Project and assembly of a system for muscle activity monitoring during physical exercises

A A da Costa Filho, C P B Barros, R A L de Andrade e J S da Rocha Neto *Senior Member IEEE*

Universidade Federal de Campina Grande.

E-mails: antonio.costa@ee.ufcg.edu.br, clarisse.barros@ee.ufcg.edu.br, renato.andrade@ee.ufcg.edu.br, zesergio@dee.ufcg.edu.br

Abstract: The design of a system for muscle activity monitoring that provides the speed and uniformity of execution of a physical exercise it is described in this article.

Keywords: electromyography, instrumentation, digital signal processing.

1. INTRODUCTION

Electromyography (EMG) is typically used for physiology and biomechanics research and diagnosis, but its applications extend to areas such as physical therapy, rehabilitation, sports' medicine, ergonomics, robotics, and entertainment [1]. The electromyographer may be an aid to the evaluation of performance and fatigue in sports, as well as of muscle activity during a diagnostic or a therapeutic process [2]. Furthermore, it is present in some medical and wearable devices, games, and exoskeletons.

During physical exercises, depending on the person's specific objectives, the manipulation of variables such as series, repetitions, training frequency, time interval between exercises, are rather common [3]. Despite the existence of studies that prove the results achieved out of each type of training according to the purpose, the movement speed is barely mentioned or controlled and this lack of control may interfere in the muscular recruitment pattern [4-6].

By measuring the movement execution speed, it is possible to exert a greater control over it and, consequently, to obtain better results within a shorter period. The project and construction of a relatively low-cost device with a user-friendly interface dedicated to measuring this speed is described in this article.

2. ELECTROMYOGRAPHY FUNDAMENTALS

Electromyography is a field of Biomedical Engineering that deals with the detection, analysis and utilization of small electric currents emitted by skeletal muscles due to the exchange of ions between the muscle membranes. The electromyographer is the instrument used for the acquisition of the electromyography signal, also known as electromyograph [7].

The SENIAM (Surface EMG for the Non-Invasive Assessment of Muscles) defines the main directives for the electromyograph acquisition and analysis, including the protocols for electrodes location and signal conditioning [8-9]. The choice of sampling frequency for signal digital reproduction is performed according to the information desired: for the project presented herein, for instance, a 20 Hz sampling frequency and a 6 Hz low-pass filter, with which one may obtain time data on muscle activity only, are sufficient [10].

3. HARDWARE DESIGN

3.1. Sensor circuit and microcontroller

The first phase of the sensor circuit (figure 1) comprises an instrumentation amplifier. The gain is used to elevate the EMG signal amplitude to voltage levels compatible to the analog-digital converter resolution, from which is obtained the raw EMG signal.

The second phase is compounded of a high-pass filter with a 106.1 Hz cut-off frequency in series with a full-wave rectifier. The use if this filter is due to the need for removal of low frequency noise components such as the instrumentation amplifier DC offset, sensor's variations on the skin and temperature fluctuations.

The rectified signal is passed through an envelope detector, third phase of the sensor circuit, to obtain a signal easier to be interpreted and digitally processed as compared to the raw EMG one. A last gain is used to adjust the signal amplitude to the maximum acceptable input voltage level of the subsequent device.

For the digitalization of the measures, an *Arduino Uno* was used, which contains the microcontroller *ATmega328P*. The latter works with a RISC architecture, has clock frequency of 16 MHz, and has analog inputs with a 10 bits resolution.

3.2. IEEE 802.15.4

The standard IEEE 802.15.4 defines the operation of wireless, low-baud-rate personal-area networks, focusing on low cost and energy consumption, and specifies their physical and MAC (Medium Access Control) layers. XBEE Modules from the company Digi International are used to establish the wireless communication.

The topology implemented is the peer-to-peer one, with the node connected with the computer configured as the coordinator and the node connected to the Arduino as the end device. The modules immediately transmit what they receive, similarly to a simple serial standard, and the baud rate of 9600 bps is established.

3.3. Assembly

The EMG signal acquisition is performed by means of a bipolar configuration. In this set-up, two electrodes are used for signal detection and a third one is used as a reference. The circuit output is connected to an analog input of the Arduino, which samples the signal at each 10 ms. The UART baud rate is configured at 9600 bps.

