Bioelectric signal processing: the first step to create a low-cost prosthetic arm

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***Abstract*— In Mexico, the amputation of an upper limb is more frequent than is known, affecting the motor skills of the person who suffers it. That is why, as a response to this problem, and taking into account both improving the quality of life of patients and their budget, we have chosen to create a system that functions as a human-machine interface for an arm prosthesis, that works by a microcontroller and fuzzy logic, fed with electromyographic signals. In particular, this article focus on the processing of EMG signals, and their amplification and filtering. Also, our contribution to society is to offer an alternative to commercially available prostheses: a reliable, safe and easy-to-use device, at a lower price.**

Keywords—* *EMG Signals, Transducer, Sallen Key Filter, prosthetic arm, Fuzzy Logic, low-resource microcontrollers.

I. Introduction

A very common health problem in today's society is the loss of one or more limbs, generally due to accidents or illnesses. For example, in Mexico, the 80% of major lower limb amputations are done in diabetic patients, according to the Faculty of Medicine of the UNAM (Universidad Nacional Autónoma de México) [1]. Currently around 6 million Mexicans over 20 years of age suffer from this disease. Not being able to walk or move independently affects almost 6 out of 10 people in Mexico. At least 3.5 million of the population cannot move without the help of prosthesis, according to INEGI in 2010 [2].

This situation is not usually easy for the patient to assimilate, as there are psychological conditions, such as sadness, anger, frustration, and even a sensation of pain in the absent limb, better known as "phantom pain" [1]. Of course, for this there is psychological therapy, although, on the other hand, many patients choose to use a replacement limb, due to the difficulties involved in not having one. Taking advantage of advances in technology for human benefit, it has been decided to create mechanisms that allow functional replacement of an amputated limb [4].

The idea may seem obvious, since there are already several commercial prosthetic options [10]. However, our proposal lies in the implementation of techniques for the processing and interpretation of bioelectric signals, in order to take advantage of their properties and use them in the control of the aforementioned devices.

In the moment that the signals produced by the brain receive a direct consequence (an action from the prosthesis), then will be possible to build a system that operates as a human-machine interface [10]. All those things are an effort to build a robotic arm that operates in a more natural way for the affected individual, and whose cost will be accessible to people with limited resources.

II. Background

Previously, the existence of various options to acquire a device of this type was mentioned, which fulfills both basic and aesthetic functions, as well as motor functions. Next we will talk about the most notable ones, their developers and their price.

The first on the list is the called LUKE Arm (Like Under Kinetic Evolution), developed by the Biomedical Engineering team at the University of Utah, and named after the main character from Star Wars. LUKE is a motorized prosthetic arm, capable of feeling touch and moving with thought. It is made primarily of motors and metal parts, covered with a transparent silicone "skin", powered by an external battery, and connected to a computer. We can appreciate this mechanism on Fig. 1 [4].

Fig. 1 LUKE prosthetic arm created by DEKA R&D.

The company DEKA Research & Development has been in charge of the physical implementation of the LUKE project, while the Utah team has been developing a system that allows the prosthetic arm to touch the nerves of the wearer, causing them to behave like a biological cable. This is achieved thanks to the Inclined Electrode Array. This array of microelectrodes and leads is implanted into the amputee's nerves in the forearm and connected to a computer outside the body. Its function is to interpret signals from the nerves in the arm and the computer translates them into digital signals that tell the arm to move [4].

To perform tasks such as picking up objects, the prosthetic hand is also capable of “feeling” the object, thus learning how much pressure is required to exert [4].

Regarding the Mexican development, the company Probionics created an electronic prosthesis for arm and hand, with a cost 50% lower than the existing offer, with a cost of 5,000 USD, it is light and has a chip that makes it possible to use it in a similar way to a computer mouse, just by making movements with the hand, without using the fingers [5].

For its part, the “Tigre-Robotics” university group, of the UANL, has developed the initiative “Brazos que Cambian Vidas” (Arms that Change Lives), which consists of the development of low-cost arm prostheses for infants. The program was designed for low-income children, since figures indicate that in Mexico 25 thousand arm amputations are performed annually, but only about 1,500 prostheses are produced. According to the group, the economic conditions that affect the majority of those who require arm prosthesis, and they see in this a window of opportunity, by offering low-cost devices: the most expensive arm prosthesis that they have developed is approximately of about 1000 USD. These work through a myoelectric bracelet, fitted on the child's biceps, which sends signals captured from the muscle to a Raspberry card, programmed in Python [6].

