Electromechanical Hand Prototype for the Simulation of the Opening and Closing Movement.

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Abstract. This work aims to describe the construction of a low-cost functional prototype of an electromechanical hand with opening and closing capacity. The device, built on an ABS filament extruder, is actuated by a MG995 high torque servo motor, controlled by an Arduino UNO R3 board, from the processing of electromyographic signals carried out by: MyoWare Muscle Sensor. The realization and functional evaluation of the device is developed in six phases: The first is to select the thermo-deformable materials, the second is to select the electronic components; the third phase is the design of the electromechanical hand prosthesis, the fourth phase was the construction of the mechanical parts; the fifth phase is the development of the control program on the electronic card; and the sixth phase of the project consists of validating the developed prototype by observing its opening and closing through the oscilloscope. Due to the low cost of development and ease of reproducibility (because it is built under the open-source philosophy), this work is expected to make a contribution to the disabled community, especially the one with limited resources.

Keywords: Hand prototype, Electromiogrphic Signals, 3d print

1. Introduction.

This paper describes the construction of a functional electromechanical hand model for opening and closing functions. Therefore, the information on the materials, control, methods and methodology is described in it.

The device has a muscle sensor (EMG) brand Myoware, used in the development of biomechanical projects [1] [2] y [3], and an Arduino UNO electronic board is used as controller.
This work can generate a contribution to the disabled community, especially those with limited resources, by providing a low-cost device which can be improved and replicated, since this system was built with the philosophy of open access (open-source). There are currently 2,632,255 people with disabilities, that is, 6.4 percent of the general population [4]. Of this important percentage, 20.8% have a permanent alteration of the body, hands, arms and legs. On the other hand, according to data from the same registry, 49.3% of all disabled people belong to the subsidized regime, while 29.7% do not have any type of affiliation to a general health system. Therefore, the realization of low-cost prostheses responds to an important need for the lives of a large number of low-income Colombians without the economic capacity to use commercial prostheses.

Rapid prototyping developments, the integration of manufacturing with CAD programs, open access to biological information through repositories, and even the making available of components for modification and construction, has been shown to significantly reduce prosthetic design and construction costs [5]. For this reason, for the execution of this prosthesis, the UTS make available a 3D printing machine with autonomous electrical and mechanical positioning, while the hand is designed on the Repetier free access platform. In turn, a low-cost controller is implemented for the processing of the EMG signals and the actuation of the device. For the development of this project, a descriptive methodology was used with a qualitative and experimental approach divided into five stages: 1) bibliographic review of the state of the art, 2) consultation with experts, 3) definition and selection of components, 4) final tests prototype validation and 5) system results.

2. Prototype development: Manufacture of the external structure of the prototype

For the design and manufacture of the structure of the hand, CAD and Repetier software were used, in order to create the virtual model that will later be printed and assembled. Repetier is a free software for 3D printing with several applications for robotics developments [6] which also allows remote printing and storage of developed parts [7].

1) **Mounting files to Repetier-Host software**: Then the flexy-hand file is loaded [2] representing the structure of the hand in CAD, loaded in the Repetier – host software see (Fig. 1). The design was prepared and limited for the development of 3D printing, and the construction parameters such as the type of material to be printed, internal structure of the pieces, speed and quality of the printing were adjusted.

![Fig. 1. Virtual model of the 3D hand in Repetier-Host.](image)

2) **Printed Components**: The components are grouped in the program template and subsequently the print order is executed. How material was ABS selected. Printing took around 10 hours in total for printing only part of the palm and fingers. Additionally, it took approximately 4 hours to print the rest of the components. The pieces were built using a honeycomb-type internal filling, which is the most recommended internal structure for biomedical applications given its structural
capabilities in which low weight, high rigidity and porosity stand out [8]. In Fig. 2 the printing result is shown.

