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Simulator of surface electromyography
Simulador de electromiografía de superficie

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ABSTRACT

The study of electromyographic signals at the time of a global pandemic has been reduced, since the possibility of attending a bio signal laboratory has been null for some people, in this article a surface electromyography simulator (EMGs) is proposed with pedagogical application, this is carried out to characterize a real EMG signal, obtaining characteristics characteristic of it, in the domains of time, such as amplitude and frequency, as the harmonics are signal, noise and randomness, so that in this way, its behavior can be emulated through 21 harmonics (11 for the state of contraction and 10 for the relaxation), using different circuits composed in principle by operational amplifiers, an sEMG signal with behavior similar to a real one is obtained that can be used in signal processing or observing behavior without attending a laboratory.

RESUMEN

El estudio de señales electromiográficas en tiempo de una pandemia mundial ha sido reducido, puesto que la posibilidad de asistir a un laboratorio de bioseñal ha sido nula para algunas personas, en el presente artículo se propone un simulador de electromiografía de superficie (sEMG) con aplicación pedagógica. Para esto se caracterizó una señal de sEMG real, obteniendo características de amplitud y frecuencia para los eventos relajación y contracción voluntaria de un musculo. Las señales características de relajación y contracción se simularon mediante señales periódicas, así como los ruidos más frecuentes que contaminan la señal (artefactos por movimiento, 60Hz de la línea eléctrica y transmisiones de radio). Las señales constan de 21 armónicos (11 para el estado de contracción y 10 para el de relajación), sumadas y acondicionada con amplificadores operacionales. Las señales de sEMG obtenidas, presentan características similares a las señales reales. Esta simulación de EMG puede ser utilizada en el desarrollo de dispositivos que necesiten de la captura de señales EMG.

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1. Introduction

Physical rehabilitation has its beginnings in the Chinese empire, where it was used as therapy based on movements of the Cong Fu. The Greek doctor Herodicus developed a series of exercises based on gymnastics for the prevention and/or treatment of diseases in the fifth century. Doctor Romano Galen described interventions to rehabilitate military injuries in the second century after Christ. During the Middle Ages, the philosopher and physician Maimonides highlighted the Talmudic principles of healthy exercise habits, as well as diet, methods of preventive medicine. In 1569, the medical philosopher Mercurialis promoted gymnastics as a method of both prevention and rehabilitation, calling it "the art of gymnastics". In the 18th century Niels Stenson explored the biomechanics of human movement and Joseph Clement in 1780 promoted the value of movement as an alternative to rest after surgery [1].

One of the sciences that has been developed in conjunction with rehabilitation is electromyography (EMG). The EMG is a study in charge of sensing the electrical signals of the muscles in two different events, resting and active, said technique can be performed in 2 ways, directly or indirectly, with the first being invasive electromyography, using needle electrodes inserted directly into the muscle to be analyzed, the second, is surface electromyography, is performed from electrodes placed on the surface of the skin, which channel and add temporarily and spatially the activation of the motor units at the time of contracting the muscle to be analyzed [2 - 4].

The use of technologies during the last decades has been widely developed and is being applied to the diversity of medical scenarios, these have allowed generating multiple methodologies and techniques used for physical rehabilitation, mainly to significantly improve the quality of life of patients, improving their optimal level of physical, sensory, intellectual, psychological, and social performance [5].

Currently medical technology has robust equipment, resulting from a process of refinement in the design, development, manufacture, and testing of operation. However, in the field of rehabilitation, equipment capable of automatically diagnosing and evaluating the physical progress of a patient in rehabilitation is still not very popular [6]. To evaluate each damage of patients, it is important to verify the electrophysiological state, through the EMG, this is a diagnostic test that allows to identify the neuro-muscular state according to standard healthy predetermined values [7].

During the 2020 pandemic by COVID-19 impact on society at large. Universities had to restrict access to laboratories, and classes were replaced by telepresentiality. Programs such as Biomedical Engineering perform laboratories to acquire, condition, and process biosignals. Given the impossibility of using laboratories and being in contact with other people, this study proposes a simulator of sEMG signals with characteristics similar to real sEMG signals, as an alternative in the process of training professionals who wish to design future medical devices, focused on the physical rehabilitation line [8].