III. Methodology

A. Fundamentals of neuro-muscular communication and its characteristic signals.

The neuromuscular system, as its name indicates, is comprised of the nervous system and the locomotor system, which work together to generate movements from the reception of stimuli. The nervous system is in charge of the harmonious work between the skeleton, the joints and the muscles; and is made up of the brain, spinal cord, and nerves. For its part, the locomotor system functions as a complex set of levers, in which the muscles provide force, the joints act as a fulcrum and the bones behave as mobile segments. Coordination here is of utmost importance to adopt the various positions and movements [7].

Much of the nerve cells have processes called axons, which allow the conduction of electrical impulses throughout the body. Axons are stimulated from the environment and through pressure, heat, chemical factors, or electrical shocks. When this stimulation exists, a succession of small voltages in pulse train begins [6].

The record of the changes produced by the discharge of muscle fibers is known as Motor Unit Action Potential (MUAP). Under normal conditions, the average amplitude of a MUAP is approx. 0.5 mV, and its duration is 8 to 14 ms depending on the size of the MU [8].

To transfer the information that circulates through the human body to some electronic device, a transducer is used: a device capable of transforming one type of input energy to another type of output energy. In the field of bioelectricity, the transducers used are small metal plates (sometimes accompanied by electrolytic material to reduce noise) called electrodes, and they are in charge of making the ionic transfer of living tissue to an electronic device capable of processing and / or interpret it [7].

Among the most studied biosignals are electrocardiographic (ECG) and electromyographic (EMG), the latter being the object of study of this article. A comparison between the spectrums that different EMGs can generate can be seen in Fig. 2 [8].

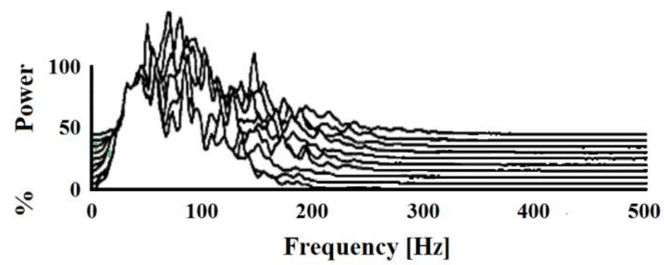

Fig. 2 Graph of the frequency spectrum of some EMG signals.

Electromyography is a mostly diagnostic procedure that is used to evaluate the health of the muscles and the nerve cells that control them, but also, another part of the study is responsible for measuring the speed and intensity of the signals that travel between two or more points [8].

Electrodes take part in this process. Afterwards, the information extracted from the EMG signals is selected in such a way as to minimize the error in control, and for this the motor units are taken into account, since the frequency of their activity can sometimes be involuntary. The frequency spectrum of motor units during MVC (voluntary muscle contraction) can be seen in Fig. 3[8].

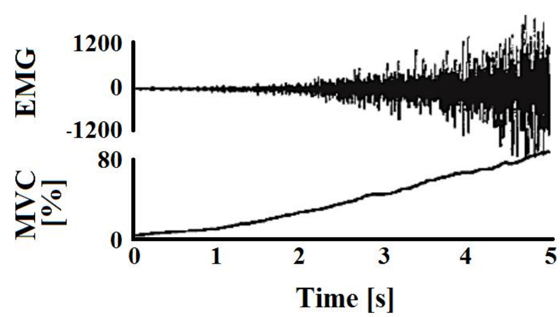

Fig. 3 Correspondence between Voluntary Muscle Contraction (MVC) and electromyographic signal (EMG).

There are mainly two types of electrodes: surface and invasive. The former are placed on the surface of the skin and are capable of taking records of bioelectric activity; while invasive electrodes are inserted into the tissue to directly measure the potential difference between the cell membrane and the skin [7].

It should be noted that invasive electrodes are automatically discarded, as they involve a painful process and special attention. It must be remembered that the purpose of the device is to improve the quality of life of the patient, not to complicate it with additional setbacks [7].

