Acquisition and Conditioning of Electromyographic Signals for Prosthetic Legs

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***Abstract*— The Surface Electromyography (SEMG) is a technique used for many applications in different areas such as: Neurology, Rehabilitation, Orthopedics, Ergonomics, Sports, etc. [15]. In the last years, this technique has led to great research, and several groups of researchers throughout the world have made inroads in the field of the electromyography applied to the myoelectric prostheses control. This project aims to detail the stages of amplification and filtering of a myoelectric signal, as well as to check the device's function for certain muscles of the lower limbs; as the project's first stage, the completed tests were made with obtained data in healthy subjects. For the circuits' design and implementation, components of easy acquisition and existents in the environment, were used, contributing with the technological development of the country.**

Keywords*— Surface Electromyography; Prosthesis; Rehabilitation, Orthopedics; Myoelectric signal; Acquisition and conditioning; Lower limbs; Detection circuit

I. Introduction

According to the world report on disability published by the World Health Organization (WHO), more than one billion people, or, 15% of the world's population, live with some kind of disability [1]. In Ecuador, according to a national record of disabilities published by the Ministry of Public Health (MPH), 416.177 people suffer from some kind of disability, of which 203.880 have physical disability [2]; today the majority of people with physical disability in Ecuador have access to passive prostheses (cosmetic), which partially solve the problem. Few people use active prostheses (functional) with some mechanism of operation (mechanical), robotic prostheses or myoelectric prostheses.

Research related to the use of electromyography, such as: spectrum analysis of surface electromyographic signals [3], myoelectric rehabilitation systems [4] [5], man-machine interface using superficial electromyography [6], systems of recognition and detection of myoelectric signals [7] [8], among others; they demonstrate the usefulness of the electromyography in the robotic prostheses' control, nowadays it is possible to find researches that link electromyography with active prostheses, such as: electromyography sensor based on the control of a hand exoskeleton [9], classification of the fingers' movements for the control of a prosthesis [10], recognition of an electromyographic signal for the control of a transfemoral prosthesis [11], among others. All of these systems involve the use of SEMG for their non-invasive and easily applicable characteristic, unlike the invasive electromyography that uses needle electrodes or wires, which are used in medical applications for the study of disorder of the muscular system.

The acquisition and conditioning of myoelectric signals in recent years has experimented a major breakthrough with the development of technology [12]. The need for the use of prostheses in persons with physical disability, in addition to the study and evaluation of the patients with muscular diseases, make this topic of great interest to researches. The design of a device of superficial electromyography, elaborated with elements of low cost and available in Ecuador, will allow innovating and improving the nation's technological area, through the design and development of myoelectric prostheses.

II. Electromyography

The electromyography is the study of the muscular function through the electric signals sent by the muscles [13].

The functional unit of a muscle is called a motor unit; it is composed of an alpha motor neuron and all of the muscle fibers that are linked by axonal branches of the motor neurons [14]. This generates an action potential that shows the activity in the muscle fibers due to the muscle contraction [15] [16].

To acquire these bioelectrical signals it is necessary to use sensors known as electrodes, which can be invasive and non-invasive. Among them are the superficial and the ones of needle or wire respectively. Each one of these electrodes is applied in different areas and depending on the type of study. To determine the appropriate type of electrode in the implementation it is necessary to employ a selection procedure [13] [14]. For its location, the recommendations established by the Project SENIAM will be followed [15].

The main features of the SEMG signal are the following:

- The action potentials generated in the muscles have a peak-to-peak value typically in the range of one of the few micro Volts to 5 mV [13].
- Range of frequency for surface electrodes: 20-500Hz [13] [14] (see Fig. 1).
- Importance signal between: 50-150 Hz [17] [18][19].

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- Noise in the signal caused by muscles near the electrode's detection area [17] [20].
- Noise generated by components running at 60[Hz] [4].

