Development of a control system for a prosthetic hand assisted by electromyographic signals

John Calle - Sigüencia
Grupo de Investigación en Ingeniería Biomédica (GIIB)
Universidad Politécnica Salesiana
Cuenca, Ecuador
jcalle@ups.edu.ec

Edison S. Tenesaca Lliviganay
Grupo de Investigación en Ingeniería Biomédica (GIIB)
Universidad Politécnica Salesiana
Cuenca, Ecuador
etenesacal1@est.ups.edu.ec

Ronny N.截Tituana – Salinas
Grupo de Investigación en Ingeniería Biomédica (GIIB)
Universidad Politécnica Salesiana
Cuenca, Ecuador
rtituanas@est.ups.edu.ec

Fernando Urgiles - Ortiz
Grupo de Investigación en Ingeniería Biomédica (GIIB)
Universidad Politécnica Salesiana
Cuenca, Ecuador
furgiles@ups.edu.ec

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***Abstract*— This paper presents the development of a controller for a prosthetic hand prototype considering the acquisition of electromyographic signals through the Myo Armband (MYA), which consists of eight medical grade surface sensors. The myoelectric signals are acquired from the forearm muscles of a 23 years old male person, then amplified and filtered to obtain a suitable signal which, by means of a program in a controller, is in charge of issuing commands to the actuators and micromotors to perform the different types of grasps and movements established for the prosthesis. It enables obtaining filtered signals capable of efficiently controlling seven hand movements without modifying the aesthetics nor the anthropometry of the prosthesis prototype.**

Keywords*— *controller, prosthesis, myoelectric signals, electromyography.

I. Introduction

In 2017, the National Council for the Equality of Disabilities (CONADIS, Consejo Nacional para la Igualdad de Discapacidades) determined that there were 418001 people in Ecuador with some type of disability. Physical disabilities affect 14630 people, which corresponds to a rather high percentage of 47.07% [1]. According to the Laboratory of Technical Orthopedics of Pichincha, from 2012 to 2015, 92 people with transradial amputation, 46 with transhumeral amputation, 6 with elbow disarticulation and 5 with shoulder disarticulation were benefited with different types of prosthesis [2].

In 2014, the Universidad Politécnica Salesiana (UPS), at Cuenca, made a first prototype of a biomechanical right-hand prosthesis named MAKI 1.0, whose control system is based on the acquisition of a signal with an optical proximity sensor that responds to the signals obtained from the patient stump, and a system that controls a degree of freedom for each finger, generating sequences programmed for the different types of grasps [3]. In 2015, the second phase is carried out in the Biomedical Engineering Research Group (GIIB, Grupo de Investigación en Ingeniería Biomédica), obtaining the MAKI 2.0 prototype which presents a new design with dimensions and shapes similar to the human hand; it integrates the rotational movement of the wrist which produces the pronation and supination movements, maintaining the optical sensor for signal acquisition, achieving a better definition of the default grasps and the rotational control of the prosthesis [4].

Seeking to improve the capabilities of the prosthesis prototype, in 2018 the members of the GIIB developed MAKI 3.0, which integrates a mechanism for obtaining the flexion and extension movements of the hand, and also improves the materials and manufacturing techniques used, considering the stereolithography process to make the components. The MAKI 3.0 prototype is constituted by fingers: little, ring, middle and index, each with two phalanges. The prosthesis has seven degrees of freedom (DOF): one for each finger, which are connected to a linear actuator that performs the extension-flexion movement; one degree of freedom for the pronation and supination of the wrist, and a degree of freedom for the flexion and extension movements [5].

The hand is considered as a mechanical and sensitive tool [6], being the main part of physical manipulation due to the pressure and tactile functionalities that enable performing the different movements, grasps and objects manipulation [7] [8]. The loss of one or both upper or lower limbs is an event that considerably changes the life of a person. Based on the above, the purpose of a prosthetic hand is providing some physical manipulation functionalities, but the prosthesis will never replace a missing limb of the human being [9] [10].

The mechanical system and the control system of the prostheses are two key components that enable an efficient integration to improve the quality of life of amputee patients [11]. As time went by, the prostheses were gradually adapting to human physiology and the electric activity generated by the muscles was integrated to control them [12]. The generated electric signals are known as electromyographic (EMG) or myoelectric signals, produced during muscular contraction [13]. The development of new technological devices contributes in a considerable manner to improve the control systems, and this is the case of the Myo armband, an instrument that thanks to the

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researchers of the Johns Hopkins University was adapted to a patient that completely lost the two arms, from the shoulder down, so that such patient makes the most of the robotic arm movements, and this is an important advancement in the development of biomechanical prostheses [14].

