Muscle Fatigue Detection Through Wearable Sensors. A Comparative Study Using the Myo Armband*

Extended Abstract

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ABSTRACT

Novel wearable systems allow the measure of very complex physiological phenomena extending their capabilities and maintaining their non-invasiveness. A good example of this is the use of superficial electrodes for recording electromyography signals (also called superficial electromyography- sEMG) which can reveal information regarding muscle force and fatigue. Aiming at demonstrate the accuracy of a commercial grade wearable system for sEMG, the Myo Armband for fatigue measurement, we carried out a comparative study. 3 subjects were used under a standard protocol for fatigue detection using two different sensors: a Base ground-truth sEMG sensor, and the commercial wristband Myo, both connected in the biceps brachii. Time and frequency domain parameters were compared using an ANOVA test and a correlation analysis. Results showed a median correlation for the three subjects between 0.4 and 0.6 between the Base Sensor and the Myo Armband signals exposing significant differences $p < 0.05$ for all three cases. The biomarkers of the sEMG signal of both sensors were consistent research found in the literature. Novel wearables sensors can be used in medical scenarios where high accuracy is not a requirement, instead, non-invasiveness can provide ubiquity for rehabilitation treatments as well as a continuous signal recording and data logging processes.

CCS CONCEPTOS

• **Mathematics of computing → Probability and statistics**; *Redundancy* • **Networks** → Protocol testing and verification.

KEY WORDS

Surface electromyography, muscle fatigue, wearable sensors, correlation of signals, biostatistical analysis.

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1 INTRODUCTION

Physiological computing systems are the meeting point between the human nervous system and its technological electronic counterparts, as computers [1]. There are many types of interaction that can be facilitated by this form of input ranging from intentional control to implicit software adaptation. The rapid advance in the development of new sensors for the recording of physiological signals has allowed the birth of wearable sensors, sensors that can be used in daily life and that minimize the "intrusiveness" of this technology, and some of them enable the measurement of complex signals such as electroencephalography (EEG), electrocardiography (ECG) and electromyography (EMG) signals. [1]. In particular, the EMG signal are widely used in rehabilitation, ergonomics, biomechanics and prosthesis control systems.

Perhaps the most popular wearable EMG system used in the Human Computer Interaction (HCI) community is the Myo Armband. This system uses non-invasive sensors for monitoring the superficial EMG (sEMG) signal in the muscle. This wearable has been used for the development of therapeutic video games [Ref], control of robotic systems as drones [Ref], and mainly as an alternative device for controlling applications both on the computer and on mobile devices. Few studies have been performed to verify the accuracy of the sEMG signal derived from the device, despite his notorious benefits in non invasiveness, portability, low cost and connectivity. Some of the most interesting possible applications of this sensor are in the clinical field since its accuracy in the measurement of the myoelectric phenomenon is fundamental to guarantee the truthfulness in the diagnosis that involves processes such as the recovery of the force and the muscular fatigue. This last one has been extensively studied and differentiated within the electrical signal; it is well known that muscle fatigue can be found by studying the behavior of the RMS value and the median frequency (MDF) of the signal spectrum sEMG. Under fatigue conditions, factors such as recruitment of fast twitch muscle fibers, synchronization of motor units in the muscle, and nonlinear recruitment pattern, cause spectral shift toward low frequency regions and greater magnitude in the signals [2]. In order to verify the functionality of the Myo Armband sensor for clinical applications, its signal is compared against a sEMG ground-truth sensor (Base) with standard performance, through an ANOVA analysis of the muscle fatigue markers.

2 EXPERIMENTAL AND COMPUTATIONAL DETAILS

A comparison was carried out in three athletes (1 female, 2 males) from a local university, with an average age of 22.66 ± 0.57, who followed a protocol of muscle fatigue for brachial biceps. The protocol consisted in: isometric contractions for 15 seconds, at 60% of its maximum force with the arm in the 90 ° elbow flexion. Repetitions were carried out until: a) users could not flex again or until the 90 °, b) notice that the position was altered maximum by 10 degrees. sEMG signals were recorded with the two sensors under the same protocol in two different sessions (Fig. 1).