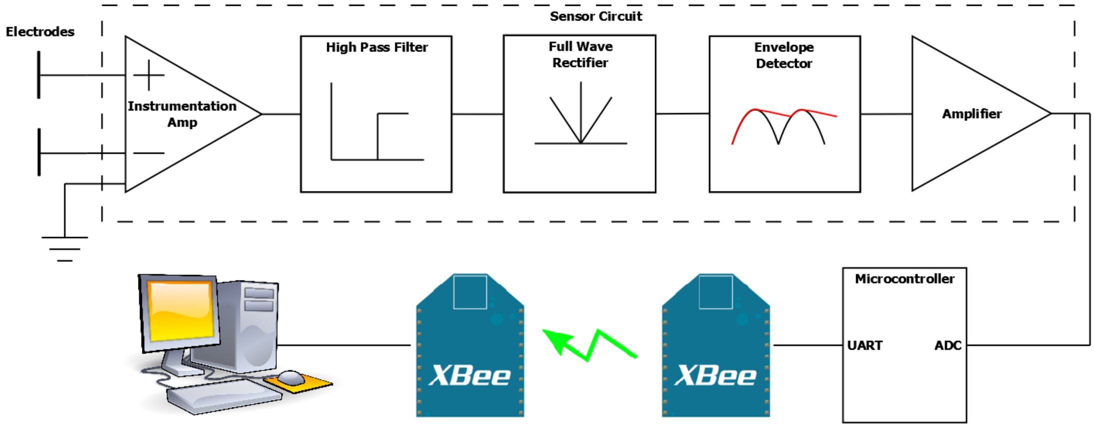

Figure 1. Schematics of the system

4. SOFTWARE DESIGN AND DATA PROCESSING

A program with a graphic interface was developed in *Matlab* in order to process the collected signals and display the results.

4.1. Data processing

Initially, experiment involving contraction of the muscle biceps utilizing different weights were executed with women and men, ranging from 23 to 27 years old. A visual analysis of the collected signal evolution (figure 2) allows a preliminary identification of the sequence of muscular contraction (spikes) and relaxing (dips) movements.

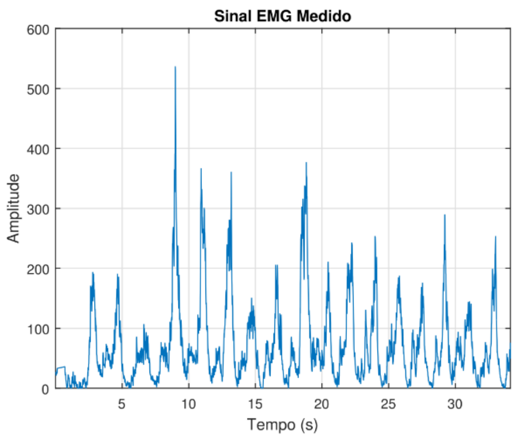

Figure 2. EMG signal collected by the sensor.

The first procedure is the application of a moving average filter to smooth the signal, whose number of points used in the computation should span half period of a movement – of approximately 2.0 s for the experiments carried out. As it is possible to notice in the figure 3 (solid blue curve), this strategy allows the removal of most of the noise disturbance, such that the resulting signal presents lobes that clearly represent the evolution of the movements with time.

Afterwards, the beginning and the end of each contraction are identified. For this purpose, a new moving average is applied, this time using twice as many as the number of points used to perform the signal smoothing so as to obtain a filter with cut-off frequency close to that of the movement (about 0.50 Hz). Hence, the oscillations due to the sequence of contraction and relaxation moves are eliminated and one obtains an approximation of the instantaneous average value for the signal amplitude that is used as a variable amplitude threshold, indicated by the dashed orange curve in the figure 3. This threshold further grants to the system an autocalibration characteristic. The points of intersection between the two curves are then used as bound references for each contraction along the exercise.

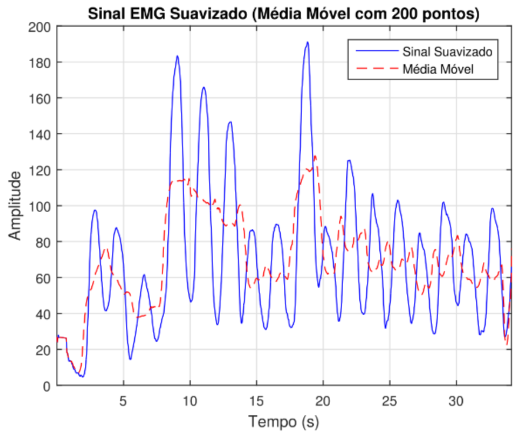

Figure 3. Smoothed EMG signal (solid blue curve) and variable amplitude threshold (dashed orange curve).

The last procedure of the processing is the identification of the time instants at which the maximum amplitude values are recorded within each contraction interval. The times when each amplitude peak happens are stored in a vector and these instants correspond to an approximation of the moment when the muscle is contracted along the exercise.

4.2. *Graphic interface*

The algorithm and the interface were developed so that the measurement is executed in an automatic manner: after the connection between the sensor circuit and the computer is established, the user should solely indicate when to start and finish the process.

When the measurement starts, a window (figure 4) is opened, where the data acquired by the hardware is displayed in real time. By closing this window, the program processes the data and another window is opened (figure 5) where the user has access to: the average time interval between contractions, the exercise average speed (in contractions per second), the standard deviation of the time intervals and their maximum absolute deviation relative to the average value. A graphic displaying the contractions instants over a time scale and another one with the standard deviation of the inter-contraction intervals are also exhibited.

