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To cite this article: G Laverde et al 2020 J. Phys.: Conf. Ser. 1514 012012

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# Characterization of hand movements using a low cost electromyography sensor

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Abstract. Electromyography signals are commonly used to control prosthetic or orthotic devices. The electrodes attached to the skin capture the muscular activity coming from neuromotor signals. Robotic prostheses help to improve the quality of life of people who suffer from physical disabilities such as amputations of lower or upper limbs. However, these prostheses are quite expensive, and the operation of the robotic prosthesis depends on the contraction muscles that generally uses two movements, contraction and relaxation (closing and opening). In this paper, we propose the characterization of hand movements by means of an inexpensive electromyographic sensor, the MyoWare AT-04-001, which acquired neuromotor signals due to muscle contraction in the forearm. Four movements were recorded: flexion, extension, opening and closing of the hand. Hand movements were performed at one movement per second, as indicated by a metronome. Signals were acquired with an Arduino one at a sampling frequency of 200 Hz for 30 s. Using time-domain, frequency-domain and nonlinear measures we characterized the electromyography signal for each movement. We observed that the closing and extension of the hand produced the greatest amount of variance and entropy of the electromyography signal as well as the greatest energy in the frequency domain. These results were related to the location of the electrode in the forearm, since the sensor was placed in the muscles involved in the execution of these movements.

### 1. Introduction

Worldwide, about 200 million people experience some type of disability and have fewer options to access services, such as health, employment, education and transportation, than people without disabilities. In Colombia, almost two million people (approximately 6 % of the population) had disabilities in 2005, and around one million people presented disabilities in 2017, of which 80000 people were from the department of Santander. Among the disabilities, physical disabilities include people who suffer problems in the locomotor system, resulting in a decrease or absence of motor or physical functions [1]. For example, amputations are physical disabilities that involve the loss of a member of the body whether due to diseases, trauma, traffic accidents, accidents at work, military accidents or antipersonnel mines [2].

In the last decade, a great technological advance has been achieved in the development of devices, such as prostheses and orthotics, which have allowed improving the quality of life of people with physical disabilities. These devices can simply focus on supplying the missing limb or controlling limb movements by means of myoelectric signals commonly taken with surface electrodes [3]. These electrodes capture the electrical signals from motor neurons that then carry

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the information to the brain to be transmitted to the muscles during muscle contraction [4]. Electromyography (EMG) signals have allowed the study and development of devices in the area of medicine, particularly in the area of muscle rehabilitation that focuses on neuromuscular damage or muscle atrophy. Thanks to prostheses, orthoses and exoskeletons, doctors have helped improve the quality of life of patients who need special therapy treatments to reduce their disability [5].

Several limb prostheses have been designed to treat physical disabilities. For example, the I-Limb bionic prosthesis, a hand prosthesis developed by Touch Bionic, has five motors that act independently with coupled sensors that generate different types of movement, their fingers are articulated independently [6]. The Myo bracelet allows the recording of the electrical activity of the muscles and sends the data to a computer or mobile device [7]. The classification of hand movements has already been done using the Myo Armband [8]. In Colombia, Prostésica, a company based in Barranquilla, designs and sells leg and hand prostheses and orthotics, however, their cost varie from USD 25,000 to USD 35,000 and the devices tend to be quite large, heavy and cumbersome. Following these previous works, in this paper we present the characterization of four hand movements from EMG signals acquired in the forearm using a low-cost device, specifically the MyoWare AT-04-001, whose cost is just USD 20. The characterization of the signals is performed using temporal, frequency and non-linear measurements. This characterization would be useful to conceive an automatic classifier of hand movements and in the development of a low-cost hand prosthesis.

# 2. Materials and methods

## 2.1. Electromyography sensor description

The MyoWare AT-04-001, depicted in Figure 1, is a small, cheap and easy to use EMG sensor consisting of three electrodes: one for the middle muscle electrode, tip of the end muscle electrode, and a reference electrode. The card incorporates two clips, one for the middle muscle electrode and one for the final muscle electrode. The MyoWare sensor can work up to  $\pm 9$  V, with reverse polarity protection. Two outputs can be obtained, one filtered and another unfiltered (raw signal). In this work, we processed the raw signal, since relevant information could be suppressed in the filtered signal by the filter embedded in the card.



Figure 1. Characteristics of the MyoWare At-04-001 EMG sensor [9].

### 2.2. Data collection protocol

We used the MyoWare AT-04-001 sensor to collect four moments of the hand. To do this, three steps were carried out, as depicted in Figure 2. In the first step, the sensor was placed on the forearm, specifically, in the radial flexor muscle carpo [10], because in this area, the electrical activity of the neuromotor signals corresponding to the hand movements is strong.

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Journal of Physics: Conference Series	<b>1514</b> (2020) 012012	doi:10.1088/1742-	6596/1514/1/012012

Since the output of the MyoWare AT-04-001 sensor is an analog signal, we used the analog-to-digital converter of an Arduino One as second step, by mapping the input voltage ranging from 0 to 5 V to 0 to 1023 levels. The sampling frequency was set to 200 Hz and the serial communication speed to 115200 baud.

Finally, the data was exported to MATLAB<sup>®</sup> R2016a (The MathWorks, MA, USA) for processing, storage and visualization.



Figure 2. Steps carried out to collect the EMG data.