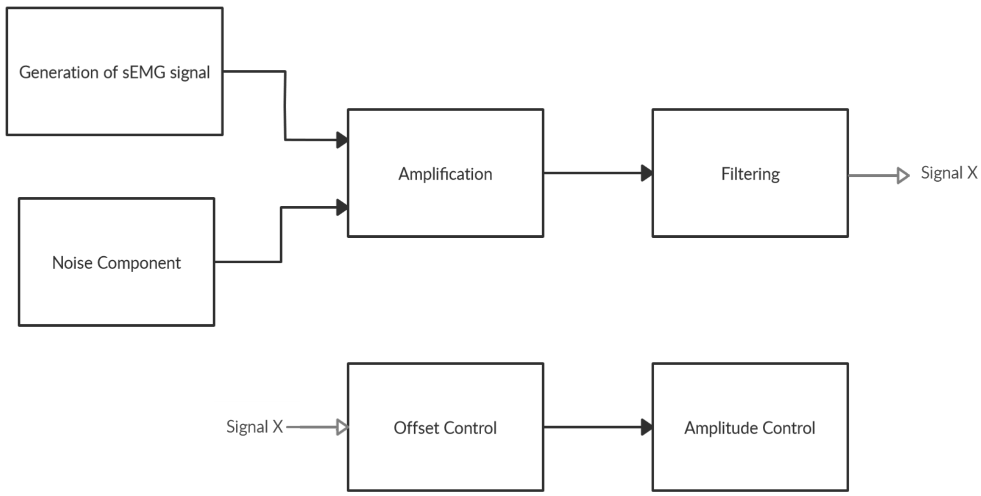
2. Materials and Methods

An EMG signal emulator was designed taking into account real characteristics from signal EMG (amplitude, frequency, noise, among others). This section describes all the stages of generation (signals in mV), amplification, filtering and conditioning, to achieve the control of a sEMG signal in a range of 5Vpp.

3. Simulation of sEMG

Based on a real signal acquired under controlled conditions, signal 21 harmonics are extracted (11 for contraction and 10 for relaxation), real factors are considered, as are different types of noise: artifacts, electrical and environmental networks of 1 Hz, 60 Hz and 2 kHz, respectively. The simulation of sEMG is followed by 2 stages: preamplification with a gain of 10820 times and a filtering consisting of 2 parts, 1) it is a 10 - 500 Hz band-pass filter and 2) a 60 Hz Notch filter. Finally, it has 2 control circuits, the first of these is an offset level control and the last is a signal amplitude control.

Figure 1. sEMG simulator block diagram.



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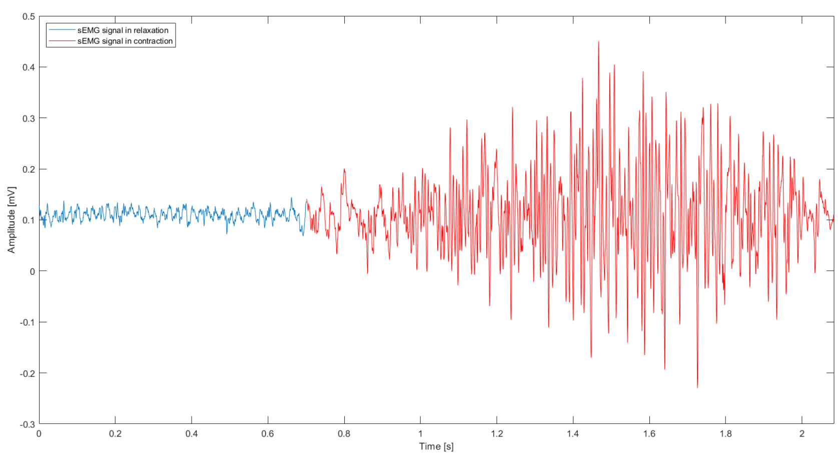
3.1. sEMG signal

Surface electromyography (EMGs) is the measurement of the sum of the action potentials produced by motor units (MUAPs) in a muscle contraction [9,10], these potential differences are sensed by electrodes placed on the skin [11]. The EMG measures the signal with an amplitude of its activity in microvolts, while the EMG can have an amplitude in the order of millivolts [2,12, 13].