In the study conducted by the New Jersey Engineering and Technology School, the MYA is used for the control of 6 movements in a robotic hand. The study initiates with the construction of the hand by means of material deposition printing in a 3D printer and programming in Visual Studio 2013 using an Arduino, which performed the movements of the actuators according to the programmed movement [15].

Another interesting study compares the bandwidth of the MYA, with an EMG conventional acquisition system (CONV); six features are extracted from the data of eight patients and they are classified using Linear Discriminant Analysis (LDA), which enabled to determine that the armband may be appropriate for pattern recognition applications despite its bandwidth limitation [16].

In 2017, a study was conducted in the Biomedical Engineering Research Group (GIIB-UPS) using the MYA, consisting in the identification of three types of basic hand movements that extract essential features for its use in pattern recognition [17].

In spite of the studies conducted, it has not been developed in Ecuador an EMG controller with the MYA device that may be integrated to a prosthesis of the type MAKI 3.0; in this context, the development of a control system is presented in the following, capable of integrating in the prosthesis all electronic elements required to perform the movements of extension-flexion of the fingers, lateral grasp, cylindrical grasp, precision grasp, hook type grasp, typing position, pronation-supination of the wrist system and flexion-extension of the hand, providing the user an efficient control system for the prosthesis.

II. METHODOLOGY

For developing the model, the prosthesis is first constructed according to the MAKI 3.0 prototype, and then the control system is developed and implemented.

A. Construction of the MAKI 3.0 prototype.

The MAKI 3.0 prosthesis for which the controller will be implemented has 7 DOF, which are distributed as follows: 1 DOF for every finger that performs the flexion-extension movements, 1 DOF for the pronation-supination movement and 1 DOF for the flexion-extension movement of the palm of the hand, with its set of mechanical and electronic components.

Two fast prototyping techniques are utilized for the construction, namely 3D printing by stereolithography (SLA) and 3D printing by material deposition, with the help of Form 2 and RAISE3D Pro2 Plus printers.

The prosthesis is structured by: palm, back, fingers, phalanges, couplings, links, guides, coupling ring, wrist body and socket. The final assembly of the prosthesis is shown in Figure 1.

The following materials are used for the development of the control system: Myo armband which consists of 8 medical grade stainless steel sensors, placed following a circular shape; a Bluetooth HM-11 SMD module, a third generation Core i5 computer with 8 GB of RAM memory, an Arduino Nano, an Arduino ProMini and finally the IDE Arduino programming software.

Fig. 1. Assembly of the MAKI 3.0 prosthesis.

B. Development of the controller

The interface used is the Myo-Arduino through which it is obtained the values of the EMG signals in real-time and the representation of each of the eight signals acquired by the armband. Figure 2 illustrates the sequential diagram used for the acquisition and visualization of the signals.

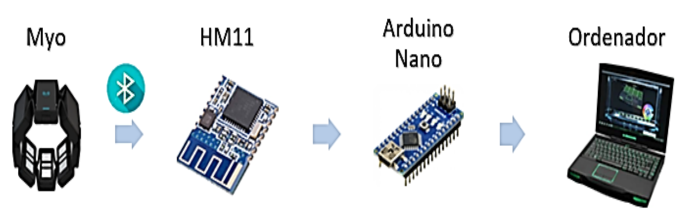


Fig. 2. Diagram used for signal acquisition.

Most of the Bluetooth models with low power consumption have a set of limited features, due to the factory programming. This is why to connect it directly to the Myo armband, the MyoBridge library firmware is loaded in the HM-11 module, and this library enables that the reading of the armband data is accessible to the Arduino board.

For loading the firmware, the HM-11 is connected in the Arduino Nano according to the pin distribution shown in Figure 3. The pins of the HM-11 module are respectively connected to the inputs D5, D6, D4, 3V3 and GND of the Arduino Nano.

