) signal with which the servomotor works. According to the pulse width of the output signal, a fixed angular position is obtained in the clamp.

IMPLEMENTATION

Because the EMG signals have approximately an amplitude value of 10mV, to identify the signal it is amplified by means of an operational instrumentation amplifier (INA106kp) configured as an inverter amplifier, taking an input resistance of 10kΩ and a feedback resistance of 150kΩ, thus obtaining a gain of 15.

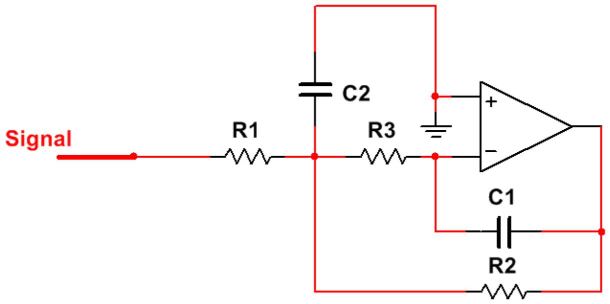

Figure 3: Second order low pass Rauch filter structure (MFB)

Once the signal is amplified, it passes through a butterworth-type second order high pass rauch filter (MFB) configured with gain of 1 and a cutoff frequency of 122.68Hz, so this way part of the frequencies produced by the noise is suppressed. Later the signal is rectified eliminating the possible negative values that are obtained; this because the signal must be compared to a positive reference voltage. To achieve this, a half-wave rectification is performed by two fast-response diodes at the output of the operational amplifier. Once rectified, the signal is filtered by a chebyshev-type second order low pass rauch filter (MFB) with gain of 1 and a cutoff frequency of 1,908Hz. The circuit is powered by two batteries of nine volts forming a dual source. The signal is conditioned by means of a comparator to obtain a digital signal with a minimum threshold, set for this case at 1.5V; this value varies depending on the position of the electrodes and the person using the device.

The following is the structural description of the implemented low pass Rauch filter (MFB), see Fig. 3:

$$C_0 = \frac{1}{2\pi * R * Fc}$$

$$C_i = K_i * C_0$$

Where:

- R = R1 = R2 = R3 = 82KΩ. For the simplified calculation of the Rauch structure (MFB) for low pass filters the same values were taken in R.
- Fc represents the cutoff frequency, for the implementation it was 1,908Hz.
- C_0 represents the base value of the capacitors, then a product is made with the coefficient that allows defining the type of filter with which one works. For the Butterworth filter case a value of 1uf was obtained.
- C_i Subindex i is a representation of the capacitor in the diagram, for the case of the low pass filter, 2 capacitors $C_1 = 2{,}2uf\ and\ C_2 = 470nf$ are used, these values were approximated to the closest value in the commerce.
- K_i represents the work coefficient, because the filter is butterworth-type the following coefficients were taken: $k_1 = 2.12\ , K_2 = 0.47$.
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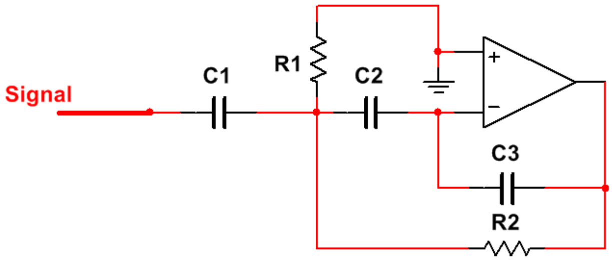

Figure 4: Second order high pass Rauch filter structure (MFB)

Similarly, the structural description of the high pass Rauch filter (MFB) implemented is presented, see Fig. 4:

$$R = \frac{1}{2\pi * C * Fc}$$

$$R_i = K_i * R$$

Where:

