Low Cost Electromyogram and Electrical Muscle Stimulator

Montenegro-Monroy, Hector-Miguel
Researcher for the Catedras CONACyT program assigned to the Faculty of Engineering, Autonomous University of Mexico State
Toluca, México.
hmontenegrouaem@gmail.com

Martinez-Mendez, Rigoberto
Portillo-Rodriguez, Otniel
Faculty of Engineering, Autonomous University of Mexico State
Toluca, México

***Abstract*— Muscular system function could be affected by neurological disorders such as cerebral strokes, injuries and neurological disorders. Healthcare experts usually relay on their experience to diagnose and recommend a specific treatment. However, there exist technological devices capable to measure the electrical activity in the muscle improving the diagnostic; also there exist devices capable to aid on the rehabilitation of the muscle known as Transcutaneous Electrical Nerve Stimulators. Nevertheless, these devices are only available on laboratories or well-equipped clinics due mainly to the relatively expensive cost. This manuscript presents a low-cost device capable not only to measure the electromyographic activity but also is capable to stimulate the muscles in order to improve the rehabilitation of the muscle. Data could be visualized on a generic computer using the sound card as a data acquisition. This paper presents the development of such devices and preliminary results.**

***Keywords—EMG, Muscular Electro Stimulation, Rehabilitation, Fatigue* assessment**

I. Introduction

The muscular system, responsible for the movement of the human body could be affected by aging, injuries, neurodegenerative diseases, surgeries, genetic disorders, etc., [1], [2], [3]. Such affections must be diagnosed and treated as soon as possible in order to reduce other damages on the skeletal system and, in general, to improve the quality of life of the patient [4].

There exist electronic devices capable to detect electrical signals generated by the muscular activity, allowing to the physicians and healthcare experts to measure and diagnose the origin of the disorder [5], [6]. Also, these devices are typically used to evaluate the results of the treatment for the rehabilitation of the patient by measuring the muscle electrical activity and comparing the results with prior measurements [2], [4], [7]. The technique for evaluation and recording of the muscular activity is known as Electromyography (EMG) and the device used to acquire the EMG signals is an electromyograph [8]. The EMG signals, also known as biopotentials are acquired attaching electrodes to the body directly on the muscle of interest. Electrodes can be divided on two types: needle electrodes, designed to be inserted on the muscle, allowing to measure very specific zones, and surface electrodes, attached over the skin, directly above the muscle of interest. Needle electrodes are used for very specific measurements and avoided when possible due to the discomfort caused to the patient [9], [10]. EMG devices are usually available in laboratories and well equipped clinics, due mainly, to the relatively elevated cost.

The EMG is an important tool for diagnosis of neuromuscular diseases and motor control disorders [6], [8]. The EMG was first used in 1929 by Adrian and Bronk and the first clinical report for neurological disorders, using EMG was reported by Weddel in 1944 [11]. Nowadays, many physicians expert in neurological disorders use EMG for diagnosis. Once the physicians diagnose the problem, related to the muscular activity, the treatment is initiated depending on the origin of the problem. Many times, the muscle should be stimulated externally in order to improve the healing process. Electric stimulations have been proved as an effective technique to treat several problems such as chronic pain, osteoarthritis, tendinitis, bursitis, fibromyalgia and even pain caused by cancer. Devices used for electric stimulation are known as TENS (Transcutaneous Electrical Nerves Stimulators). These devices are considered safe [4], [5].

Both devices EMG acquisition system and TENS are commonly found separately. The EMG systems are usually employed by physicians to diagnose and TENS are generally used by therapist in order to apply the treatment. However, due to this separation, therapists normally apply only the treatment without make a closer follow up of the patient advances.

This document describes a low-cost system capable to measure and visualize EMG and to apply electric stimulation to the affected muscles. Furthermore, a preliminary test measuring fatigue using the proposed device is presented This prototype is designed mainly for didactic purposes for biomedical engineering students and others interested on these techniques.

II. Material and Methods

A. EMG subsystem

The EMG acquisition is based on the block diagram shown in Fig. 1. It consists in a differential amplifier stage, a high pass

978-1-5090-1775-1/16/$31.00 ©2016 IEEE.

filter followed by a preamplifier stage and finally a low-pass filter stage. The signals are acquired by using the sound card of a generic computer (not show on the figure) and displayed on the screen using freeware software (*Visual Analizer*™) for data storage and signals analysis.

