Design of a Biofeedback Device for Muscle Rehabilitation

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Abstract— There is currently a strong need for new technical means for neuromotor rehabilitation in order to intensify treatment, to respond to the increase in the number of patients clogging up care services, to lower costs and, above all, to implement new rehabilitation approaches that are more effective and better scientifically based than the current therapies, which are largely based on empirical observations.

This project aims to develop a new tool for neuromuscular reeducation. Its function is to improve the quality and the duration of muscular strengthening training sessions and training of motor function for patients suffering from muscle deconditioning. A "smart" electromyostimulator using, at the same time, techniques of electrostimulation (EMS) and analysis of electromyography (EMG) allows the control in real time electrical stimulation parameters considering the physiological fatigue of the stimulated muscle. This control, performed on stimulation parameters depending on electrical response of muscles (M wave), allows the muscle stimulation taking into account the muscular reaction to the electrical

Keywords—a) Surface electromyography; b)Myoelectric signal; c)Electromyography; d)Acquisition and Conditioning; e)Electromyographic- system

I. INTRODUCTION

Rehabilitation refers to any process that aims to restore the patient to a previous level of health. Different types or expressions of the rehabilitation process focus on the task of restoring at least one function to the damaged part of the body or using the rehabilitation process to help the individual compensate for damage that cannot be repaired. .The movements of the various limbs of the human body are controlled by electrical signals. These signals originate in the cerebral cortex and act on the muscles which contract in response to stimulation, resulting in the development of mechanical tension [1]. The collection of the electrical signal at the level of the muscle can inform us about the force and the power developed but also about the state of the musculoskeletal system [2]. Understanding electromyography therefore implies knowledge of the muscle and its various components and thus the way in which physiological signals are generated

In addition, the force generated by the muscle is of interest to sports specialists with a view to improving technical gestures and at the same time athletic performance. The detection, recording and processing of the emg signal must obey principles related to its intrinsic characteristics [3].

The use of surface electrodes is the most common method for its collection, as they are non-invasive and the tests can be performed by other personnel.

This present work consists in carrying out the acquisition of the EMG electromyogram signal. It is an instrument commonly used by medical personnel in the field of muscle rehabilitation. It should be noted that it does not exert any electrical influence on the body.

II. METHODOLOGY

Weak electrical currents are produced by muscle fibers prior to the production of muscle force. These currents are produced by the exchange of ions across muscle fiber membranes, part of the signaling process for the fibers to contract. The signal called the EMG electromyogram can be measured by applying conductive elements or electrodes to the surface of the skin, or invasively planted in the muscle through the skin. Surface EMG is the most widely used method in sports medicine, since it is non-invasive and can be performed by personnel other than physicians, with minimal risk to the subject. Surface EMG measurement depends on a number of factors.

The amplitude, time and frequency domain properties of the EMG signal depend on factors such as:

- The timing and intensity of muscle contraction;
- The distance of the electrode from the active muscle area;
- Tissue properties (eg skin thickness);

Furthermore, the measurement of the EMG signal depends on the properties of the electrodes and their interaction with the skin, the amplifier design…etc. The quality of the measured EMG signal is often described by the ratio of the measured signal and the contribution of environmental noise. The goal is to amplify the signal amplitude while minimizing the noise [4].

For the acquisition stage must be compared and selected an instrumentation operational amplifier (OA) available nationally; the review of data sheets allows to develop this stage since all manufacturers recommend protection circuits for the patient and circuits to eliminate unwanted signals.

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All the circuits belonging to the signal acquisition and conditioning stages are simulated using Proteuse's isis computer software. The use of virtual sources provided by the latter can simulate the interference which affects such systems once already implemented; based on these components, the filter signal is checked. By analyzing the input graph (semg potential with interference) and the output graph (dc voltage output), the operation of signal amplification, rectification and smoothing can be verified.

III. ELECTROMYOGRAPHY

A. Definition

Electromyography studies muscle function through the acquisition of the electrical signal generated by muscles [5].
The process of generating a muscular movement starts when the brain sends a series of electrical impulses (instructions) through neurons, these special cells are responsible of sending and receiving these impulses through the central and peripheral nervous system; in this process, a neuron has the function of sending and receiving electrical impulses from the spine to muscle fibers [6]. The assembly formed by a motor neuron in the ventral horn of the spinal cord, its axon and muscle fibers innervating axons are known as a motor unit (see Fig. 1) [7] [8].