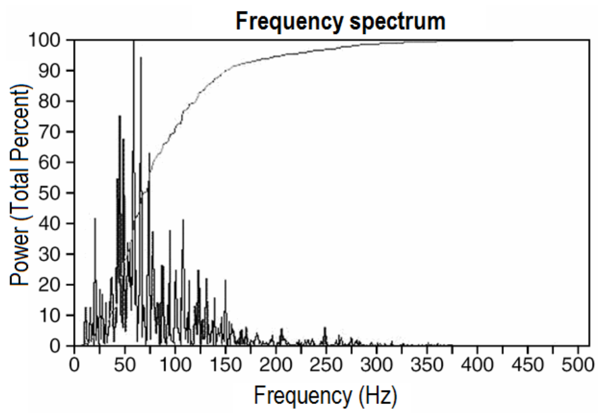

Fig. 1. Frequency spectrum of an electromyographic signal, obtained by the Fourier transform. [26]

III. Design of the Acquisition and Conditioning Stages

For the conditioning of the myoelectric signal, it is necessary is necessary the application of filters, which allow to obtain a signal with a low level of noise and at the same time, eliminating or mitigating the unwanted frequencies in the acquisition of the myoelectric signal. There are many sources of noise, some of them are: skin, electromagnetic fields, motion artifacts and other electrical appliances that may be in place during registration. Other sources may be interference with the network, at 60 [Hz] (in other countries 50 [Hz]) and the phenomenon of crosstalk, caused by adjacent muscles to the area of importance. Noise removal is important to have a good quality myoelectric signal.

The general block diagram of the system is shown in Fig. 2:

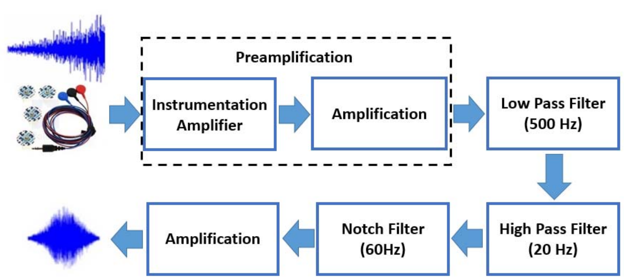

Fig. 2. Device block diagram

An AD620 instrumentation amplifier is used for the pre amplification stage, this device amplifies the muscles' weak signals, repeatedly (gain), until a level of voltage suitable for its registration is obtained. Its main features are: an excellent performance in DC, rejection ratio to the high common mode (CMRR) and a low level of noise [21]. According to Basmajian and De Luca (1985) [13], the minimum CMRR must be of 85 [dB], the input biasing should be as low as possible (normally<5 [fA]) and the input electrical impedance should be as big as possible (around [GΩ]).

To protect the patient from any electrical damage, a feedback circuit proposed by the manufacturer is used [22], known as right leg circuit (see Fig.3) which is normally used to submit electrocardiogram signals (ECG) [4]. For this circuit it is required to modify the position of the right arm (RA) and left arm (LA) electrode, by placing these on the muscle of interest, and the right leg (RL) electrode was placed as the electrode of reference, which was installed in the ankle based on the recommendations of the SENIAM (see Fig. 3).

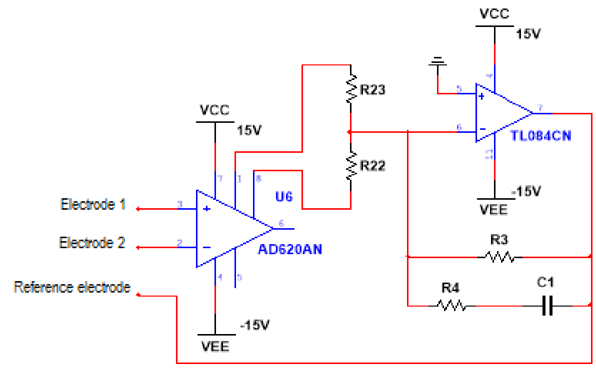

Fig. 3. Intergrator circuit

To reduce the tension of offset in the instrumentation amplifier output and prevent the device from saturation, an integrator circuit was designed (see Fig. 4).