- $C = C_1 = C_2 = C_3 = 1$uf. For the simplified calculation of the low pass Rauch filter structure (MFB), equal values were taken in the capacitors.
- Fc represents the cutoff frequency, for the implementation it was 122.68Hz.
- R Represents the base value of the resistances, then a product is made with the coefficient that allows defining the type of filter with which one works. For the Chebyshev filter case a value of 1.5KΩ was obtained.
- R_i Subindex i is a representation of the resistances in the diagram, for the case of the high pass filter 2 resistors were used $R_1 = 322.58\Omega\ and\ R_2 = 5K\Omega$, these values were approximated to the closest commercial value $R_1 = 330\Omega\ and\ R_2 = 5.1K\Omega$.
- K_i represents the work coefficient, because the filter is Chebyshev-type, the following coefficients were taken: $k_1 = 4.65, K_2 = 0.3$.

Microcontroller algorithm

In the execution of the algorithm, see Fig. 5, first it is asked if a falling or rising edge is detected in the digital signal, this is done by comparing the current value (X1) and the previous value of the signal (X2). If a rising edge is present, the variable '*En*' is activated and immediately check if the current value is greater than the previous one, if this is the case, the maximum recorded value is saved until a falling edge is detected in the digital signal. When a falling edge is detected in the digital signal, the variable '*En*' is deactivated so that the maximum value of the analog signal will no longer be consulted.

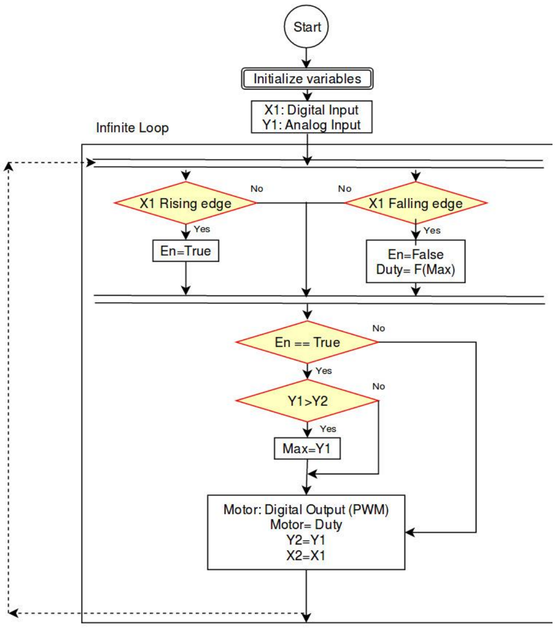

Figure 5: Microcontroller algorithm flow diagram

Subsequently the linearization of this signal is performed regarding the useful signal cycle of the PWM; this linearization represents the opening angle of the gripper actuator. The output of the control unit is a cyclic square signal of 50Hz, with a useful cycle that varies between 7.5% and 10%, where 10% would represent an opening of 0 ° and 7.5% an opening 90 °.

Final effector clamp - Gripper

This type of interfaces such as manipulators, actuators, anthropomorphic hands, end effectors (grippers) allow to manipulate and grab objects. They are designed to perform diverse functions, such as parallel finger claws, welding tools and specialized clamps, and are commonly used in robotics, biomechatronics, biomedical engineering and clinical engineering systems. [4]

For the implementation of controller a clamp type gripper was designed, see Fig. 6, taking into account the operation of the motor, in such a way that at 0 degrees the clamp is in a state of rest and in 90 degrees in a state of complete fastening, allowing the physical implementation of the controller.