#### 2.3. Hand movements

Four movements of the hand were collected from a young healthy person. The person performed the experiment sitting, with their back straight, resting completely on a flat surface. The forearm was suspended in the air forming an angle of  $90^{\circ}$  with the arm. The hand was relaxed in a natural way. The data was acquired in the right forearm. Four movements of the hand were performed [11,12]:

- (i) Closing (fist): as illustrated in Figure 3(a).
- (ii) Flexion (wavein): refers to the decrease in the angle of the joint from the anatomical position to the palm of the hand, as illustrated in Figure 3(b).
- (iii) Extension (waveout): defined as the increase of the articulation angle from the anatomical position towards the back of the hand, as illustrated in Figure 3(c).
- (iv) Opening (spread): as illustrated in Figure 3(d).

Regarding the above, the movements are similar to those of the Myo gesture control armband. The movements of the hand were made at a rate of one movement per second during 30 seconds. The person listens to a metronome set at 60 beats per minute through headphones and performs the movement at the moment of listening the beat.

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**Figure 3.** Movements of the hand. (a) fist, (b) wavein, (c) waveout, and (d) spread.

#### 2.4. Features of the electromyography signals

We estimate different features of the EMG signals for each hand movement on three different domains: time, frequency and nonlinear. In the time domain, we computed the mean, median, variance, kurtosis, skewness and interquartile range (IQR) of the signals. In the frequency domain, we estimated the total energy and the magnitude and locations of the two greatest peaks in the power spectral density of the signals obtained through the fast Fourier transform algorithm. Finally, the Shannon entropy of the signals were computed as a measure of information content.

#### 3. Results

Figure 4 shows an excerpt of the EMG signals for each hand movement. We can clearly observe the different dynamics and amplitudes of the signals captured by the EMG sensor when performing the hand movement. For instance, the fist and wavein movements have stronger amplitudes while the waveout movement has the lowest amplitude.



**Figure 4.** EMG signals caputed by the sensor for different hand movements. (a) fist, (b) wavein, (c) waveout, and (d) spread.

Figure 5 shows the power spectral density of the EMG signals on the range [0, 5] Hz, for each hand movement. The mean value of the signals was eliminated to reduce their DC value (offset) given that it can shade other frequency components presented in the signal. We can observe a peak around 1 Hz corresponding to the rate at which the movements were performed. Table 1 shows the features extracted from the EMG signals for each hand movement.



**Figure 5.** Power spectral density of the EMG signal for each hand movement. (a) fist, (b) wavein, (c) waveout, and (d) spread.

Table 1. Values of the features for each hand movement.

Feature	Fist	Wavein	Waveout	Spread
Mean (v)	2.4184	2.4186	2.4196	2.4180
Median (v)	2.4194	2.4194	2.4194	2.4194
IQR (v)	0.0147	0.0147	0.0098	0.0098
Variance $(v^2)$	0.0008	0.0005	0.0000	0.0001
Kurtosis	14.4765	15.9446	4.7597	14.7917
Skewness	-0.0954	-0.1013	0.0930	-0.3373
Energy $(v^2)$	0.0333	0.0223	0.0026	0.0061
Magnitude of the 1st peak	0.0021	0.0033	0.0014	0.0015
Frequency of the 1st peak (Hz)	1.0500	1.0500	0.2441	1.0500
Magnitude of the 2nd peak	0.0011	0.0010	0.0013	0.0006
Frequency of the 2nd peak (Hz)	2.1000	0.2197	0.3662	0.5127
Entropy	0.8029	0.9119	0.4253	0.9047

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Journal of Physics: Conference Series	<b>1514</b> (2020) 012012	doi:10.1088/1742-6596/1514/1/012012

Table 1, we can observe that the fist and wavein movements have higher IQR, variance, energy and entropy than waveout and spread. Moreover, the fist, wavein and spread movements have similar distribution (leptokurtic and skewed to the left). The two most significant oscillations of the signals occurred at around 1 Hz (the rate of the hand movement) and between 0.22 Hz and 0.51 Hz, except the fist movement which was around 2 Hz.

#### 4. Discussion

The location of the sensor in the radial flexor muscle carpo leads to the closing hand movement (fist) signal with larger energy, variance and entropy than the other movements, given that, at this location, the neuromotor signals concentrate more when the muscle is contracted. In contrast, the extension movement (waveout) produced the lowest energy, variance and entropy of the EMG signal, given that the contraction of the muscle was not recorded with larger amplitude at the location of the sensor, i.e. the sensor is on the back of the contracted muscle. Using another sensor placed at the muscle contracted when the waveout and spread movements take place would allow improving the quality of the signal recorded and better characterize these movements. Our research team is currently working in this direction.

The characterization of signals and the feature extraction are fundamental steps for conceiving a system that automatically detects and classifies an event, in this case, the movement of the hands. We are also interested in the automatic detection and classification of the hand movements with the aim of conceiving a hand prothesis.

#### 5. Conclusion

The characterization of EMG signals acquired using a low-cost sensor in the forearm of a subject performing four different hand movements (extension, flexion, closing and opening hand) was successfully carried out using different measures issues from time-domain, frequency-domain and nonlinear methods. Using only one sensor, different measures were obtained for each movement, particularly, the variance and the entropy of the signals and the energy of the power spectral density of the signals were different among the hand movements.

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