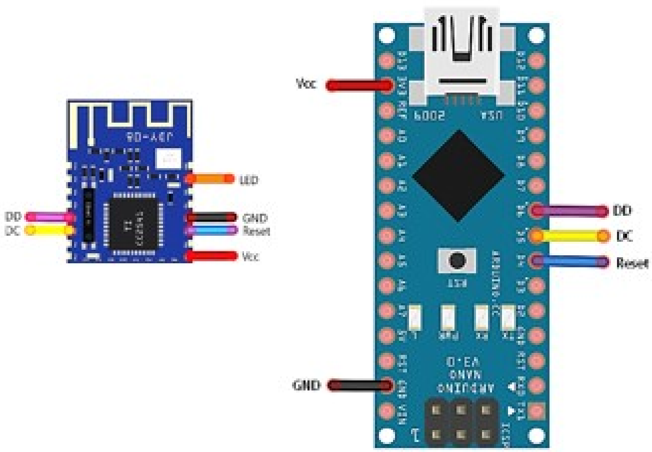


Fig. 3. Connection Bluetooth module-Arduino

For loading the firmware, it is required to download the CCLoader-master folder of RedBearLab [18] and the MyoBridge-master folder [19], both available at GitHub; the steps for the load are detailed in the blog of Ahmed Alsharif [20].

Once the firmware has been loaded, the armband is turned on and it is proceeded to the matching with the Bluetooth module, which is successful when the blue indicator led in the armband is lit.

- *Acquisition of signals*

The acquisition of myoelectric signals is carried out from the forearm of a 23 years old person, with a weight of 52 kg, a height of 1.65 m and a forearm diameter of 24 cm. The armband is located at approximately 3 cm below the bending of the forearm and with the upper side of the hand aligned with the brand logo on the device (Figure 4).

Fig. 4. Location of the armband on the patient forearm.

Once the armband is put on, the patient performs with the fingers the seven movements stated in Table 1; these movements will enable acquiring the signal, which will then be filtered and processed in the microcontroller to issue to the prosthesis the command according to the particular type of grasp; the types of grasp were defined considering the user needs.

TABLE I. MOVEMENTS ESTABLISHED FOR THE PROSTHESIS

MOVEMENT PERFORMED BY THE USER		TYPE OF GRASP
Fist		Cylindrical grasp (bottle)
Hand to the left		Point or precision grasp
Hand to the right		Lateral or card grasp
Extended fingers		Typing position
Double touch between thumb and middle finger		Cylindrical grasp (pen)
Fist and hand up		Hook type grasp
Double touch between thumb and little finger		Pronation-supination

For each movement performed, a window of 10 data is taken, where the person remains with the arm at rest for the first 60 seconds, and then performs various repetitions of the first movement. Once the repetition of the signal is available, the movement is validated and the values of the signals for each of the armband electrodes are saved. Then the user relaxes the forearm during 15 seconds until the signals stabilize, and the same procedure is carried out for the movements remaining.

From the moment in which the person puts on the armband and remains with the muscles relaxed, it is observed that noise gets into the signal, due to the presence of external sources such as the computer and the circuit power supply source (Figure 5).

Fig. 5. Values of the EMG signals in the IDE Arduino serial monitor with the forearm at rest

- *Filtering*

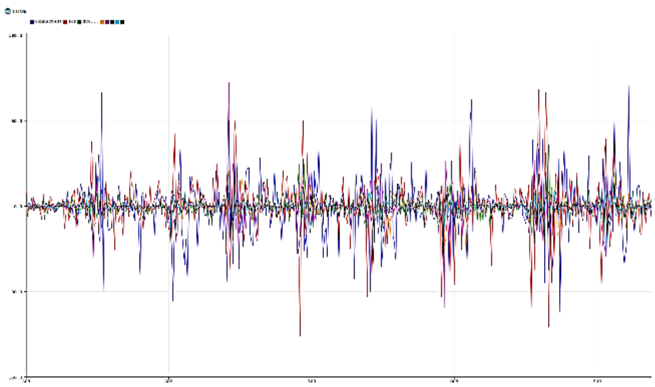
The signals acquired by the Myo armband have noise due to the parasitic currents that entered during signal acquisition, and thus it is necessary to implement a digital filtering algorithm to these values.

Considering the specifications of the MYA which include a pre-amplifying and filtering stage, which is not accessible due to a manufacturer policy, the values obtained in the acquisition are employed and a digital filtering algorithm is implemented in the microcontroller.