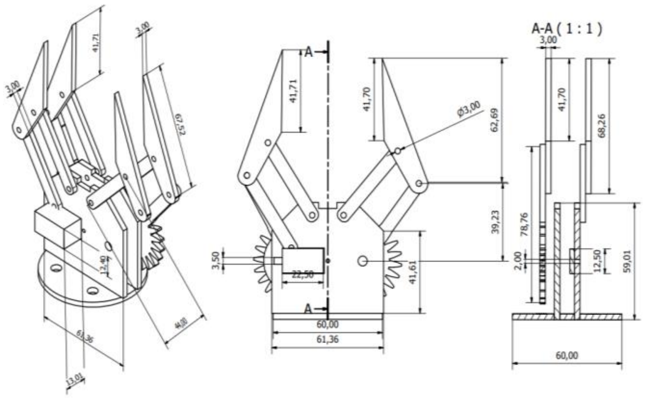

Figure 6: Designed Gripper

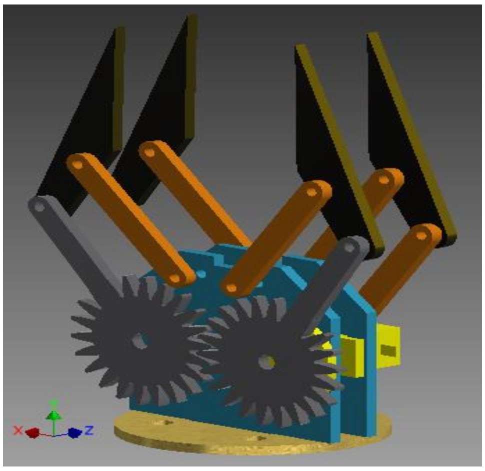

Figure 7: Design visualization in CAD tool

In the first instance, the motor is conditioned to the signal coming from the microcontroller by means of an optical coupling, thus transmitting the PWM signal to the servomotor. In this way the servomotor is mechanically coupled with the clamp. The material for the physical design of the motor clip was acrylic. The pieces of the clip are fitted having the structure developed using INVENTOR 2015a software, a parametric modeling package of 3D solids produced by the software company Autodesk, see Fig. 7.

RESULTS

Filter design and selection

In order to choose the most suitable filter for the development, a series of simulations were carried out in the MATLAB 2015a software, see Fig. 8, this in order to analyze the general behavior of the acquisition stage of the electromyographic signal. The operation of the different types of second order filters was validated, taking into account the behavior of the low pass filters opting to use the butterworth-type filter. As can be seen in Fig. 9 it was found the behavior of the high pass filter with a cutoff frequency of 122.68Hz, in this specific case the Chebyshev filter was selected.

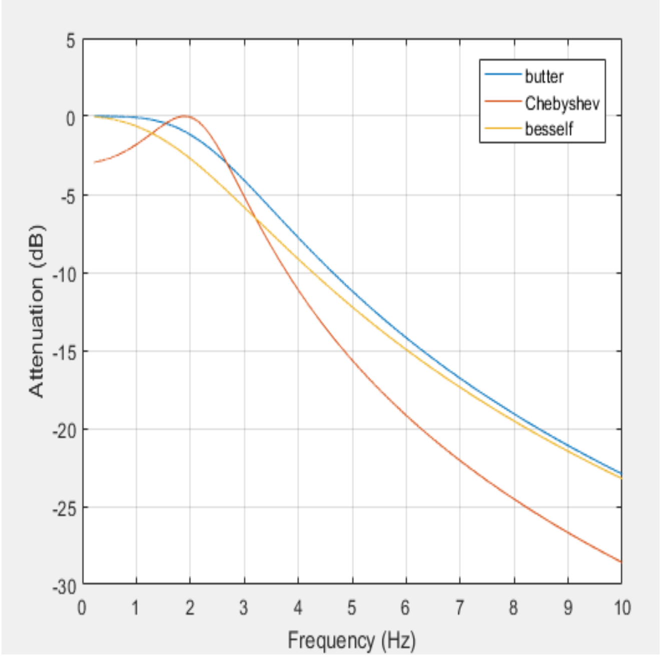

Figure 8: Second order low pass filters simulated using MATLAB.

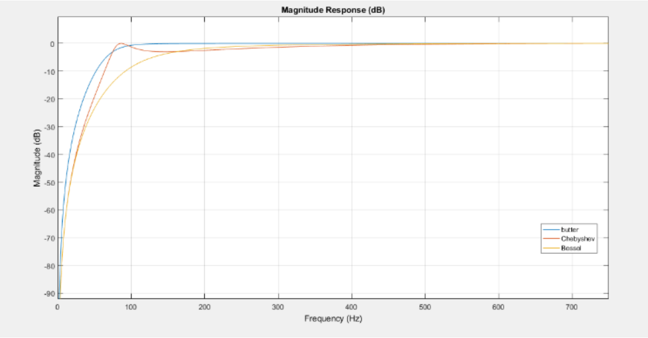

Figure 9: Filters pass second order highs simulated in MATLAB.