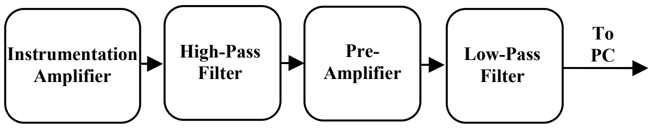

Fig. 1 Simplified diagram of the EMG amplifier.

For this prototype, Ag-Cl disposable electrodes are proposed, mainly because they are widely available and cheap. Disposable electrodes are connected to the instrumentation amplifier but not directly, first, a voltage limiter was instrumented in order avoid possible damages on the circuit due to high voltage inputs that could come from the electric stimulator.

The instrumentation amplifier employed in the initial stage is the AD620 which is a low cost integrated circuit very used for bioinstrumentation applications. According to literature [12], the typical amplitude of an EMG signal is from 0 – 10 mV with a bandwidth of 20 Hz to 500 Hz using surface electrodes. In the other hand, the nominal voltage level for computer sound cards in the line level input is about 0.2 V with a maximum of nearly 1 V and a bandwidth from 20 Hz to 20 kHz [13]. Taking this into consideration, the gain of the instrumentation amplifier is set to 50. A first order RC high-pass filter at 20 Hz is connected to the output of the first stage. The amplifier circuit following this stage is implemented by using a very low offset Amplifier OP07 (Analog Devices ™). The purpose of this amplifier is to obtain an extra gain in case the, the sound card of the computer could need more voltage but without exceed the maximum voltage that it could support, for this reason the gain can be varied from 1 to 2 times the input. Finally, a Butterworth 4th order low–pass filter was implemented as an anti-aliasing filter previous to the ADC stage on the sound card of the computer, and also to limit the bandwidth of the EMG signal. The cut-off frequency was selected at 500 Hz [5], [10].

The proposed system uses a single 9 V battery as power supply. The voltage of the battery is divided by two using a resistance voltage divider and an OPAM as a buffer (See Fig. 2).

Using this circuit it is possible to create a “virtual ground” for supplying voltage to the instrumentation amplifier and the filters stage which require a symmetric power supply.

Laboratory test were made to verify that the filtering and amplifying stages worked correctly, after that the EMG subsystem was connected to the line level input of a PC using a generic 3.5 mm audio stereo jack.
For visualization and analysis the software *visual analyser*™ was used. This software is a freeware intended for real time analysis using the sound card of any computer, allowing to use a common computer as a two channels oscilloscope, spectrum analyzer (amplitude and phase), frequency meter and voltage meter (true RMS and peak to peak voltage) [14].

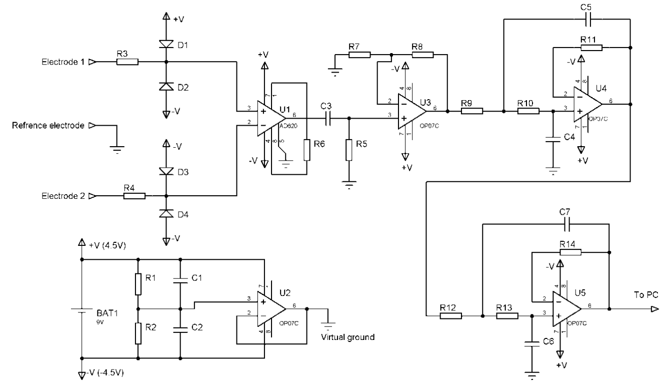

Fig. 2 EMG acquisition circuit

Fig. 3 shows an EMG signal acquired from the Biceps Branchii of a healthy subject using the developed system.

Since the software is capable to amplify the gain of the input signal and to change the sampling rate in prefixed values, for this test the input gain of the sound card was set to 1 and the sampling frequency was set to 3600 Hz. This sampling rate was selected because the immediately inferior value is 200 Hz and the immediately superior is 36000, thus 3600 Hz is the best choice [7].

