Low Cost Surface Electromyographic Signal Amplifier Based On Arduino Microcontroller

Igor Luiz Bernardes de Moura, Luan Carlos de Sena Monteiro Ozelim, Fabiano Araujo Soares

***Abstract*—**The development of an low cost acquisition system of S-EMG signals which are reliable, comfortable for the user and with high mobility shows to be a relevant proposition in modern biomedical engineering scenario. In the study, the sampling capacity of the Arduino microcontroller Atmel Atmega328 with an A / D converter with 10-bit resolution and its reconstructing capability of a signal of surface electromyography is analyzed. An electronic circuit to capture the signal through two differential channels was designed, signals from Biceps Brachialis of a healthy man of 21 years was acquired to test the system prototype. ARV, MDF, MNF and RMS estimators were used to compare de acquired signals with physiological values. The Arduino was configured with a sampling frequency of 1.5kHz for each channel, and the tests with the circuit designed offered a SNR of 20.57dB.

***Keywords*—**Eletromyography, Arduino, Low-Cost, Atmel Atmega328 microcontroller.

I. Introduction

DUE to the advantages inherent to its usage, the surface electromyography (S-EMG) has been increasingly used in the study of muscular activities [3]. Features as safety, and non-invasiveness make this technique a good alternative while dealing with muscular signal acquisition, especially during exercises and prosthesis control [3]. One of the most common problems related to this technique is the presence of artifact noise, which comes from the relative movement between the electrode and the skin [4]. In general, the commercial S-EMG equipments are not compact, ultimately compromising mobility, what makes difficult evaluation on real dynamic exercises such as running or usage of heavy equipment on assemble lines by humans.

The development of a low cost acquisition system of S-EMG signals which are reliable, comfortable for the user and with high mobility shows to be a relevant proposition in modern biomedical engineering scenario.

The use of wireless data transmission provided by Wearable systems [1] is also interesting to avoid wires that could limit the movement of subjects in studies. In order to evaluate the applicability of such type of system, a survey has been undertaken regarding commercial availability, costs and whether or not the technologies were open source.

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Among the possibilities available, we choose Arduino family of products to address this issue due the fact that it is an open hardware project; it is compatible with ZigBee transmission systems and its wearable version (LilyPad [2]) attend the requirements of this project.

In order to verify the feasibility of this project, it was developed a prototype with Arduino Uno R3 version [2] to test filter circuits, acquisition performance, etc. It is worth noticing that the microcontroller in the latter version is the same as the one in LilyPad's version.

The present effort is carried out to address two issues, namely: the capability of the Arduino microcontroller to sample and rebuild with enough quality the S-EMG signal acquired. In order to verify such capability, estimators as RMS, ARV, MDF and MNF are used and evaluated by means of the computational tool presented in [5], [6].

The second issue of interest regards the usage of disposable electrodes. It is verified whether this type of material enables as good signal acquisition as the electrodes generally used during clinical exams.

An electrical circuit for the new acquisition system is developed and the usage of Arduino Uno R3 has been verified. This shows that the microcontroller – common to both Uno R3 and LilyPad versions – is capable of correctly processing the signal acquired.

By means of the results presented, in the future, it is possible to migrate the code proposed to a LilyPad platform and do a 6-channel acquisition of signals.

II. Materials and Methods

A. Hardware Description

In order to obtain a low cost electromyography amplifier, at first, a detailed survey about signal's behavior and the existent alternatives for its acquisition has been carried out. A list of necessary actions to be performed, such as filtering, amplification with high signal-noise ratio, analogical-digital conversion and signal processing has been done. The electronic components have been specified based on their commercial value and availability. This way, the experiment is easily reproducible and its parts replaceable. The circuit layout has been elaborated by means of the software ISIS Proteus Professional from Labcenter Electronics [version 7.08].

The frequency range of the EMG signal is a deeply discussed topic. Notwithstanding, most of the literature predicts values between 10 and 500 Hz [7], [10]. Following

BASMAJIAN and DE LUCA [11], EMG's signal presents components that range from few micro-volts up to five mili-volts. The circuit has been designed to amplify the signal by a factor of 500, which ensures the voltage ranges from negative to positive 2.5V in the output of the amplifier. Simultaneously, the circuit filters the signal, attenuating the components whose frequency is lower than 10 Hz and higher than 500 Hz. As the A/D convertor used only accepts positive tensions, a tension adder has been inserted to add 2.5V to the filtered signal, ultimately leading to tensions between 0 and 5 V. The acquisition scheme of a differential channel is shown in Fig. 1. In short, the components of the scheme are: an instrumentation amplifier INA 118 (responsible for providing a gain with ratio 5), two filters (a high-pass one in 10 Hz and a low-pass one in 500 Hz), a gain stage with rate 101, a voltage follower buffer, and finally the 2.5V tension adder.