Controller response times.

A 32-bit microcontroller with 16MHz frequency was implemented. In order to decrease the response time and execution of the algorithm, it was decided to distribute the work in two main states; these states are typical of a control system with threshold, however it is usually presented that the detection of the muscle when overcoming the Vth grab or release. In this case one of the states called "detection state" determines the maximum value acquired during the action potential. The resting state maintains the signal of the maximum value detected by the algorithm. The algorithm changes its state when observing changes in the action potential. The detection state is activated by the rising edge and the resting state is activated by the falling edge. During the potential detection state the algorithm executes a comparison between the current value and the maximum value previously detected, so if the current value is higher it becomes the new maximum value. When the algorithm executes a constant comparison its time goes to be 168us. Once the maximum value is detected and the action potential is lower than the Vth value, the algorithm changes to the idle state maintaining the maximum value previously detected, running at a speed of 60us.

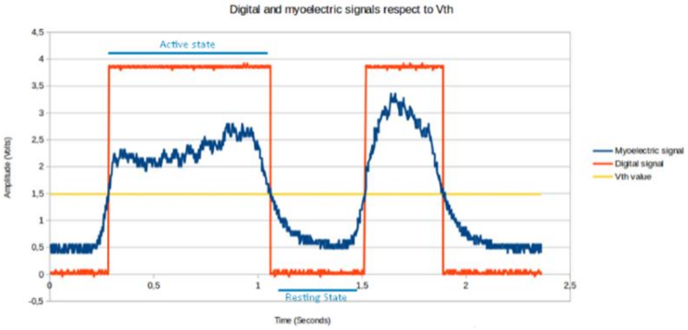

Figure 10: Operation of controller states.

Behavior of the output signal

A PWM signal adapted for a servomotor was obtained, with a period of 20ms and useful cycle between 10% and 7.5%, this to generate a variation in the servo motor of 0 ° - 90 °. The opening angle of the clamp changes when the algorithm enters the resting state, making a change in the output signal as seen in Fig. 11, so in this way it is possible to maintain an opening angle even while the muscle is at rest.

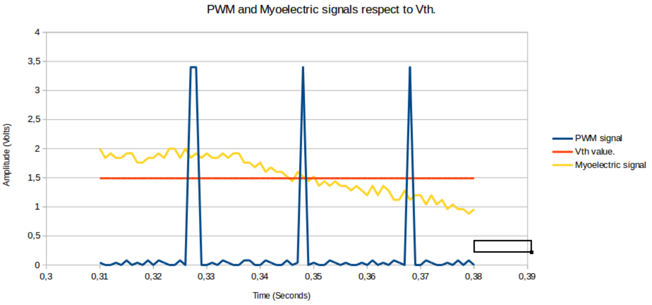

Figure 11: Controller output signal.

CONCLUSIONS

A controller was developed allowing the user to adjust the opening angle of a gripper clamp without causing muscle fatigue, which is possible because the controller recognizes the action potential through a myoelectric signal measured in the Palmaris Longus muscle. This signal is conditioned by a filtering and amplification stage that allows the controller to find the maximum value of the myoelectric signal that represents an opening angle in the clamp. The Analog-Digital converter used has a resolution of 10 bits, it is important for it to be high since this parameter decides the accuracy and resolution of the actuator when determining the opening angle. The controller maintains two states of operation and therefore there are two execution periods for the algorithm, one when there is action potential (168us) and the other in idle state (60us), where the controller responds 2.8 times faster to detect the next action potential. In general terms, the developed tool provides a low cost and high performance applicable technological solution, so it can be widely used in any development area of the rough environment of the robotics world.

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