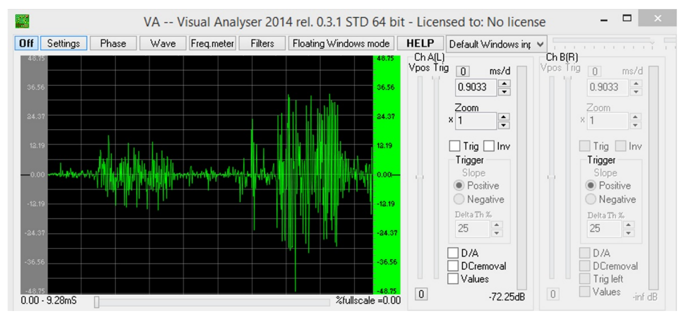

Fig. 3 EMG signal acquired using the prototype and visualized on the *Visual analyser*

B. *Muscular Electric Stimulation subsystem*

For the electric stimulation on the muscles, it is necessary a circuit capable to increase the low voltage provided by a 9V battery to a range between 40 and 80 volts necessary to stimulate the muscle correctly.
This part of the system was implemented using a DC-DC converter capable to amplify from 3V to 40 V. An IC MC34063 (ON semiconductor ™) was used for this purpose. Fig. 4 shows the circuit implemented for muscle stimulation. It uses the MC34063 to amplify the voltage and a H-bridge to switch the high voltage as necessary to form a waveform to stimulate the muscle. The H-Bridge was implemented using a L298 (ST microelectronics ™) integrated circuit. The pulses necessary to switch the H-Bridge are provided by a microcontroller PIC18F2550 (Microchip Inc.) not shown in the figure.

The voltage applied to the electrodes, attached to the skin for stimulation purposes, is monitored using the same microcontroller. Monitoring is done to avoid injuries on the patients. When a high voltage above the limits is detected, automatically the microcontroller shuts down the signals on the H-bridge avoiding injuries.

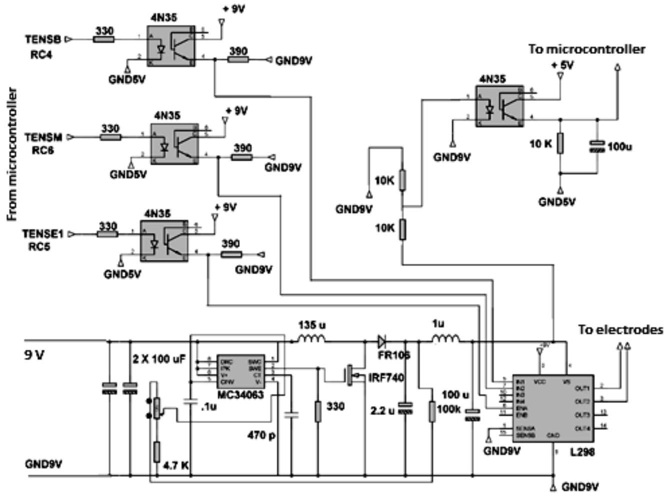

Fig. 4 Step-up circuit for muscle stimulation

Fig. 5 shows an example of the waveforms generated with the developed device. This test was performed as the majority of commercial devices report their voltage values, this is, attaching a 1 kΩ resistor to the output of the TENS wave generator as a load. This resistor value is typically used to mimic the impedance of the skin. It is important to know that without the 1 kΩ resistor, the output amplitude of the square signal is about 150 V.

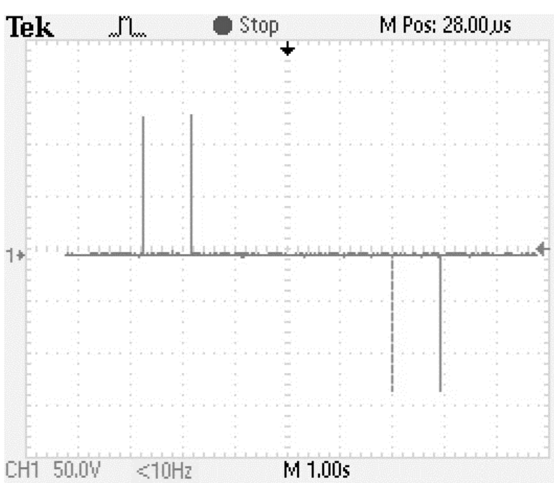

Fig. 5 Waveforms generated using the electro stimulator with a 1kΩ connected at the output.