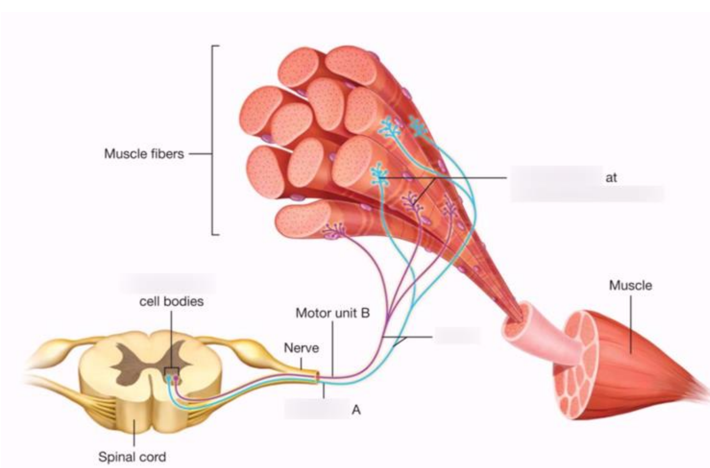

Fig. 1. Motor unit. [9]

In surface electromyography because multiple muscle fibers are innervated by a single motor neuron, the neuron is active, activating simultaneously to several muscle fibers [28]; the sum of all these individual potential generates an action potential in the motor unit (MUAP), the algebraic sum of these action potentials are considered as the SEMG signal from the set of muscle fibers constituting a specific muscle (see Fig. 2) [5].

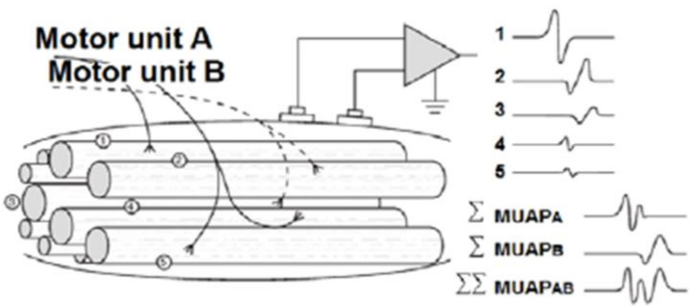

Fig. 2. MUAP algebraic addition (surface electromyography) [9]

B. Characterization of SEMG signal

The waveform of the action potential depends of the orientation of the electrode relative to the muscle fibers [5].

• Peak amplitude range - peak within the range of 0, 02[mv] - 5 [mv] [9] [5] .

• Frequency within the range of 0 [Hz] - 500 [Hz] (see Fig. 3) [5].

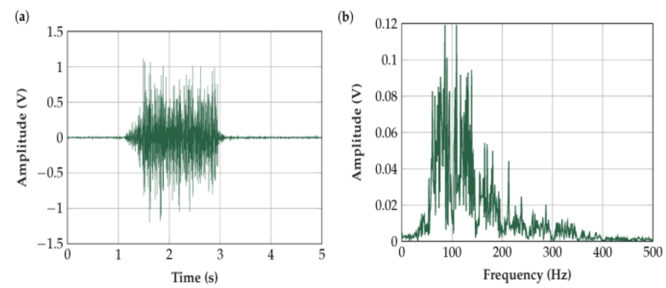

Fig. 3. Frequency spectrum of an electromyographic signal.

C. Factors affecting the SEMG signal

Within muscular level and instrumentation used in the detection circuit level, there are several factors that characterize and influence the SEMG signal specifically in the peak to peak amplitude and frequency:

• The firing rate of the MUAP [5] .

• The number of motor units [5] .

• Synchronization of activation of motor units [5].

• The driving speed of muscle fibers [5].

• The orientation and distribution of muscle fibers on the motor units [9] [5].

• The diameter of muscle fibers [5].

• The number of motor units within the detection zone of the electrode surface relative to the muscle fibers [5] .

• Materials and preparation of electrodes [10] .