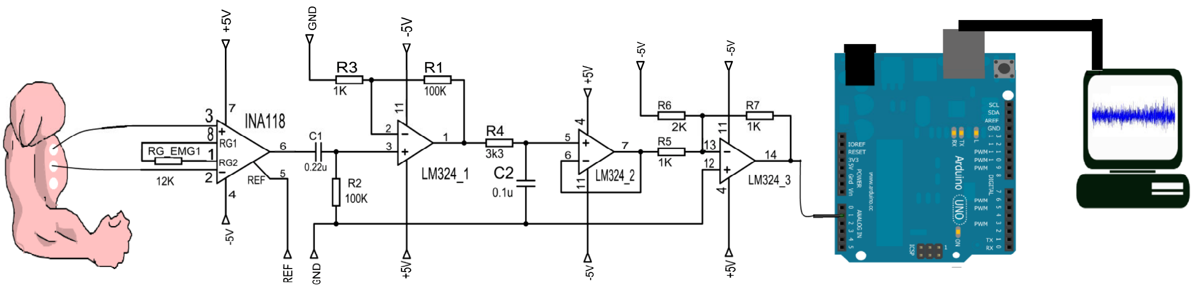

Fig. 1 Electrode configuration (left) followed by the amplification (500x) and band-pass filter (10-500Hz) circuit, the output of this circuit is digitalized by the Arduino microcontroler that export the result to a computer

Signal acquisition has been performed by means of circular disposable gel electrodes Meditrace 200. Following Day [7], Hermens et al. [8] and Merletti and Parker [9], the electrodes to be used in signal acquisition must be manufactured in Ag/AgCl, have maximum dimensions of 10 mm and be set with a maximum 20mm interelectrode distance. It is also recommended by such authors that the interelectrode distance should be reduced to ¼ of the muscular fiber while dealing with small muscles. Due to the type of electrodes used in the present effort, they had to be resized by manually cutting the electrodes and letting just the sensitive region of Ag/AgCl and a sufficient amount of conductive gel. This way, the interelectrode distance could be reduced to 20mm as recommended in the literature [7].

Regarding the digitalization resolution, it is shown by Machado [13] and Laskoskie and Pichorim [14] that a satisfactory reconstruction of the signal can be achieved with 10 and 8 bits. This way, based on the work of Machado [13] and Laskoskie and Pichorim [14], in the present paper, a 10 bits resolution A/D converter has been used.

In the circuit developed, it has been used the microcontroller Atmel Atmega328, available in the development kit Arduino Uno R3. Following Atmel [12], this microcontroller has, among other peripherals, an A/D converter with resolution of 10 bits and sampling time of 1 microsecond. With this time it is possible to obtain a sampling rate of 10 kHz. In a future work it is desirable to have a 6 channel acquisition system, resulting in a maximum rate of 1.67 kHz per channel. This way, in the present effort, the maximum sampling rate for the S-EMG signal has been set to 1.5 kHz.

The NYQUIST principle [9], [10] has been considered in the process of signal sampling. It has been established that each channel would have to be sampled at a rate of 1. 5 kHz in order to avoid signal's aliasing [4]. In the programming process of the Atmega328 microcontroller, ordinary resources such as timers and interruptions have been used in order to acquire one sample every 650 microseconds.

Data is read periodically and quantized in values from 0 to 1023. After 100 samples are collected by each channel, data is sent to a computer by means of the serial port. The BAUDRATE of communication has been set to 115200. This way, it is possible to ensure no data is lost in the communication process.

The data sent by the Arduino are received in the computer by a Matlab 2011 (Mathworks Inc., South Natick, MA, USA) routine. In short, in the code of the latter, every serial communication parameters are configured as well as the amount of time the serial port has to be opened. By means of repetition loops, the values are received and stored in two vectors. Data acquisition ends when the established time is up and the signal is ready for rebuilding.

The 10 bits resolution represents, in practical terms, that the difference between two quantized levels – in the 0 to 1023 scale – with reference in 5 V is 0.0049 V. In order to rebuild the signal, the values stored are diminished by 511, which corresponds to the 2.5 V added to the signal. After that, the signals values range from -511 to 512. Subsequently, each sample value is multiplied by 0.0049, making the signal go back to the -2,5V to 2,5V scale.

B. Subject

Experimental tests have been carried out in a 21-years-old male, whose height was 1.93m and weight, 100kg. The subject's arm circumference was of 42cm and body fat percentage of 18%. Also, the subject was physically active and did not show any symptom of neuromuscular disorders nor ligament problems. Besides, the subject did not use anti-inflammatory or muscle relaxants. Finally, the tests were carried out in the electronics instrumentation laboratory (LEI in Portuguese) at University of Brasilia (UnB).