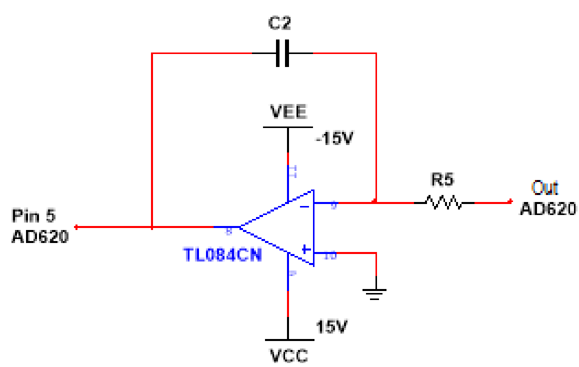

Fig. 4. Integrator circuit

Once the myoelectric signal is amplified by the AD620, with a minimum income to not increase the noise in the signal, an additional amplification stage is required; which is achieved with an amplifier circuit in a non-reversing configuration (see Fig. 5), in order to obtain the appropriate amplitude of the signal to be filtered.

A TL084 integrated circuit was used for the configuration of filters and different stages of amplification [23]. The used filters are Butterworth type, due to their main characteristics such as: the bandwidth tends to be maximally flat, has decreasing response of frequency and a mild attenuation at low frequencies [6].

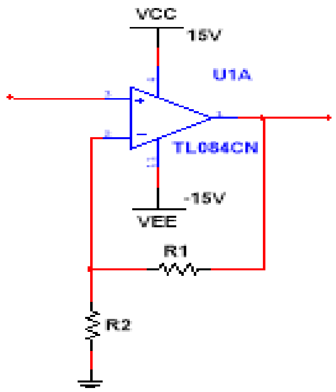

Fig. 5. Non-reversing amplifier

To eliminate the DC component, the phenomenon of crosstalk, caused by muscles adjacent to the area of detection of the electrodes and noise caused by the movement of the electrodes and wires, in addition to set the minimum limit of frequencies in which an EMG sign will be found (Fig. 1), a fourth-order high-pass filter is implemented (see Fig. 6) with a cut-off frequency of 20 [Hz], since these interferences are between 0 to 20 [Hz] in frequency ranges [24].

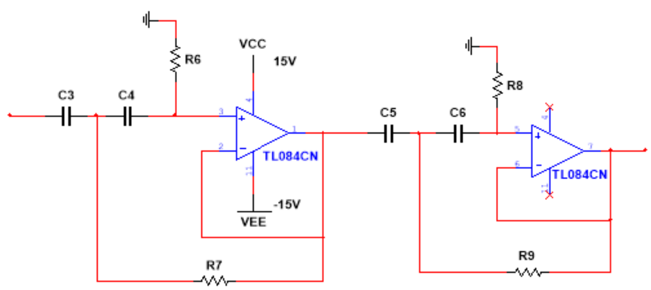

Fig. 6. High-pass filter

To limit the frequencies higher than 500[Hz], thus establishing the upper limit of the range of EMG signals according to (Fig. 1) a fourth-order low-pass filter must be used (see Fig.7).

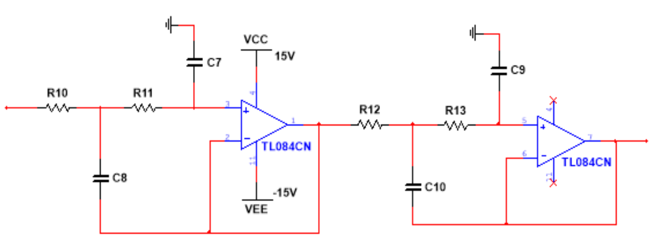

Fig. 7. Low-pass filter

To eliminate the noise of elements or alternating current devices, a band-rejection filter of a 60[Hz] narrowband, with a 6 [Hz] bandwidth (see Fig.8). This filter attenuates the frequencies within the bandwidth, avoiding causing noise in the signal because of the frequency [13].