• The location of the electrode [9] [10] [5].

• The orientation of the detection electrodes relative to the axis of muscle fibers [5].

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IV.SEMG SISTEM DESIGN

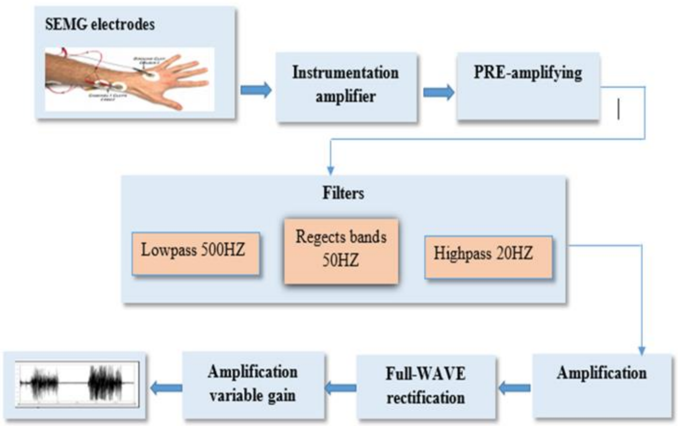

Fig. 4. SEMG System block diagram

The electrodes represent the starting point to design the acquisition and conditioning system of EMG signals, selected a particular type electrode the stages of amplification and filters are designed; checking several previous studies [17] the system, the non-invasive passive Ag / AgCl and gelled adhesives electrodes are used (see Fig. 5), selected by the study of suppliers and manufacturers at global and national level [11] .


Fig. 5. Surface EMG electrodes for muscle sensor Covidien H124SG - 6

The cables used to the connection between the electrodes and wires instrumentation amplifier are the electrodes used in the "Muscle Sensor v3" (see Fig. 6) [12]; this wire has three subdivisions: an inverter electrode, an non-inverting electrode connected to the instrumentation operational amplifier terminals with the same denominations, also it as one subdivision to the reference electrode.


Fig. 6. Wire used in the SEMG system. [13]

The preamplifier is the first stage of the project because the EMG signal detected at the level of the electrodes is of very low amplitude and drowned in different sources of noise. In addition, the signal is very often detected at the terminals of two electrodes, which will lead to the presence of a voltage in common mode. It is then essential to amplify it while minimizing the effect of these noises by using an instrumentation amplifier.

The use of an instrumentation amplifier to acquire electromyographic signal [14] [15] requires the fulfillment of certain essential characteristics [5] such as high input impedance [GΩ], high gain (200-100000), a ratio of common mode rejection (CMRR) greater than 90 [dB] frequency response within the range of an EMG signal (1 [Hz] - 3000 [Hz]), polarization current less than 50 [nA], low isolation [µA] and noise less than 5 [µV] RMS.

The AD620 instrumentation amplifier manufactured by Analog Devices [16] is an instrumentation amplifier inexpensive of high precision that requires only a resistor to set the gain from 1 to 10000. For dual operation it requires a minimum supply voltage ± 2, 3 [V] and maximum ± 18 [V] also a low current (maximum supply current of 1, 3 [V]). This amplifier is ideal for precision data acquisition because it has a high accuracy of 40 [ppm] maximum nonlinear gain, low offset voltage maximum 50 [mV] and offset drift of 0, 6 [µV/°C] max. The high ratio of common mode rejection, low noise, low input bias current and low power allows use in medical applications such as ECG, EMG, monitors non-invasive blood pressure, etc. (see Fig. 7)

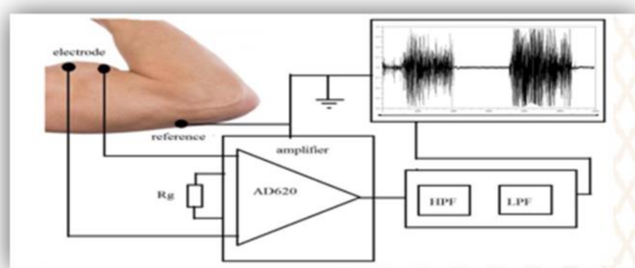

Fig. 7. the general operation of the AD620

To complete the acquisition stage, the output signal of the AD620 is amplified using a TL081 operational amplifier in inverting configuration with a gain of about AV=11 times the source signal (see Fig. 8).