C. *Experimental Protocol*

During signal acquisition, the subject has been kept sited. Before acquiring the signal, asepsis has been performed by means of alcohol gel at 70%. The signal has been collected from the right arm of the subject. A 10kg weight has been used to provide an isometric muscular contraction. The elbow of the subject was kept deflected at an angle of 90° during 10 seconds. This process has been repeated 4 times and the signal chosen for analysis was the one that most closely reproduced the outcomes obtained by means of standard commercial equipments. The reference electrode has been placed in the right ribs of the subject

III. Results and Discussion

In order to perform the analysis of the results, the computational tool described by SOARES [6] has been used. This tool provides classical S-EMG estimators, such as mean frequency (MNF), median frequency (MDF), average rectified value (ARV) and root mean squared (RMS) [9].

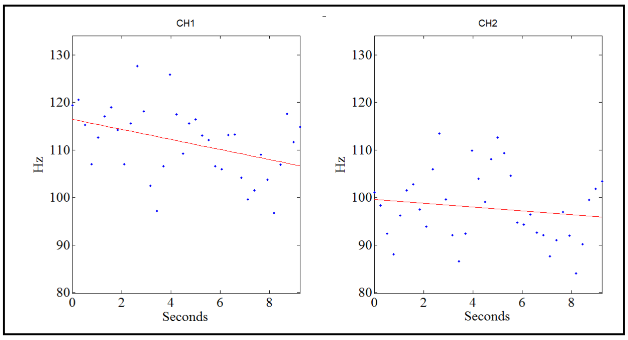

Fig. 2 MNF estimator

On Fig. 2 we can observe the behavior of Mean Frequency (MNF) estimator. The MNF value is in the physiological spectra. It is possible to see a decrease on this estimator, indicating fatigue process.

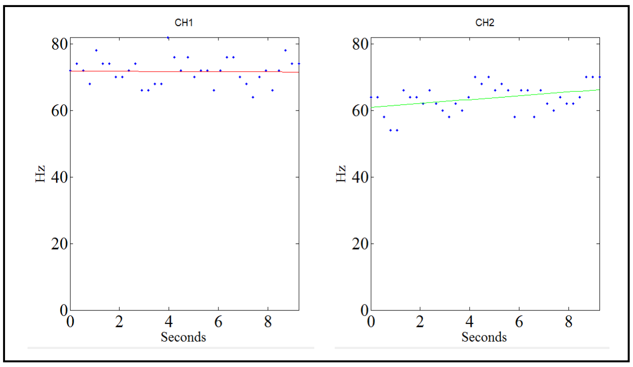

Fig. 3 MDF estimator

Fig. 3, on the other hand, shows the behavior of Median Frequency (MNF) estimator. The MDF value shows some disturbance (positive slope inclination) in channel two values (graph on the right of Fig. 3), probably caused by external factors, such as noise in the electric network (60 Hz) or artifact noise. The graph on the right of Fig. 3 has a negative slope inclination, which one more agrees with physiological spectra.

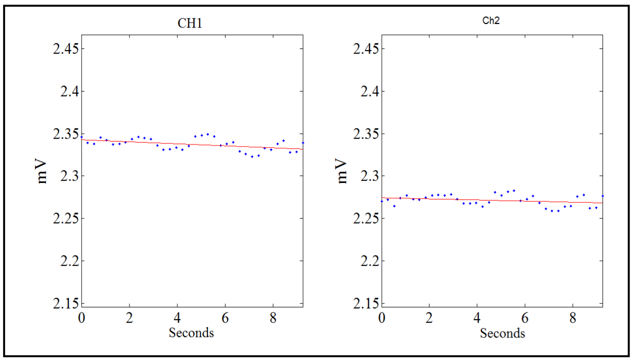

Fig. 4 ARV estimator

On Fig. 4 the behavior of the average rectified value (ARV) estimator is shown. Expected derecruitment of muscular fibers is verified, which is justifiable by the heavy load of 10kg lifted in the experiment.

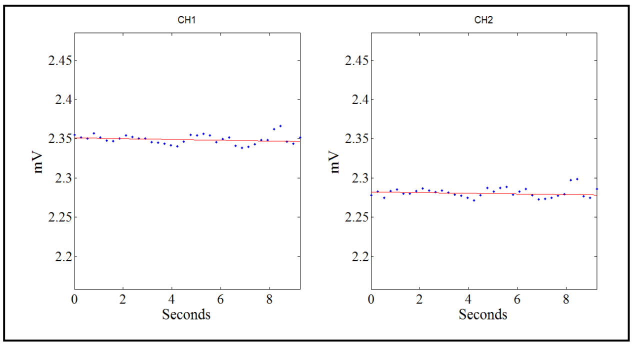

Fig. 5 RMS estimator

Fig. 5 shows the behavior of the root mean square (RMS) estimator. As in the case of the other amplitude estimator analyzed (ARV), expected derecruitment of muscular fibers is verified, which is justifiable by the heavy load of 10kg lifted in the experiment.