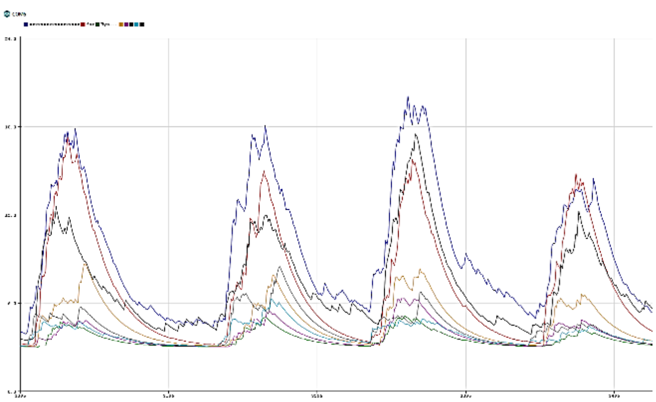
Among other operations, the algorithm applies a moving average filter, which converts the negative part into positive to have an absolute value.

The signal of the forearm at rest has noise whose amplitude varies between 0 and 5, either produced by the circuit supply or other currents that enter at the moment of acquisition; to overcome this, a code is implemented that does not take into account values in that range; a window of five values is considered and the average is calculated, which enables reducing the peaks that may interfere with the signal, thus obtaining a more distinguishable and numeric signal that enables a correct characterization of the signals.

Figure 6 shows an example of a signal performed by the user, where it can be seen the pure EMG signal and the signal applying the moving average filter.



a)



b)

Fig. 6. Movement of double touch thumb-middle finger: a) Initial signal, b) Signal applying the moving average filter.

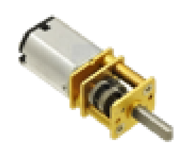
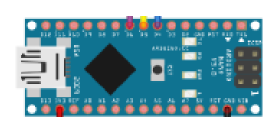
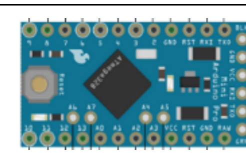
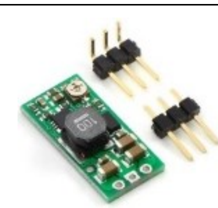
Once the signals have been filtered, using the method explained in the filtering section, it is proceeded to identify patterns that repeat when performing each of the movements, taking real-time signals while the user performs particular movements; for instance when making the fist, a greater amplitude is generated in electrodes 1 and 2, and from this, the programming code is implemented based on an algorithm that identifies when the signal corresponding to each electrode is within a range or has surpassed a threshold and identifies the movement performed by the person, and a grasp previously assigned to that movement is performed in the prosthesis.

The controller is in charge of identifying the command and then executing it; first the command is sent from the Arduino ProMini card to the Arduino Nano, and once both have received the command, they activate or deactivate their digital outputs to move the motors. The control is proportional to the actuators of the fingers and the wrist to perform each default movement.

- *Control circuit*

The control circuit is designed from the electronic and mechanical elements that are in charge of performing the different grasps in the prosthesis. The elements that constitute the prosthesis are presented in Table 2.

TABLE II. ELECTRONIC ELEMENTS OF THE PROSTHETIC HAND

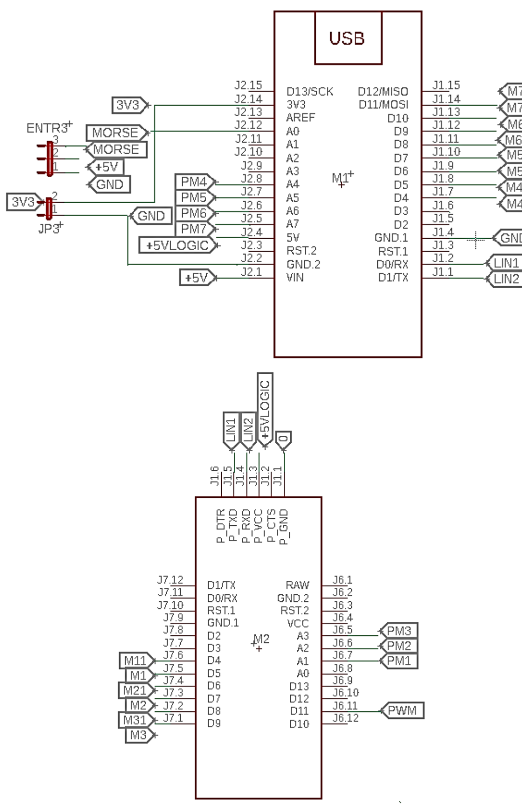
Element	Picture
Linear actuator PQ12-P	
Micromotor 1000:1	
Bluetooth module HM-11	
Arduino Nano	
Arduino ProMini	
Voltage regulator 2.5 – 9.5 V	
Lithium battery 3.7V	

Initially, the control system circuit is assembled on a board for experimental tests, to help determining the necessary elements and the controller functionality.