B. Modeling of a prosthesis based on anatomical principles.

Entering into the specific functioning of the limb, the human hand allows us to perform innumerable actions thanks to its essential function: pressure. The multiple actions, positions and movements are largely due to the thumb, which can oppose the rest of the fingers, since being fixed below them, the closing and rotation movements can be performed [9].

The shape of the hand can be adapted depending on the object that comes into contact with it, on a flat surface for example: the hand is extended and flattened by the thenar eminence, the hypothenar eminence, the metacarpal head and the palmar aspect of the phalanges; the range of flexion in the interphalangeal joints increases from the second to the fifth finger, to reach up to 135 ° at the level of the little finger; flexion at the distal interphalangeal joints is slightly less than 90 °; with regard to active extension in interphalangeal joints, it is null in proximal and distal joints [9].

In order to determine a good mathematical model of a human hand, six Cartesian reference systems must be kept in mind. These are used to define the position and orientation of the tendons and describe the configuration of the joints. By means of this system, the position of the fingers in a three-dimensional space can be determined [9].

The type of prosthesis that best meets the needs of this article is the myoelectric prosthesis: an electrical limb controlled by an external voltage EMG. It is the best option for an artificial limb, as it has the highest degree of rehabilitation, as well as the best aesthetic appearance or has great strength and speed of arm grip. The closest model to our ideal and the exact operation are shown respectively in Fig. 4 and 5 [10].

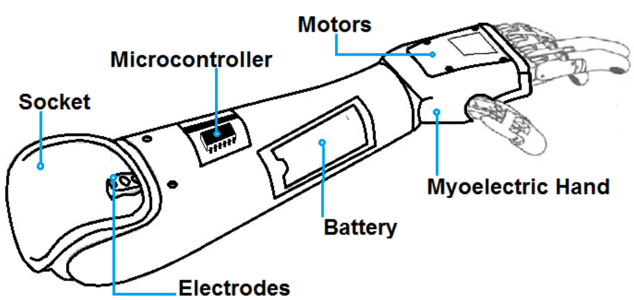

Fig. 4 Ideal model of a myoelectric limb.

Fig. 5 General Block Diagram.

The complete project is still under development, but the fundamental part is ready, and has been taken to the tests at an electronic level, in other words, we have results about the conditioning of the signals based on MUAP parameters.

IV. Circuit Design and Testing

A. Primary concept of amplify input signals.

For the amplification stage, it was necessary to considerate that the gain must be very large, because the input signals are in the millivolt range. Fig. 6 details the operation of the stage.

Fig. 6 Block diagram of the amplification stage.

It is essential to contemplate that this type of signals are surrounded by a large amount of noise, caused by different factors such as interference due to external media, the influence of another signal or electrostatic charges. The solution to this problem is selecting an amplifier that works in differential mode, which has a high Common Mode Rejection Ratio (CMRR) [11]. It was decided to use an LM741 Op Amp because it is a cheap general purpose IC.

B. Signal filtering.

For the design of the filter it was considered to use a Butterworth, because it provides a gain that is as flat as possible. [11]. It was configured using the Sallen Key parameters, for its simplicity and performance as a good band pass filter. Fig. 7 shows its construction, and Fig. 8 shows the frequency response of the system, theoretical and experimental.

Fig. 7 Sallen Key Filter block diagram.

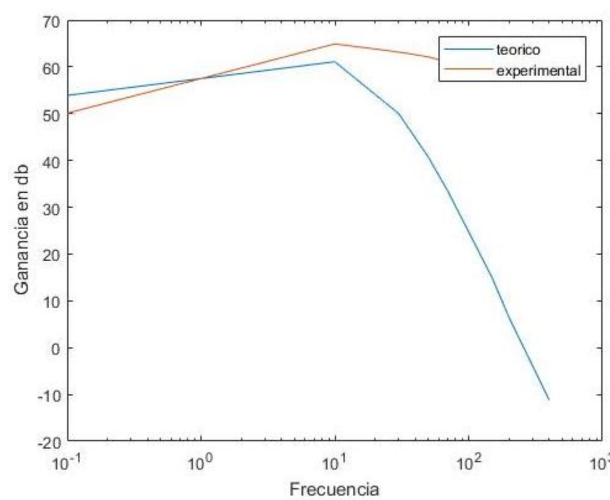

Fig. 8 Theoretical and experimental behavior of the Sallen Key filter.