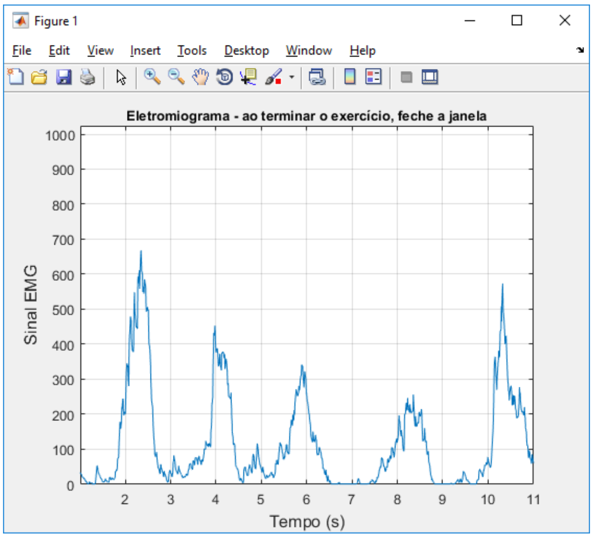

Figure 4. Window that displays the data acquired in real time for the user.

4. CONCLUSION

Portable wireless EMG signal acquisition devices are already available in the market; however, they are dedicated to clinical applications, with more demanding requirements regarding the signal characterization and that are, thus, offered at higher cost. In this article, the phases and strategies used in the design of a simpler and more economical solution were reported, aiming at applications involving EMG with a lower complexity level, such as in the maintenance of a specific pace with uniform speed patterns in the execution of repetitive movements.

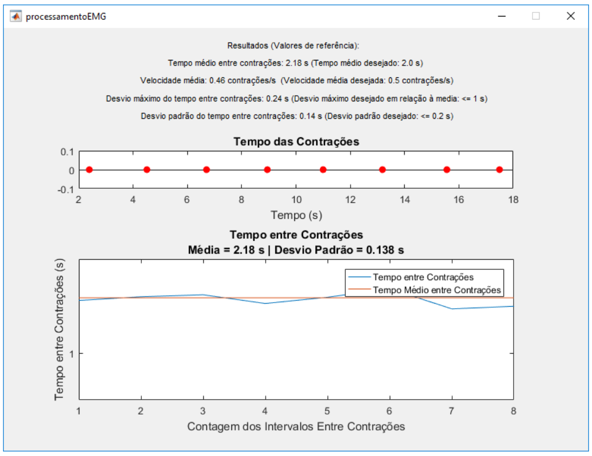

Figure 5. Window that displays information about the physical exercise.

This device is autocalibrated and capable of supplying information on muscular contraction time, although improvements may be further performed. The development of alternative strategies for signal processing, aiming at augmenting its robustness, as well as the utilization of other wireless communication technologies, such as Wi-fi and Bluetooth, and more powerful microcontrollers are regarded as useful to allow verification of the influence derived from the use of higher sampling rates.

ACKNOWLEDGEMENTS

The authors of this article acknowledge the support of CNPq (The Brazilian National Council for Scientic and Technological Development), CAPES (Coordination for the Improvement of Higher Education Personnel) and COPELE (Post-Graduate Program in Electrical Engineering - PPgEE).

REFERENCES

[1] Jamal M Z 2012 *InTech* 427-448

[2] Massó N, Rey F, Romero D, Gual G, Costa L and Germán A 2010 *Apunts Med Esport* **45**, 121-130

[3] Fleck S J and Kraemer W J 2017 *Fundamentos do treinamento de força muscular* Artmed Editora

[4] Germain P, Guevel A, Hogrel J and Marini J 1996 *Science & sports* **11** 39-45

[5] Hatfield D L *et al*. 2006 *The Journal of Strength & Conditioning Research* **20** 760-766

[6] Bottaro M, Machado S N, Nogueira W, Scales R and Veloso J 2007 *European Journal of Applied Physiology* **99** 257-264

[7] Konrad P 2005 *The abc of emg: a practical introduction to kinesiological electromyography* **1** 30-35

[8] SENIAM *Recommendations for sensor locations on individual muscles* [Online] Available in: http://seniam.org/sensorlocation.htm [Accessed in May, 2017].

[9] Hermens H J, Freriks B, Disselhorst-Klug C and Rau G *2000 Journal of electromyography and Kinesiology* **10** 361-374

[10] Stegeman D and Hermens H 2007 *Standards for surface electromyography: The European project surface emg for non-invasive assessment of muscles (SENIAM)* [Online]. Available in: http://www.med.unijena.de/motorik/pdf/stegema.pdf [Accessed in May, 2007]