Fig. 7. Initial assembly of the control system on a board for tests.

Once the results are verified, the circuit is modeled with the help of the Eagle software, and it is connected to the Arduino Nano the H bridges that enable reversing the rotation of the motors, for both the actuators and the micromotors integrated in the prosthesis, and to the Arduino ProMini the Bluetooth module, for the wireless connection with the armband, and the voltage regulator from 2.5V to 9.5V, which is required to raise the voltage of the battery mounted on the back of the hand for supplying power to the Arduinos.

The designed control circuit is shown in Figure 8.



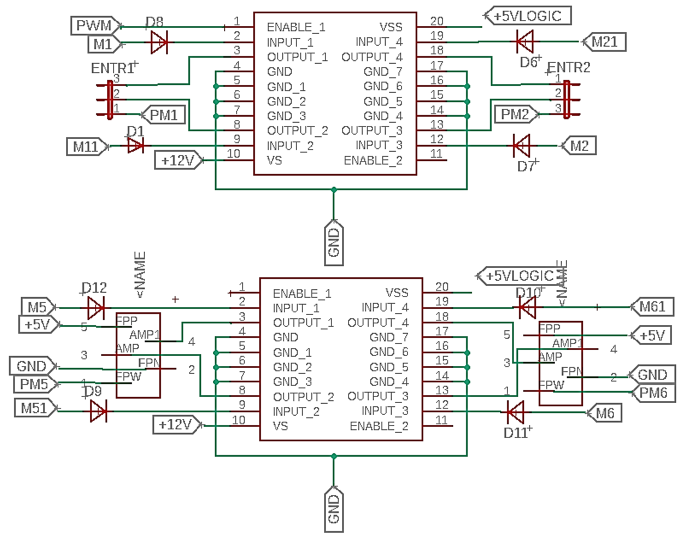


Fig. 8. Circuit desgined for the control system.

- *Printed circuit board (PCB)*

The control board is designed taking into consideration the space reserved in the palm of the hand (Figure 9), using SMD components for its optimization and correct integration inside the prosthesis.

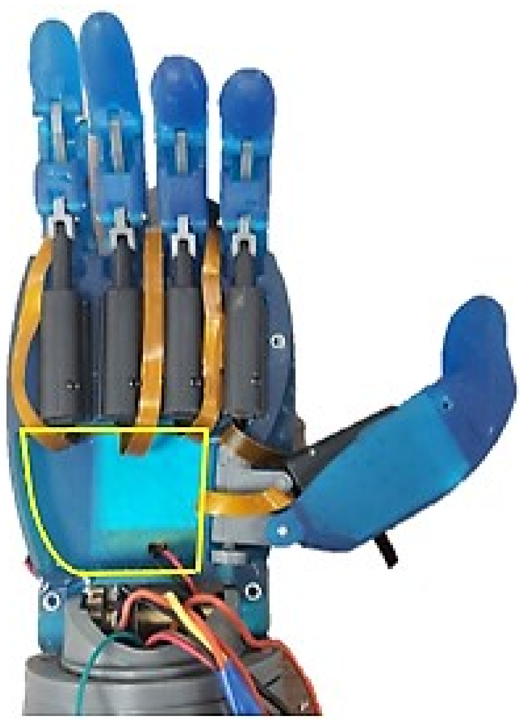
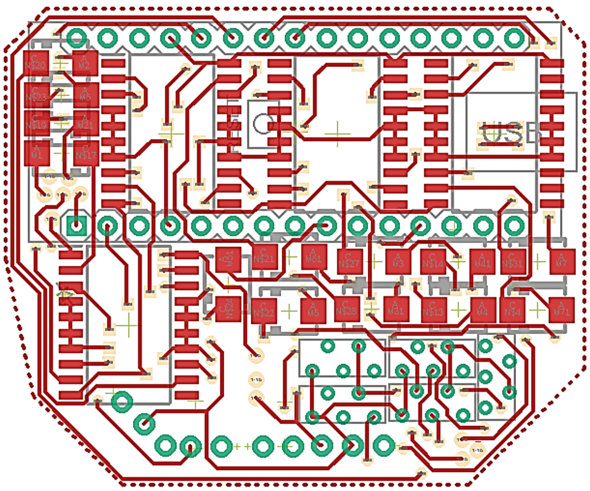
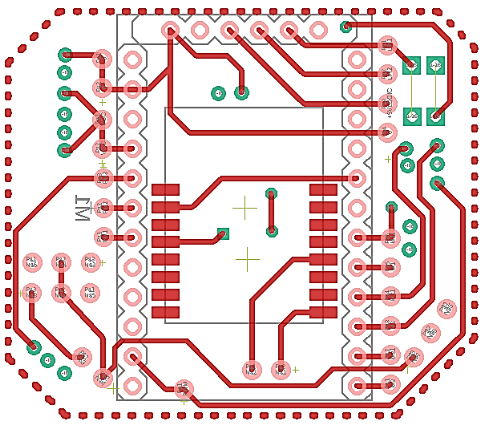