IV. Final Remarks

Fig. 6 shows the rebuilt S-EMG data collected by the two channels. It can be seen that the Arduino circuit proposed is able to well rebuild the signal.

Fig. 7, on the other hand, shows a 0.15 seconds window collected from Fig. 6 in other to better visualized the MUAP signal propagation process.

Signal-noise ratio (SNR) was also analyzed for the acquisition realized with the proposed equipment. A sample was collected during arm's rest and no voluntary contraction. The SNR was evaluated by means of the following (1):

$$SNR = 10 \cdot \log\left(\frac{\overline{Pot\ signal}}{\overline{Pot\ noise}}\right) \qquad (1)$$

in which $\overline{Pot}$ represents the mean value of Pot.

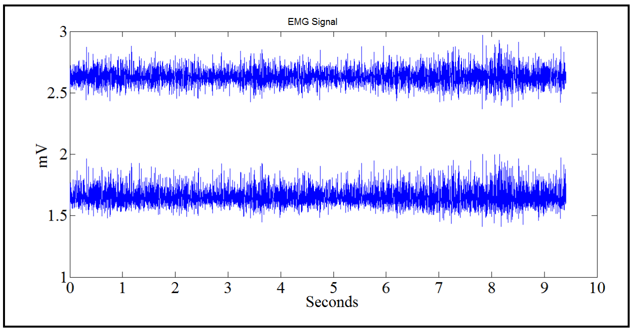

Fig. 6 EMG signal

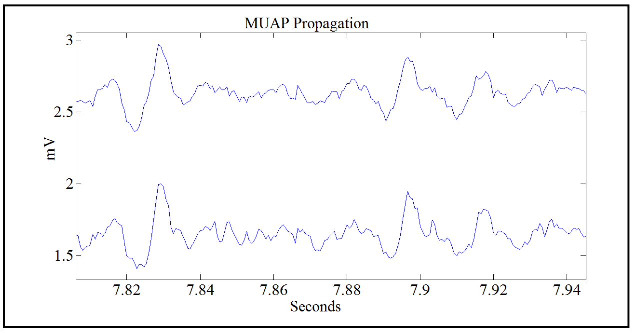

Fig. 7 Two differential channels of a 0.15s window of a S-EMG signal. It is possible to see the MUAPs traveling from the left to the right. The Inter Electrode Distance is 20mm

Equation (1) has been evaluated by means of the software Matlab, resulting in a SNR of 20.57dB. This result shows that the circuit designed, shown in Fig. 1, provides a medium quality amplification of the signal and the noise level is acceptable. However, it is interesting to reduce the latter in the future using better filters or high quality components.

Due to the circular format of the electrodes used and the physical limitation for reducing the interelectrode distance, the conduction velocity could not be evaluated.

Even though the signal was sampled and sent periodically by the Arduino, the Matlab routine showed data loss. This comes from the difference between computer's clock and data send's one.

V. Future Research Topics

It has been verified that Arduino samples and rebuilds with quality the S-EMG signals. This way, the next step in the present research would be to transfer the code to the LilyPad Arduino [2], since the latter has been specially created to wearable applications. Also, it could be tested wireless communication module Lilypad xbee, responsible for implementing the IEEE 802.15.4 protocol [2].

Besides, the usage of Arduino's programming language prevents achieving the full processing power of Atmel Atmega328 microcontroller. Thus, pure programming languages, such as C, shall be used to implement the routines involved.

Finally, a different acquisition system could be designed by means of a new scheme of electrodes parallel to muscular fibers.

VI. Conclusions

The development of new low cost S-EMG acquisition systems is of great interest in modern biomedical engineering. In the present paper a simple, reliable and low cost circuit has been designed for performing this task. The circuit uses the Arduino Uno R3 family, with the Atmel Atmega328 microcontroller. Tension adders, low and high-pass filters besides amplifiers are used in circuit's design.

The usage of low cost disposable Ag /AgCl electrodes has been analyzed. The dimensions of the commercial electrodes used do not allow interelectrode distances in accordance with literature thresholds. Thus, the electrodes had to be hand cut. This diminished the skin contact, potencializing artifact noise. Even though this few drawbacks arise, the experiments performed show great potentiality for practical implementations.

The present paper also shows that Arduino family hardware is capable of sampling and rebuilding with quality the signals acquired enabling future migration to Arduino's wearable version – LilyPad.

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