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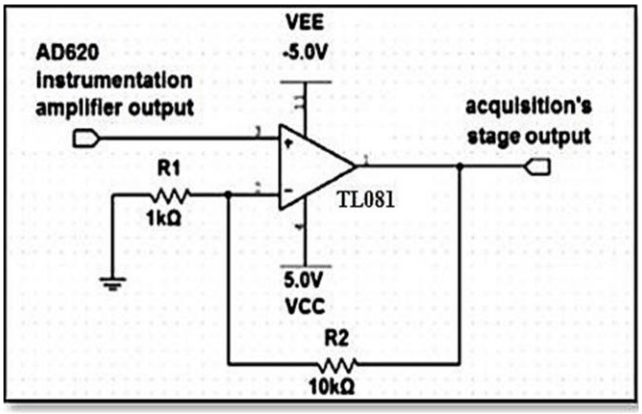

Fig. 8. Non-inverting operational amplifier.

The conditioning stage of the signal is divided in two main parts: filtering and rectification. To make all circuits used in this stage the operational amplifier (OA) of general purpose LM324N is used, which has a sufficient bandwidth within the frequency range of an EMG signal, low supply current, low noise and input voltage; using for the filter design formulas given in .

For filtering the signal, Butterworth filters with Sallen - Key topology are used, due they provide a flat response amplitude in the pass band also the higher the filter order, the greater the flattening .

The typical frequency range of a surface electromyographic signal is mostly between 0 [Hz] - 500 [Hz] [5]. in addition signals captured from 0[Hz] and 20 [Hz] are due to factors affecting the EMG signal as the size and orientation of the electrode, electrode – electrolyte interface, ambient noise, DC values, among others.
To limit the output frequency to 20 [Hz] to 500 [Hz] one band pass filter placed in series a low pass filter (see Fig. 9) and a high pass filter (see Fig. 10) of 6th order each station is designed with a slope of -60 [dB] / decade; for 6th filter order required is placed in series three 2nd order filters, obtaining the required order.

To remove unwanted signals of 50 [Hz] generated by devices of alternating current (AC) is designed by cascading two filters rejects band made up each by a filter rejects bands with Sallen – Key topology with a gain of approximately twice the original signal (see Fig. 11).