III. RESULTS

In order to assess the capability of the device to correctly measure the EMG signals, a test for neuromuscular fatigue due to isometric constant force contraction was performed in one healthy subject. It is widely known that changes in the mean frequency (MNF) and median frequency (MDF) of EMG spectrum are associated with neuromuscular fatigue. Both parameters decrease when neuromuscular fatigue increases [15] when calculated for isometric constant force conditions. The MNF is the average frequency of the power spectrum and it is defined as its first order moment by equation (1).

$$MNF = \frac{\int_0^\infty \omega P(\omega)d\omega}{\int_0^\infty P(\omega)d\omega} \qquad (1)$$

Where P(ω) is the power spectral density (PSD) of the EMG signal and ω is the variable frequency.

The MDF is the frequency at which the spectrum is divided by two parts of equal power. It can be mathematically described by:

$$\int_0^{MDF} P(\omega)d\omega = \int_{MDF}^\infty P(\omega)d\omega = \frac{1}{2}\int_0^\infty P(\omega)d\omega \qquad (2)$$

The test consisted on the following steps in order to obtain MDFs and MNFs in non-fatigue and fatigue conditions.

1) To Measure maximum voluntary contraction (MVC) of elbow flexor muscle (Biceps Branchii) of the subject in isometric conditions with a force transducer (IMADA Inc., USA. Model: DS2-110).
2) The subject was asked to sustain a force of 30% of its elbow flexion MVC for 10 seconds (elbow joint at 90^o flexion).
3) In order to guarantee the neuromuscular fatigue, the subject performed a series of 40 repetitions of full range elbow extension/flexion movements at maximum velocity, using a load set at 30% MVC, each repetition was done, in average, each 2 seconds.
4) Again the subject was asked to maintain a force of 30% of its elbow flexion MVC for 10 seconds (elbow joint at 90^o flexion).

The EMG signal of the Biceps Branchii was acquired continuously during the steps 2 to 4 of the test using the prototype presented in this manuscript. The sampling rate was set to 3600 Hz in the acquisition software. The data was saved in a txt file and processed using Matlab 2015a (MathWorks Inc., USA). Analyzing data it was noted that the sampling frequency was not exactly 3600 Hz but a variable around this number. For this reason and to improve the processing time, the signal was resampled to 1024 Hz using cubic spline interpolation. 1024 Hz was chosen because it complies with the Nyquist theorem and is a number of samples to perform the FFT faster. In order to clean possible noise added by the sound card, the EMG signal was digitally filtered using a Butterworth bandpass filter from 20 to 500Hz. Only data acquired on steps 2) and 4) mentioned above, were separated and concatenated. Fig. 6 shows the portion of interest of the signal concatenated, notice that the amplitude of the signal is lower for the first 10 seconds (without fatigue) compared to the last 10 seconds (with fatigue).

This is expected because fatigued muscles recruit more motor units in order to maintain the same force; it is reflected on larger amplitude of the signal.

In order to assess the neuromuscular fatigue on the subject, the MDF and MNF were calculated over one second time-windows. The PSD was estimated using the Fast Fourier Transform (FFT) algorithm.

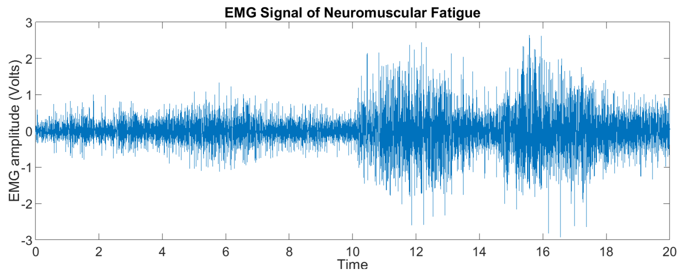

Fig. 6. EMG signal of neuromuscular fatigue. First ten seconds: non fatigue condition, last ten seconds: fatigue condition.

The MDFs and MNFs obtained are displayed in Fig. 7. Notice that it is possible to cluster their values in two groups. The first group (non-fatigue condition), are the values obtained for the first ten second and the second group is the rest of the test (fatigue condition). It can be clearly seen that for fatigued muscles the MNF and MDF values are reduced compared to non-fatigued muscles, as expected according to literature.