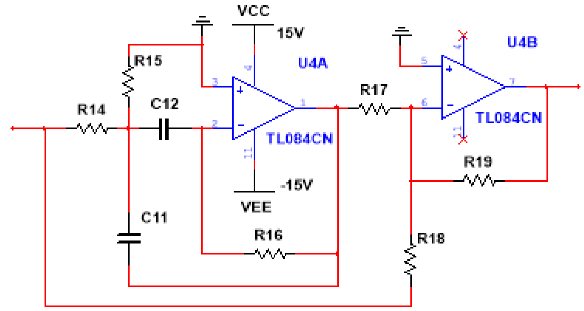

Fig. 8. Band-rejection filter.

To establish the order on the 60[Hz] notch filter, the signal without said notch filter is analyzed, then with a second-order notch filter and finally with a fourth-order notch filter [25].

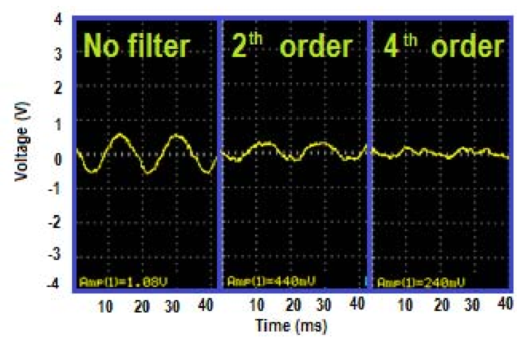

Fig. 9. Response of the system by applying filtering of signals with a 60[Hz] frequency range

Based on (Fig. 9) it is determined that the higher the order of the filter, there is a greater attenuation of unwanted signals with 60[Hz] frequency range.

For the final amplification of the signal, an amplifier circuit in non-reversing configuration was designed (see Fig. 10).

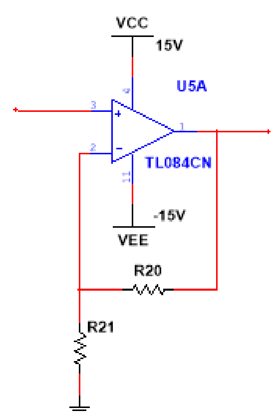

Fig. 10. Non-reversing amplifier

IV. Device Operation Experimental Tests

Record various data of SEMG signals from the major muscles of the lower limbs. To do this, a good preparation of the patient and the application of good technique is important. It is also necessary to monitor possible errors in the interpretation of the records. The SEMG for this project involves two phases (preview and registration phase) which is set out below [12] [26]:

Preview phase

1. Preparation of the skin. The impedance must be reduced in order to obtain a quality of an electrical signal. To do this, shaving the hairs and rub the skin with an abrasive gel to reduce the layer of dry skin or dead cells is recommended. Also remove the sweat through cleansing of the area with alcohol [12].
2. Placement of the electrodes. A good location of the electrodes is essential to obtain a correct signal. The location, whenever possible, in the middle line of the muscle belly is considered appropriate; in other words between the mio-tendinous junction and the motor point. It is very important keep the same electrodes location to all experiment since the registered signal varies depending on the area of muscle on which are placed the electrodes [12]. It is also convenient to maintain a distance inter-optimum electrode, separated by one or two centimeters of distance (Fig. 11 and 13).

Registration phase

1. Obtaining the maximum voluntary contraction (MVC). It is necessary for the normalization of the paths obtained with respect to the maximum interest muscle activity. To this end, three maximum isometric contractions of 6 seconds are usually obtained with a short break between them, which will serve to calculate an average of the three intermediate periods. Thus, you can compare between not absolute values [12].

The results of tests carried out by the lateral gastronemio (see Fig.11) and rectus femoris muscles (see Fig.13), were acquired using an oscilloscope and through communication with a PC were taken multiple records of the behavior for further analysis (see Fig.12 and Fig.14).

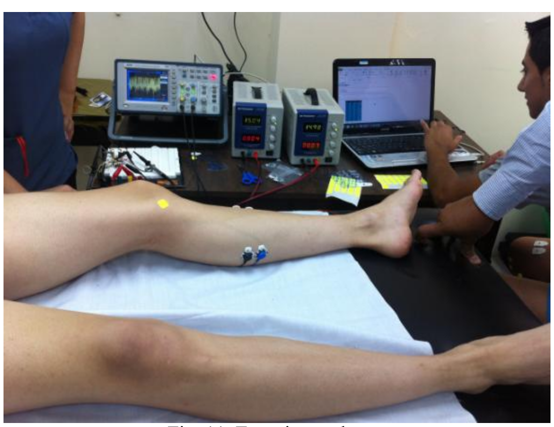

Fig. 11. Experimental tests

To register the lateral gastrocnemius muscle SEMG signal, the electrodes should be placed in the most prominent part of the muscle in the direction of the leg [11] (see Fig. 11).