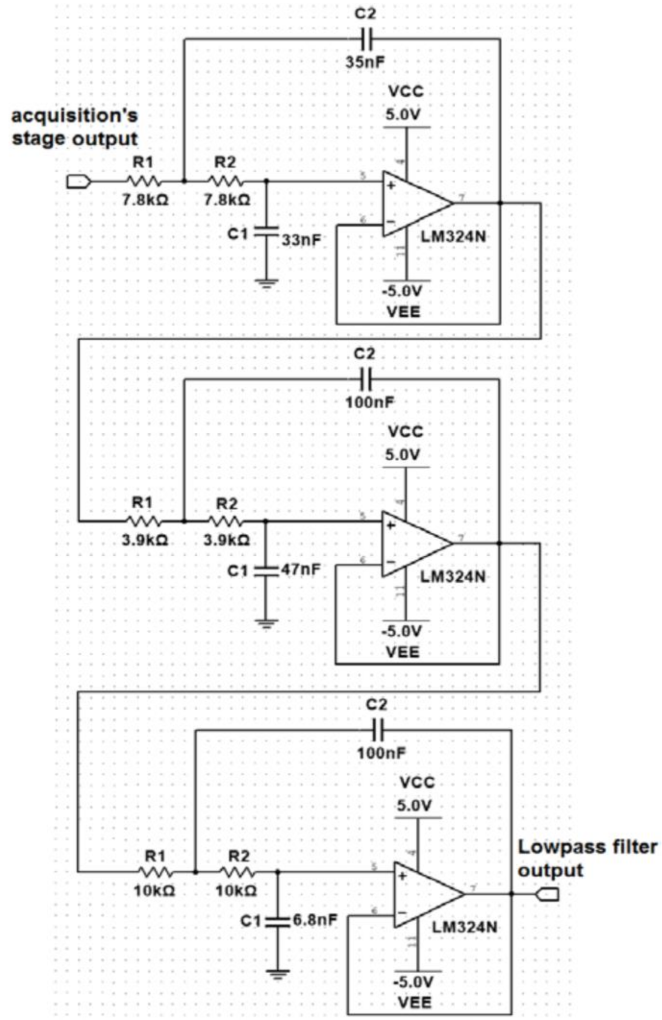

Fig. 19. Sixth order low pass Butterworth filter with unity gain

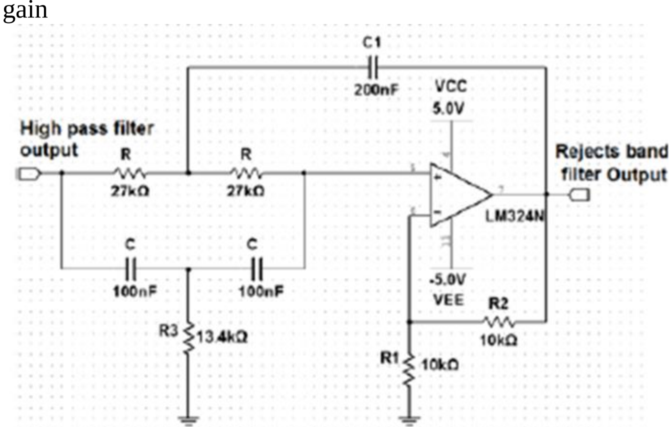

Fig. 11. Filter rejects bands of second order.

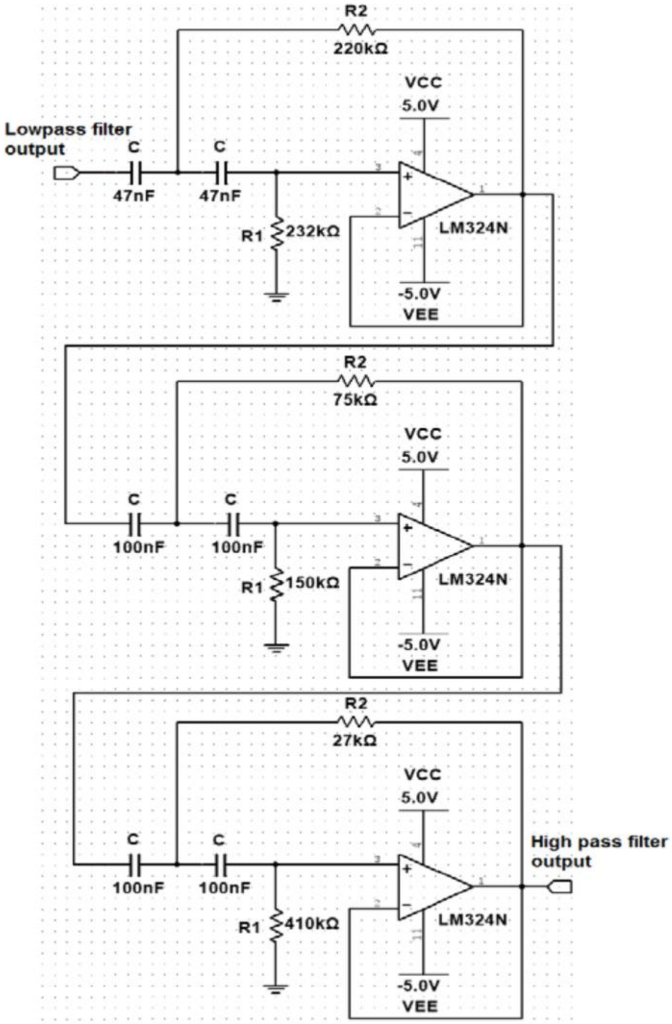

Fig. 10. Sixth order High pass Butterworth filter with unity gain.

The graph (see Fig. 12) has the amplitude and phase response of all filters designed.
We can clearly see that it is a 20 Hz-500 Hz Butterworth sixth-order bandpass filter.