Fig. 9. Space for integrating the controller.

The control board consists of two parts, a main board which integrates the Arduino Nano, the H bridges and the linear actuators; this main board will be connected to a secondary board that includes the Arduino ProMini and the Bluetooth module to which the Myo armband is connected wirelessly.



a)

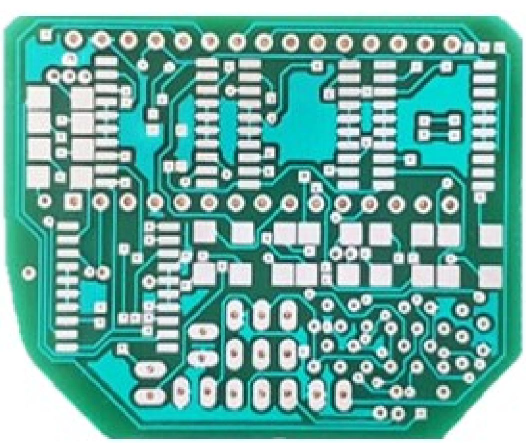


b)

Fig. 10. a) Main control board. b) Secondary board.

- *Assembly*

The board is built and all the components are soldered on their corresponding footprints with the aid of a soldering station; it is verified that the connections between the tracks and components are correct, because at the moment of soldering problems may appear, such as junctions between tracks and cold solder joints.



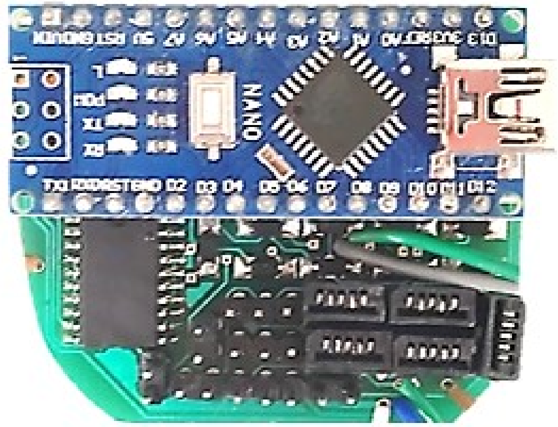


Fig. 11. Final control board.

Each of the electronic elements in charge of enabling the movements of the prosthesis are connected on the board, and the controller is integrated under the palm of the hand for the corresponding tests. In addition, the prosthesis includes a 3.7V/2500 mAh rechargeable lithium battery in the back of the hand, for enabling six hours of autonomous work of the prosthesis (Figure 12).

Fig. 12. Final assembly of the prosthesis.

A socket is required for integrating the prosthesis to an amputee patient; this socket is modeled by means of a three-dimensional scan of the arm, for an appropriate fit.

III. Results

First of all, the code implemented for filtering the signal results in reduced signal peaks, which enabled a better characterization of such signal, and it is used in the control system with an efficient response (Figure 13).

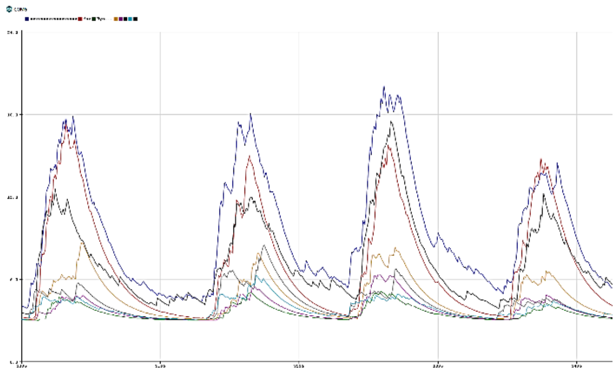
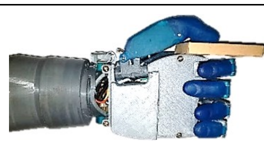


Fig. 13. Filtered signal, used for the controller.