In this study, a signal acquired with a sampling frequency of 2000 Hz was used and processed using Matlab software. Figure 2 shows the sEMG during the relaxation and contraction of the flexor muscle of the wrist.

Figure 2. Graph of the original sEMG signal from the data.



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Each state in muscle activation has its own characteristics, for relaxation it has average amplitudes of 0.109 mV, maximum of 0.144 mV and minimum of 0.068 mV, a spectrum of frequencies in a range of 10 - 100 Hz (Figure 3). The average amplitude of contraction is 0.118mV, maximum amplitude 0.450 Vm and minimum amplitude -0.229 Vm. The Matlab pwelch function is used to plot the power spectral density (normalized values) of the original sEMG signal (Figure 3).

Figure 3. Graph of the spectra of the original signal in the 2 events.

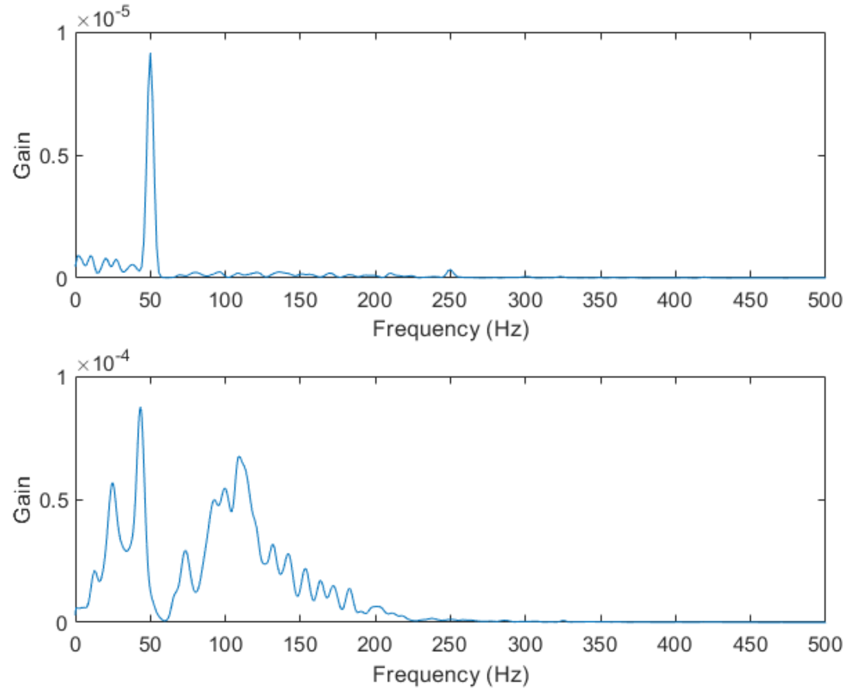

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Table 1 shows the harmonics extracted based on the spectrum of the actual signal. These harmonics will be added with an operational amplifier in inverting summing configuration, noting that each of them has a random angular phase shift between 0° and 180°, this to represent randomness in the components of the original signal. A switch was incorporated, which generates the possibility of exchanging between the state of relaxation and contraction, simulating a voluntary contraction in an electromyography study.

Table 1. Data from signals used in the sEMG simulator for contraction and relaxation.

Signals	Frequency[Hz]	Amplitude[mV]
1	10	0,066
2	20	0,133
3	40	0,183
4	60	0,216
5	80	0,233
6	100	0,226
7	120	0,19
8	140	0,113
9	160	0,066
10	180	0,04
11	200	0,023

Signals	Frequency[Hz]	Amplitude[mV]
12	10	0,022
13	20	0,044
14	30	0,061
15	40	0,072
16	50	0,077
17	60	0,075
18	70	0,063
19	80	0,037
20	90	0,022
21	100	0,013

Source: own.