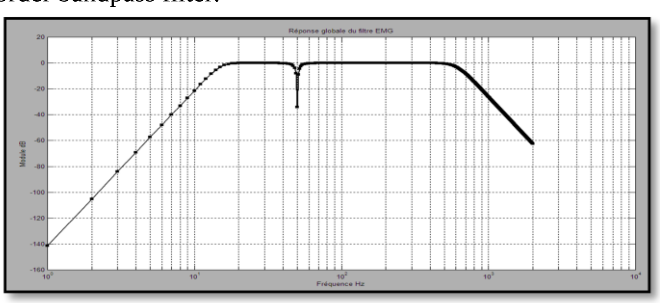

Fig. 12. Amplitude response acquired in Matlab based on the transfer function of all filters designed for the system

With the original surface electromyographic signal acquired and filtered, the next step is the rectification. For signal rectification the 1N4148 high speed diodes are used [17], these diodes are used for high speed switching applications in a full-wave rectification (see Fig. 13) [18] that obtains an average DC signal of the AC signal.

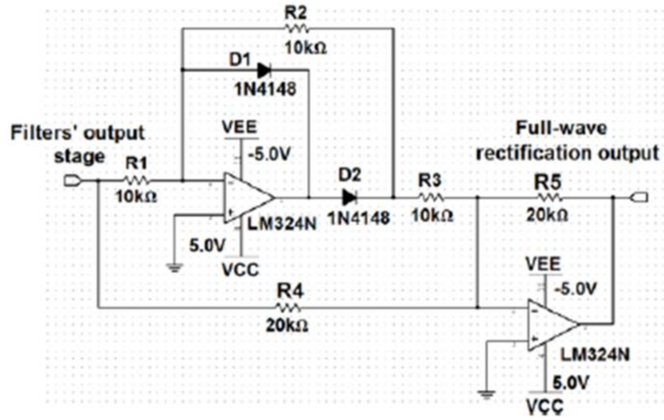

Fig. 13. Precision full wave rectifier

The results obtained are in the form of the following signals:
Red: input / blue: output

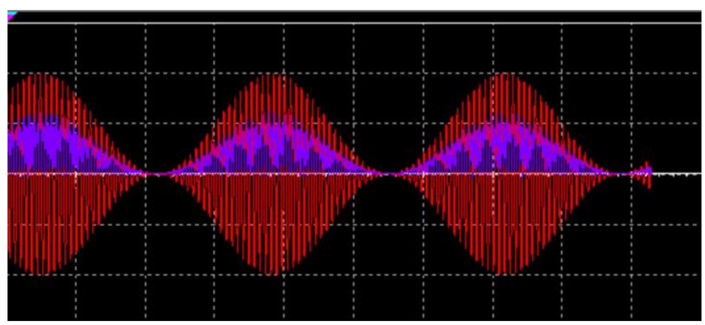

Fig. 14. Positive adjustment.

At the output of the envelope detector circuit, a DC voltage was recovered using a low pass filter. (see Fig. 15)
Blue:input/green:output

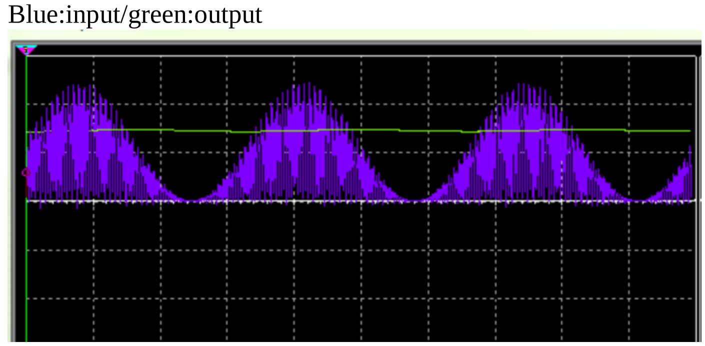

Fig. 15. Envelope detection

VI. CONCLUSIONS

In this work we have presented the different stages of the EMG signal acquisition circuit from the sensor to the filtering and amplification circuit. Also we were able to practice and report on the experimental problems that we could encounter such as (compatibility between the different stages, the quality of the wiring, the location of the electrodes, etc.). In order to minimize the 50 Hz network noise, shielding is best suited for our application. In perspective, we plan to improve this device by: Adding a system based on a microcontroller with a wireless communication module for remote field tests.

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