We can notice that at low frequencies (f<10 Hz), and high frequencies (f>400 Hz), the filter fulfills its mission of attenuating unwanted signals, allowing only the signals within this range to be manipulated.

C. Implementation and testing

In Figs. 9, 10 and 11, the filter design is shown in a strategic order in the Proteus simulation software, from

Labcenter Electronics, as well as the results and its Printed Circuit Board. The stage was fed with Arb signals in the millivolt range, and judging by the voltage level at the output, we can say that the circuit fulfills its purpose.

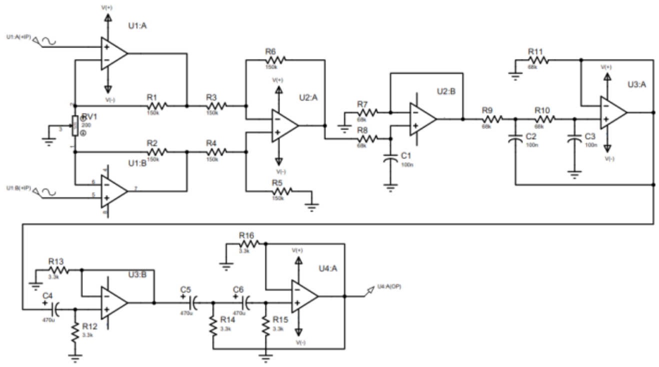

Fig. 9 Components and connections of the amplification stage.

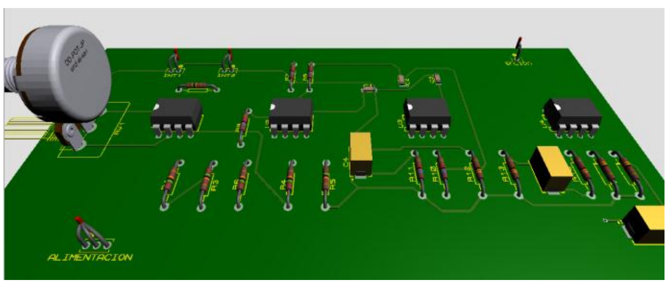

Fig. 10 Experimental PCB.

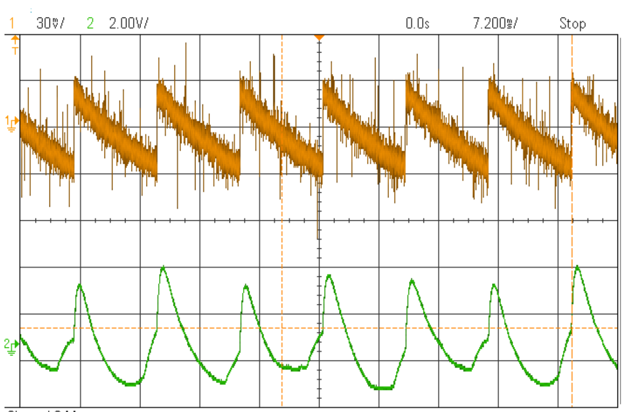

Fig. 11 Experimental output signal, where Vi = 5.10 mV and Vo = 5.3 V

C. Price comparison.

Maintaining a low price contributes to a greater number of people being able to acquire our prosthesis easily, reducing the number of cases left unattended. Our circuit generates reliable data in amplification and filtering, therefore, we consider that it performs the same functions as the MyoWare development kit (as a reference), but at a cost 9 times lower. To date, the kit has an estimated cost of $ 82.95, while our prototype, $ 1.5 + $ 5 production.

V. CONCLUSIONS

Our purpose is to create a reliable, economical and safe system. The design of the amplification stage, as well as the Sallen Key filter, works the way we expected, where a frequency of 10 Hz is set to 400 Hz, and an amplification of 5 V for the input voltage of a microcontroller, conditioning and cleaning the bio-signals as best as possible. This experimental filtered signal has a similarity to the theoretical signal obtained.

All this conditioning was done for the next stage, which is currently under development: convert them from A/D to obtain different movements by means of fuzzy control and low-resource microcontrollers. The total cost for the first part of the project was USD 6.5 compared to the USD 82.95 it costs to have a development kit. A functional and aesthetic prototype is expected to be in operation as soon as possible.

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