![Fig. 2: Resulting of printed components](image)

**Fig. 2. Resulting of printed components**

3) **Assembling the components**: A type of joint made of silicone was designed to join the fingers of the palms (Fig. 3, left). These joints were made from 3D printed molds and injected silicone. This operation allowed creating a set of 14 joints to unite all the fingers. The silicone joints were inserted into the fingers through horizontal grooves in such a way that they remain locked. This adjustment allows the movement of the pieces without disengagement (Fig. 3, right).

![Fig. 3: Silicone finger joints, left. Using the feet to develop the ensemble, right.](image)

**Fig. 3. Silicone finger joints, left. Using the feet to develop the ensemble, right.**

4) **Installation of the finger tension cables**: Nylon threads are inserted through each of the holes in the hand designed for this purpose, the process begins from each upper end of the fingers, through a hook in which a tie is made to hold it, and later the tensioner is inserted through each of the ducts until reaching the outlet located in the palm of the hand (Fig. 4).

![Fig. 4: Installation of the tensioning cables, left, assemble through one finger, right, exit of the tensioner by the palm of the hand.](image)

**Fig. 4. Installation of the tensioning cables, left, assemble through one finger, right, exit of the tensioner by the palm of the hand.**
5) **Assembly of all components:** The assembled pieces make up the final structure of the hand, to which the electronic and mechanical elements that will give it programmed mobility will be adapted. In Fig. 5 we can see the fingers already attached, a piece was designed, which is attached to the wrist of the hand, this piece is in the form of a tablet, and its purpose is to contain an Arduino uno R3 board, which will be used as control system for the mechanism.

3. **Prototype development: Linking the electronic components to the control board**

The connection of all electrical and electronic components was carried out in accordance with the requirements for which it was desired to develop the project. A muscle sensor was used to read the biceps activation of the arm, electrical conductors and electrode pads complement the installation of the sensor, meanwhile to generate the movement a high torque servo motor was implemented.

1) **Arduino R3 Control Board:** The board used to control the movements is the Arduino uno R3 which has an open code of programming. This card was selected for its versatility, low cost, easy installation, as well as having a complete hardware with multiple power inputs, an Atmel AVR microcontroller and USB port. Arduino UNO has demonstrated its ability to process multiple biological signals with biomedical applications, such as the control of heart beat [9], electromyography [10], and control of elbow movement [11], among others.

2) **Muscle Sensor:** To read the muscle signals, a Myoware electromyographic (EMG) sensor was implemented. This device has the peculiarity of having both sensor and transducer and control software incorporated in a single device, which works with Arduino hardware and software. The electronic card of the sensor, works to measure the electrical signal of the muscle fiber cells, performing preprocessing of this, through a band-pass filter and a rectification process, the signal is converted into an analog signal from 0 to Vs (source voltage, set to 6 V) that is easily read by the microcontroller. The magnitude of the signal is directly proportional to the activity in the muscle. Its operation is simple, since the electrodes have the function of capturing the amplitude of the muscle associated with the opening movement of the hand and it is configured to interpret the output voltage and possible presence of the activity to assist [12].

3) **MG995 servo motor:** The servomotor used is the Tower Pro MG995, which provides up to 11Kg-cm of torque and metal gears and high robustness, designed to work with high loads. This motor was selected for its applicability in biomedical projects [13], [14] and [15] in addition to being compatible with the control card.

4) **Connection and assembly of all electrical and electronic elements:** The electronic card and the servomotor were mounted to the red piece, which functions as a base for the servo and the electrical components, the servo was located on its bases and successively mounted on top of the servo the tablet that carries the electronic card was located. In Fig. 5 you can see the profile of the assembly of these two elements. Both the servo and the card tablet are attached by means of screws.

![Fig. 5. Visualization of the assembly of the servo and electronic card.](image)


The electrical elements were linked according to the traditional servo motor connection system, and the manufacturer's recommendations to the Arduino board, occupying a PWM output to control the servo motor [16], an analog input from the Arduino was also used for the signal EMG sensor. Both devices were powered with 5V available from an external source so as not to limit the servo motor current. Fig. 6 shows the final assembly of the prototype with the sensor attached and its implantation in the arm to perform the functional tests.