3.2. Signal processing system

3.2.1. Preamplification

The preamplification stage is carried out through an instrumental amplifier, since the second stage of this is differential, causing some of the noise to be removed without going through the filters; starting from the general voltage gain equation for this circuit:

$$A_V = \left(1 + \frac{2R_f}{R_o}\right)\left(\frac{R_2}{R_1}\right) \quad 1$$

Donde R_f is 270 kΩ, R_o, R_1 1 kΩ and R_2 200 kΩ

An amplification factor of approximately 10820 times

$$A_V = \left(1 + \frac{2(270\ k\Omega)}{2\ k\Omega}\right)\left(\frac{200\ k\Omega}{2\ k\Omega}\right) = 10820$$

3.2.2. Band pass filter

2 amplifiers are used in the configuration of non-butterworth filters active of 2 do order for each of the parts that make up the filter (filters pass high and passes low), the cut-off frequencies are calculated from the characteristic equations for each case:

3.2.2.1. High Pass Filter, must have a cut-off frequency of 10 Hz

$$F_l = \frac{1.414}{2\pi\, R_l\, C_l} \quad 2$$

Where R_l is 10 kΩ and Cl is 2.2 µF.

$$F_l = \frac{1.414}{2\pi * 10\ k\Omega * 2.2\ \mu F} = 10.22\ Hz \quad 3$$

Where R_h is 2.2 kΩ and Ch is 0.1 µF.

$$F_h = \frac{0.707}{2\pi * 2.2\ k\Omega * 0.1\ \mu F} = 511.46\ Hz$$

3.3. Notch Filter

A notch filter in second-order active T-bridge is implemented to remove the 60 Hz component from the frequency spectrum, since this harmonic is the frequency of the Colombian electricity network.

$$A_V = \frac{1}{2\pi\ RC} \quad 4$$

Where R = 5.6 kΩ, C = 0.47 µF, RR = 2.7 kΩ and CC = 1 µF

$$A_V = \frac{1}{2\pi * 5.6\ k\Omega * 0.47\ \mu F} = 60.46\ Hz$$

3.4. Offset Control

An operational amplifier in non-intrusive adder configuration is used to perform algebraic sums of the DC level of the signal processed in the previous stages, to establish it in a range between 0 and 5 V (Vcc) for a later digital analog conversion. Where R are resistors of 300 kΩ each one, and the potentiometer of 10 kΩ.

3.5. Signal amplitude control

An operational amplifier is used in non-investment amplifier configuration, with a 20 kΩ potentiometer and an R = 10 kΩ for the purpose of being the last analog processing stage of the signal, before moving to a digital analog conversion process, having as a gain equation:

$$A_V = 1 + \frac{P}{R} \quad 5$$

Where P is the potentiometer and R is the resistance

3.6. Noise components

Fundamental noise components are added to the original signal, these harmonics are:

3.6.1. Noise of 1 Hz

This component is added to emulate the device (noise produced by body movement).

3.6.2. Noise of 60 Hz

The 60 Hz harmonic is added because it is the frequency to which the Colombian electricity network works.

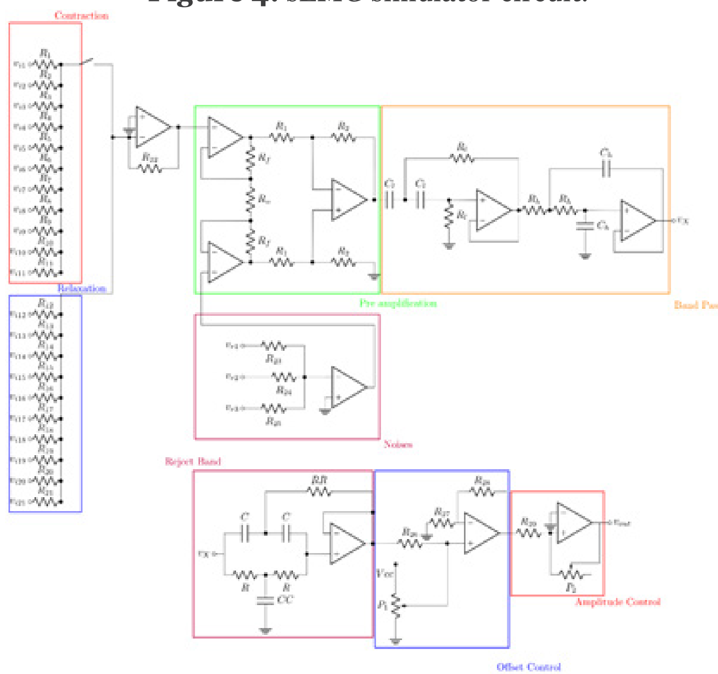
3.6.3. Noise of 2 kHz

This component reflects the noise of environmental conditions, such as the speech of people near the device, external sounds, radio transmissions, among others.