Secondly, tests were conducted on a person without amputations, to work with the acquisition of signals. Table 3 indicates the grasps performed in the prosthesis according to the myoelectric signals taken from the Myo armband.

TABLE III. GRASPS PERFORMED IN THE PROSTHESIS

Type of movement	Picture
Lateral grasp	
Cylindrical grasp	
Precision grasp	
Hook type grasp	
Typing position	
Pronation-supination of the wrist system	
Flexion-extension of the hand	

The grasps are obtained after some attempts by the user, and controlling that the signal is according to the one taken as basis, to guarantee the controller and programming efficiency. All the established grasps and movements were obtained.

As an important fact it should be considered the repeatability of the muscle maneuvers, i.e., if the fist is performed, thus generating a greater amplitude in the signals of electrodes 1 and 2, when this movement is performed again, it should produce similar signals so that the implemented algorithm is more efficient; this is achieved with a previous training of the patient for developing an agile manipulation of the prosthesis.

As an added value to the controller, it may be observed that it is flexible because it may be adapted to the specific conditions of the user of the prosthesis; this is very important because the signals of an amputee person may be different due to the loss of both muscle mass and movement capability, and in addition the free manipulation of the programming code enables changing the different types of movements of the prosthesis, depending on the requirements of the user in the daily activities.

Another important aspect is the physical space available to integrate the card, because if the amputation occurs at the level of the wrist, the space becomes an essential limitation that should be considered. The design of the card that enables the integration of all components is efficient since it does not alter the aesthetic and the anthropometry of the prosthesis prototype, which is a very important factor for the users.

Finally, the average cost of the prosthesis for a user is $1700 (one thousand seven hundred US dollars), considering all the components and its manufacturing, compared to other prostheses with similar functionalities that may cost up to $20000, thus presenting a significant competitive advantage.

IV. CONCLUSIONS

The Myo device is a tool that may be exploited for the development of controllers for prostheses, since it does not require a significant conditioning of signals and due to its eight sensors it enables developing identification methods using amplitude-based techniques; in addition, it is a non-invasive technique and eases the acquisition of muscle signals from the patient, without causing any pain or damage to the muscles.

The acquisition and classification of signals is the most critical task, since many factors such as external noise, external power supply sources and inappropriate contact of the electrodes with the skin, may influence the signal capture; as a consequence, it is important that the user is placed at a comfortable site so that the EMG signal does generate problems during filtering and processing.

Signal filtering is a crucial stage in the development of this study, since it enables eliminating noise and obtaining an EMG signal which is appropriate for performing the movements of the prosthesis. It should be taken into account that the effectiveness of the controller will depend on the ability of the user to repeat the movements performed.

The controller is flexible, since the signals may be adapted to the specific conditions of the user of the prosthesis; in addition, the free manipulation of the programming code enables varying the different types of movements in the prosthesis.

The study presents a very important cost-benefit ratio with respect to other models available in the market that have very high cost, thus making difficult the accessibility of low-income people to them; for this reason, it is intended from this work to generate a low-cost functional prosthesis, with anthropometric features and dimensions similar to a human hand, such that it provides the appropriate requirements to improve the quality of life of the user.

V. Future works

As a future work, it is intended to optimize the electromyographic controller to reduce the signal error, and to place an additional battery in the prosthesis to increase its autonomy; in addition, it is intended to conduct tests in an amputee patient in order to carry out a study of the signals, since they will vary depending on the forearm muscles and some may be null as a consequence of the loss of the limb, and a previous and exhaustive training would be required to perform the movement of the prosthesis.

Acknowledgements

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References

[1] Datos estadísticos Elaborados por: Consejo Nacional para la Igualdad de Discapacidades (CONADIS) Dirección de Gestión Técnica Julio, 2017, [online] Available: http://www.consejodiscapacidades.gob.ec/estadistica/index.html.