Fig. 6. Presentation of the prototype of the hand.

4. Prototype development: Control code programmed in Arduino IDE

The electronic control board uses Arduino software. This is an open source program. For this work, the ARDUINO 1.8.1 version was used to generate the lines of programming code. The servo.h library was necessary for managing the servomotor to associate the servo with the algorithm. Unlike the sensor, which does not require any library. A 10-line control code was developed which can be seen in Fig. 7. The programming code is designed so that when the muscle signal is activated and by means of a preset value, the <If - else> operation determines if it should close the hand, otherwise if the muscle signal is attenuated the hand should be opened. To keep the hand closed, the muscle contraction must be constant. The general flow diagram of the program is presented in Fig. 8.

Fig. 7. Programming Code in the Arduino IDE.
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Inicio

Configuración de valor umbral para activación de la mano (Treshvalue)

Lectura sensor EMG (Vs)

Vs < Treshvalue

Accionar Servomotor para abrir dedos del prototipo

Accionar Servomotor para cerrar dedos del prototipo

Fin

Fig. 8. Flow diagram of the Programming logic implemented in the controller

In Fig. 9, you can see all together the sensor signal captured by the oscilloscope, the muscle contraction of the forearm and the hand printed in 3D with its fingers closed. This answer meets the objectives set.

Fig. 9. Prototype response to a biceps contraction signal, the closure of the mechanism by action of the muscular response processed by the Arduino controller is observed

5. Discussion

The expected results of the development of this work was to obtain a 3D printed hand that had a good appearance that is capable of responding to muscle contractions, more specifically, that replicates the opening and closing movement of the hand.
The device was controlled by an Arduino microcontroller, which processed the information from a muscle sensor. The evidential type tests carried out on the electromechanical hand prototype yielded as results the visualization of the output signal of the muscle sensor and the verification of the opening and closing movement according to the muscular contractions performed by the volunteer. To guarantee the repeatability of the controller, 8 different tests were carried out, in which the behavior of the hand was replicated.

It was observed that it is necessary to locate the EMG sensor on an area of the arm where there is a large muscle such as the biceps, placing the floating electrode parallel to the muscle sensor, it was also found that the electrodes should not be reused for different practices, since contact is lost between the tests and the deposit of body sweat and environmental dust that increased the impedance of the electrode, making it difficult to read the signal.

On the other hand, this handheld prototype is very easy to operate, since the card does not require any configuration, so it only requires an electrical supply and adhere the electrodes to the volunteer's skin to perform the reading, and control this device at via Arduino.

Although the results are satisfactory, we consider that it is necessary to link the device to other muscles to observe their response. Also, evaluate the force and speed with which the movements occur. Even carry out tests on people with an amputated limb to observe what threshold values must be considered to activate the hand.

6. Conclusions

The manufacture of the pieces obtained from the virtual models was carried out correctly, obtaining pieces with the specified dimensions, which allowed a coupling with adequate tolerances between each piece, which, given the selected material and the type of printing presented an acceptable physical appearance and considerable stamina.

The connection of all the electronic components was carried out using Dupont type electrical conductors, following the electrical scheme suggested by the manufacturer, and the technical information from the collected literature.

Using the IDE Arduino software, the open programming code for the prototype was developed, in which the description of the function of each line of code was written in each of the lines of programming code to facilitate its interpretation and to be able to develop future modifications.

Functional tests were carried out for the validation of the prototype, developing 8 validation tests, yielding satisfactory operating results, in which there were no operating failures, taking into account that it is essential to always have electrode pads in good condition and not have been reused, additionally the power supply must be higher than 5V to guarantee the operation of the servomotor and the sensor. Performing tests with the oscilloscope to have a second way of verifying the operation of the hand, the output signal of the sensor was obtained and compared with the operation of the hand during muscle contraction, observing the replication of the movement made by the volunteer.

Finally, future experiments are desired, observing the operation of the hand with other muscles and integrating a more robust control system that allows controlling the opening and closing of the hand in different positions, to obtain a behavior more similar to that of the human hand.

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