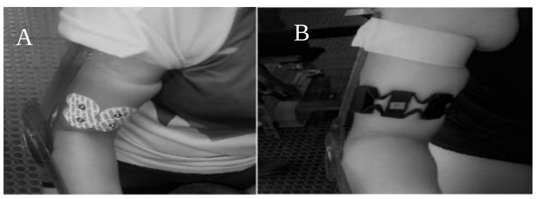

Figure 1: Position of the sensors according to SENIAM. A) Base sensor. B) Myo sensor.

The processing of the sEMG signals was performed using the Matlab programming software. The first step was to divide the signal into isometric contraction intervals, the stationary times in which it is to be analyzed. For the signal filtering, a fourth order Butterworth filters were used with cutoff frequencies from 20 Hz to 450 Hz in the Base sensor, while for the Myo sensor the same were from 20hz to 100hz. A fourth-order rejection Butterworth was applied to both signals from 58 Hz to 72 Hz, which filters the noise of the cardiac signal and the signal from the power line [2]. The normalization of the EMG signals was performed by dividing the sEMG signals during the task by the maximum sEMG value obtained from the same muscle. To find the muscle fatigue markers (in time and frequency), a moving average window of 2000 samples and an overlap of 500 samples was applied to the Base Sensor. Moreover, a moving average window with a length of 200 samples and an overlap of 50 samples was applied to the Myo sensor. For the RMS value, the trend of the signal was removed and then the signal was rectified. Continuedly , to the previously described windowed signal, Fast Fourier transform (FFT) was applied to find the median frequency of the power spectrum. Finally, for each marker, a first-degree polynomial was found, which dropped a slope to describe the increasing or decreasing behavior of each marker.

3 RESULTS AND DISCUSSION

The results of applying the unidirectional ANOVA test with 5% significance were (Fig. 2): for subject 1 F(1,192)=267.36, p<0.05, for subject 2 was F(1,114)=632.83, p<0.05 and for subject 3 was F(1,190)=1054.62, p<0.05. As we verified significant differences between the signals, we proceeded to analyze whether these signals have correlation or not, trying to verify that both can evidence the expected bioelectrical characteristics. For this, a cross-correlation analysis was used exposing a correlation index of 0.5892, 0.4549 and 0.4365, for users 1, 2 and 3 respectively.

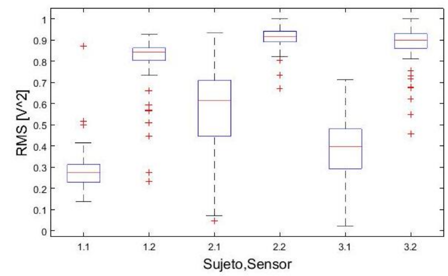

Figura 6: ANOVA test. From left to right, the first box represents the mean RMS value of the Base Sensor signal of subject 1 (1.1), the second box represents the mean distribution of the RMS value of the Myo Sensor signal of subject 1 (1.2), and so on.

Once verified the correlation between the signals and evidencing that both (Base and Myo) can manifest the markers of muscle fatigue, we analyzed the results of the signal processing looking for quantifying the differences. The RMS value showed an increasing behavior with slopes of 0.0270, 0.0185, 0.0898 for the Base Sensor, and 0.2420, 0.0107, 0.0787 for the Myo Sensor, for subjects 1, 2 and 3 respectively. In the other hand, the MDF presented a decreasing behavior, with slopes of -0.0050, -0.0059, -0.0016 for the Base Sensor, and -0.0279, -0.0232, -0.0102 for the Myo Sensor, for subjects 1, 2 and 3 respectively.

In human biomechanics study, it is often desirable to have means for assessing the fatigue of the muscles involved in performing the action. The engineers have studied the prominent characteristics of the sEMG signals to objectively understand this phenomenon. For isometric contractions under fatigue conditions spectral modification occurs mainly as a compression accompanied by an alteration in the asymmetry of the MUAP form [2]. In this study, the analysis of fatigue paramters in sEMG aim at concluding that both signals present a expected behavior according to the literature, for all subjects, evidencing the feasibility of using the Myo sensor in HCI and limited medical scenarios. A previous pilot study was previously published showing similar results and confirming the results here presented [3]. Finally, this study demonstrates the feasibility of using these new wearable physiological computing systems for applications where high accuracy levels of sEMG signal are not required.

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