[2] Boonlar, T & Prasatkaew, W. (2018). The Development of Hand Controller for Persons with Disabilities by Myo Sensor. In Proceedings of the 14th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS), (pp. 375-379). Las Palmas de Gran Canaria, Spain. doi: 10.1109/SITIS.2018.00065.

[3] J. Cuzco, M. Quinde, J. Brito, J. Calle and F. Urgilés, "Design, construction and implementation of right biomechanical hand prosthesis," 2014 IEEE ANDESCON, Cochabamba, 2014, pp. 1-1.

[4] L. F. Cajamarca, J. Matute, J. Calle, F. Yunga, J. Vargas and F. Urgiles, "Design, development and implementation of a biomechanical right-hand prosthesis: Second stage," 2017 IEEE Global Humanitarian Technology Conference (GHTC), San Jose, CA, 2017, pp. 1-6.

[5] Encalada Seminario, G. A. Análisis cinemático y cinético de los mecanismos para una prótesis biomecánica de mano y construcción de un prototipo utilizando el proceso de estereolitografía (Bachelor's thesis), Cuenca, 2018.

[6] A. I. Kapandji, Fisiología Articular, 6th ed. Madrid, España: Editorial médica Panamerica, 2006, no. 1.

[7] J. M. Dorador Gonzáles, P. Rios Murillo, I. Flores Luna, and A. Juárez Mendoza, "Robótica y prótesis inteligentes," Revista Digital Universitaria UNAM, vol. 6, no. 1, p. 15, 2004. [Online]. Available: http://www.revista.unam. mx/vol.6/num1/art01/int01.htm

[8] V. Bundhoo, "Design and evaluation of a shape memory alloy-based tendondriven actuation system for biomimetic artificial fingers," Master of applied science in the Department of Mechanical Engineering, University of Victoria, 2009.

[9] B. Peerdeman, "A Biomechanical Model for the Development of Myoelectric Hand", IEEE explore, pp. 1-2, 2010.

[10] P. Richard F, ff. Weir, "Design of artificial arms and hands for prosthetic applications," in Standard handbook of biomedical engineering and design. Chicago, Illinois: Digital Engineering Library McGraw-Hill, 2004, ch. 32.

[11] C. A. Silva Castellanos, J. E. Muñoz Riañoz, D. A. Garzón Alvarado, N. S. Landínez Parra, and O. Silva Caicedo, "Diseño mecánico y

[12] JH Bower, JW Michael, Jonh W., Atlas of Limb Prosthetics, Control of limb Prostheses, Chapter 6D, 1992, pp. 175-184.

[13] J. Hamill, K. M., Knutzenl, Biomechanical Basis of Human Movement, Muscular Considerations for Movement, Chapter 3, 1995, pp. 81–86.

[14] L. Cortes Carvajal, M. Guerrero Doria, J. Realpe, H. Romo, "Sistema detector de intención de movimiento a partir de señales electromiográficas superficiales", Revista PUENTE Científica, vol. 7, no. 2, 2014.

[15] Z. Abraham, D. B. Kwon, T. Solomon, M. Xie, K. Yeh, "Control of an affordable hand and wrist prosthesis", 15th Research Symposium Rutgers School of Engineering, pp. 1-13, 2015.

[16] I. Méndez et al., "Evaluation of the Myo armband for the classification of hand motions," 2017 International Conference on Rehabilitation Robotics (ICORR), London, 2017, pp. 1211-1214.

[17] FS Coronel-Maldonado, RA Pinto-León y FL Bueno-Palomeque, "Identificación de patrones básicos en los movimientos de las manos utilizando electromiografía de superficie", 2017 IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC), Ixtapa, 2017, pp. 1 -6. CA: University Science, 1989.

[18] "GitHub - RedBearLab/CCLoader: Burn BLE Mini (CC2540) firmware using Blend Micro board." [Online]. Available: https://github.com/RedBearLab/CCLoader. [Accessed: 30-Jul-2019].

[19] V. Roland, "MyoBridge/MyoBridge_CC2541.bin at master · vroland/MyoBridge · GitHub." [Online]. Available: https://github.com/vroland/MyoBridge/blob/master/myobridge_firmware/Bin/MyoBridge_CC2541.bin. [Accessed: 11-Mar-2020].

[20] Ahmed Alsharif. «Connecting an Arduino to a Myo armband using a HM-10 / HM-11», Raquena Engineering, 2017. https://blog.raquenaengineering.com/arduino-and-the-myo-armband/ (accedido jun. 24, 2020).