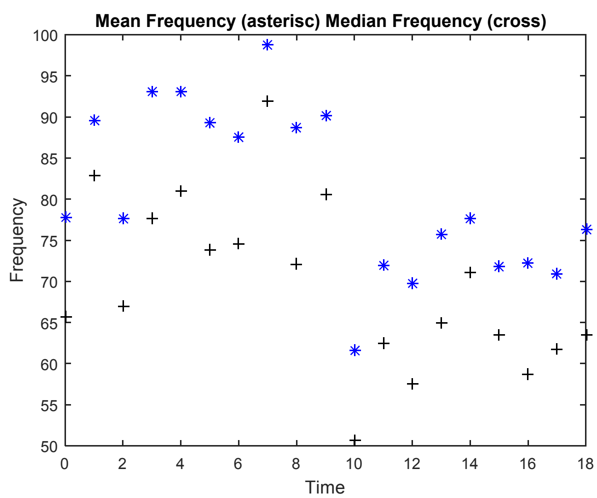

Fig. 7 MNF and MDF frequencies for fatigue and non-fatigue conditions. Frequency [Hz], Time [seconds].

IV. CONCLUSIONS

The prototype of an EMG acquisition system and Electric Muscle stimulator was designed and developed. Preliminary tests are presented. In order to evaluate the usefulness of EMG acquisition, a fatigue test was evaluated using the EMG signals acquired with the presented prototype. Preliminary results allow us to conclude that our prototype is useful. Furthermore, the prototype is easy to implement, and the construction cost is around $50 USD. In other hand, although the presented device was designed mainly for didactic purposes, authors believe that it could be useful for healthcare professionals by making some improvements on the robustness of the prototype.

ACKNOWLEDGMENT

Authors would like to thank to SEP - CONACyT for financial support for the development of this project.

REFERENCES

[1] P. F. Chinney. Muscle diseases in. Goldmans's Cecil Medicine. 24th ed. Philadelphia, PA. Elsevier Saunders. Chap 429. 2011

[2] D. Farina, D. Falla. Effect of muscle-fiber velocity recovery function on motor unit action potential properties in voluntary contractions. Publmed 2008; Vol. 37(5) 650-658.

[3] D. C. Preston, B. E. Shapiro. Electromyography and Neuromuscular Disorders: Clinical-Electrophysiologic Correlations, 3ed. Elsevier. 2012

[4] A: Sahoo, V. C. Pandaya. A brief review on TENS. Electrical, electronics, signals Communication and optimization (EESCO) International conference. IEEE conference publications. 24-25 January. 2015.

[5] R. A. Cooper, H. Ohnabe, D. Hobson. An introduction to rehabilitation engineering (series in medical physics and biomedical engineering). Taylor & Francis Group. 1st ed. 2006.

[6] A. Arul-Selvan, "Single-fiber EMG: A review" Ann Indian Acad Neurol. 14(1): 64–67. Jan-Mar. 2011.

[7] J. D. Bronzino. Biomedical Engineering Fundamentals, The Biomedical Engineering Handbook. 4ed. CRC pres. 2015.

[8] Merletti, Roberto "Electromyography - Physiology, Engineering, and Noninvasive Applications". Editado por: Merletti, Roberto; Parker, Philip © 2004 John Wiley & Sons

[9] A. I. Semciw, T. Pizzari, R. A. Green. Technical application and the level of discomfort associated with an intramuscular electromyographic investigation into gluteus minimus and gluteus medius. Gait & Posture, Science Direct. Vol. 38, issue 3. 157-160. 2013.

[10] J. G. Webster. Medical Instrumentation Application and Design. Willey. USA. 4th ed. 2009.

[11] R. Alvarez, E. Medina. La neurofisiología en el estudio de las enfermedades neuromusculares, desarrollo y limitaciones actuales. Rev Cub Med Mil. 2004, vol.33, n.3, pp. 0-0. ISSN 1561-3046

[12] De Luca Carlo J., "Surface Electromyography: Detection and Recording". Delsys Inc., 2002. Available: http://www.delsys.com/Attachments_pdf/WP_SEMGintro.pdf

[13] B. Fries y M. Fries, Digital Audio Essentials. O'Reilly Media, Inc., 2005.

[14] Visual Analyser Project, virtual real time software. April 2016. [Online]. Available: http://www.sillanumsoft.org/

[15] A. Georgakis, L.K. stergioulas and G. Giakas. Fatigue analysis of the surface EMG signal in isometric constant force contraction using averaged instantaneus frequency. IEEE Transactions on Biomedical Engineering. Vol. 50. No. 2. 2003