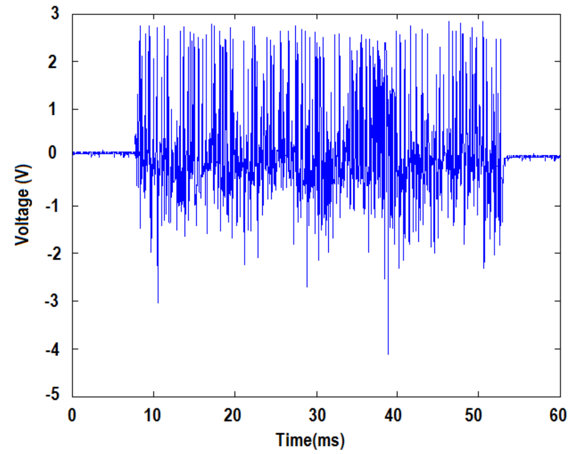

Fig. 12. Gastrocnemius muscle myoelectric signal obtained during muscle contraction.

To register the rectus femoris muscle SEMG signal the electrodes should be placed in 50% of the line that runs from the anterior iliac spine higher than the top of the head in the same direction as the line [11] (see Fig.13).

Fig. 13. Electrodes location at rectus femoris muscle

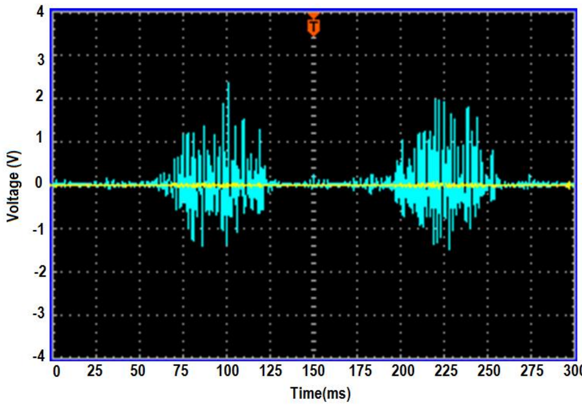

Fig. 14. Rectus femoris muscle myoelectric signal during a muscle contraction

V. Conclusions

Signals myoelectric generated by muscles at rest or in activity, despite having small voltage levels can be amplified and measurable using appropriate equipment, this information can be used to diagnose diseases of the muscular system and special applications in prosthesis.

The location and proper orientation of the electrodes to record the signal differential (of interest) is of great importance, since the extent and quality of the signal depends on it and at the same time the common mode signal can be rejected efficiently by the instrumentation amplifier.

The pre amplification of the instrumentation amplifier gain should not be so high since you may miss certain values of the signal of interest and this could increase the noise of the signal, which would affect the characteristics of the EMG signal.

The skin preparation before a record of the SEMG signal is necessary, because the skin has high impedance and certain impurities that can cause bad contact between the electrode and the skin.

The variation of the frequency and the amplitude on a surface of record is affected by the existing tissue between the source signal (adjacent muscles) and registration (skin surface) electrodes.

VI. Future research

Future research are to conduct a thorough analysis of the myoelectric signals in amplitude and frequency; also a comparative matrix of data signals from EMG will develop in people of Ecuadorian nationality of different age and genre; to do this is to improve the acquisition and preparation of the EMG signals, specifically in the use of electrodes. On the other hand, disposable surface electrodes used for this project, can be replaced by reusable electrode of dry surface [6], which will guarantee a greater selectivity and recruitment of myoelectric signals. Another improvement that can be considered is to change the devices used in this project by surface mount components to reduce the size of the circuit, and improve certain characteristics of the signal, reducing the noise.

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