4. Results

Amplitude and frequency components, seen in Table 1, are extracted to emulate the behavior of the EMGs, from which a surface electromyography simulator is developed with real characteristics, both in the domain of time and frequency, starting from harmonics taken from a real signal, with the possibility of exchanging between the states of relaxation and contraction, emulating the behavior of voluntary muscle contraction. Figure 4 shows the complete circuit developed and the main stages of the circuit are labeled.

Figure 4. sEMG simulator circuit.



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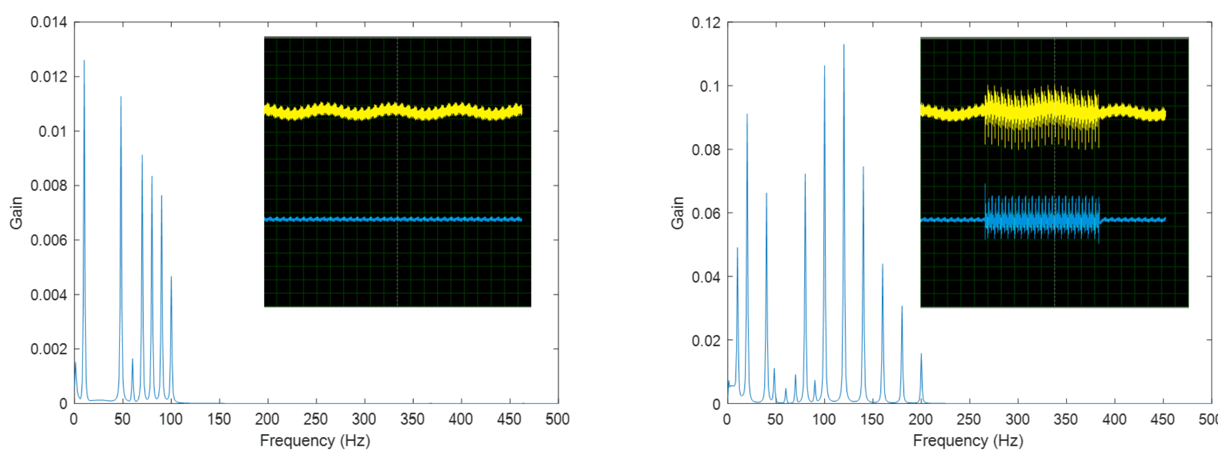
From the circuit in Figure 4, an analysis can be generated between the actual signal and the simulated signal in the time and frequency domains, where a correlation between the two can be shown in harmonics representative of each of them in the two events of an electromyographic signal, so that the use of an electromyographic signal from a simulated signal can be checked for a pedagogical purpose.

Figure 5. Resulting signals in time and frequency domains.



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5. Conclusions

The circuit obtained allows the interested in the development of medical devices, in the rehabilitation line, can continue their circuital designs, without the limitation of having a subject to carry out tests, move to electronics stores to acquire electrodes, or have a commercial simulator high cost. This proposal makes it possible to generate synthetic sEMG signals in electronic simulators in an easy and understandable way. These simulated sEMG signals consider voluntary contraction by means of a switch, thus it can be considered subsequent stages of rectification and envelopment, common processes in devices that capture and process real EMG signals. During the time of confinement and through this proposal it is possible to continue with the specific subjects of subjects such as bioinstrumentation, digital electronic sensors and analog applied to biomedical measuring instruments among others.

Students of related careers in the biomedical field have a resource that can be enhanced, can be used to obtain surface electromyography signals without having a test subject given the contingency of the moment, that you should not go to a laboratory to capture that signal with a patient, but can continue your designs from that simulated signal; to create filters, or other types of conditioning stages to aid in device design.

The designs of the devices cannot be slowed down by the COVID-19 pandemic, the dynamics of both learning and design must be continued because there is few related equipment in the field of both physical rehabilitation and electromyography capture, although commercially exist. This event that is happening in society cannot become a setback for the creation of new technologies oriented in the field of rehabilitation and biomedical or any related field.

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