

# Prototype of robotic mechanical prosthesis of upper limb at low cost

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**Abstract** — *The development of prostheses with robotics and programming solutions can be a viable low-cost alternative for simulating the functions lost by disabled people. These prostheses can be used as part of recovery and reintegration of these people with limitations, such as picking up objects and feeling textures due to the loss of part of the arm, either in the surgical process, due to genetic malformation, or by accident. Mechanized prostheses still have a high value of market, which contribute to low purchasing power, making the acquisition of this type of material unfeasible. Based on this reality, the present work aims to improve mechanical prosthesis of the upper limb with anthropomorphic characteristics focusing on low financial cost. To this end, we sought to develop prosthesis composed of mechanical parts designed in simplify3D V4.1 software for printing on a 3D machine (Anet A8), whose modeling was performed by the Autodesk Inventor program (student version), also employing EMG and force sensors Strain Gauge, whose commands were programmed on a nano Arduino platform. The results showed that the EMG sensors capture the neural signals and route them to the nano arduino providing the opening of the fingers of the projected mechanism. The force sensors also presented the closing of the fingers in a satisfactory way. Therefore, the work was relevant for the social aspect, in the development of mechanical prosthesis with accessible values, not compared to the values practiced by the market. The importance of works of this nature demonstrate the results of interdisciplinary knowledge in engineering solutions under current demands in the presentation of viable alternatives that can be improved in future research and in the creation of products.*

**Keywords**— *Mechanical prosthesis, anthropomorphic, electromyography, robotics, 3D printing*

## I. INTRODUCTION

The development of prostheses for the rehabilitation of amputees has been evolving in the market, however these mechanisms have a disadvantage in commercial acquisition. The prices charged for these prostheses are above the acquisition conditions for a large part of the population undergoing rehabilitation. The purchase of a prosthesis by people with low acquisition value ends up not being viable, and thus, they opt for non-automated mechanisms with low mechanical control and interaction with the user [2]. Studies are carried out to measure how expensive it is to develop low-cost mechanisms. In view of this problem, aiming at the design of prostheses with low cost, 3D printing has stood out in the academic environment, as it is possible to print models with characteristics similar to those of humans, giving it the ability to approach the resourcefulness of real human parts [1].

The interaction between man and prosthesis is based on the reading of the electromyography activity, where the measurement of the electrical activity in the muscle ventricle is performed through electrodes superficial to the muscle ventricle. Based on muscle contraction, it is possible to control the parts of the prosthesis by manipulating neuromuscular activity [3]. However, the high cost of these prostheses is due to the technological application and the materials that make up their structure, such as titanium or carbon. The sensors used in the structure perform the precise measurement of neural activity, and thus, situations like these allow isolating movements, giving the mechanism the ability to perform such movements similar to the original human physical structure [4].

The present work aims to present the development and improvement of upper limb prosthesis with anthropomorphic characteristics focusing on low financial

cost. The project will consist of parts consisting of a 3D printer, using EMG sensors and strain gauge force sensors.

Thus, relying on mechanisms aimed at assistive technology, such as the use of 3D printing, it is believed that there is a possibility to develop a mechanism capable of improving the social interaction of a person with physical limitations, increasing their ability to handle objects with greater skill, and also assist in a better quality of life [7].

## II. MATERIALS AND METHODS

In order to develop a mechanism capable of matching up with human reality, during the planning for the design of the project, a compatible sketch was designed for printing. The equipment used was the AnetA8 printer. Based on this model, a line of development was traced in which each segment should be modeled within the AutoDesk - Inventor student version 2018 platform.

Each structure was designed in such a way that all parts were able to interact mechanically, being then equivalent to the bone structure present in the composition of the human hand (Figure 1), which is composed of 27 bones. Thus, at the end of the modeling of the structures, the equivalent of 37 pieces was reached, all of them structured so that it was possible to pass internal cables to perform the movement of the fingers during an action (Figure 2).

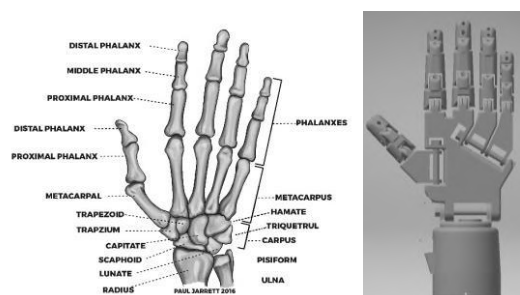


Fig. 1: Comparison between real model (left) & Developed in this work (right).

In its internal structure, perforations were arranged for the passage of cables with a diameter of 2 mm, the cable used in the assembly was of the type nylon monofilament with a diameter of 0.62 mm with mechanical resistance of 407.12 N (Newton), and to fix the fist by hand and fingers (thumb, ring and minimum), hexagon steel screws with a diameter of 12mm and a length of 70mm were used. Due to the easy deformation of the PLA material when inserting the screw, it was not necessary to use nuts to keep the structure fixed. To join the finger links, 1.5 mm hard copper was used in all joints.

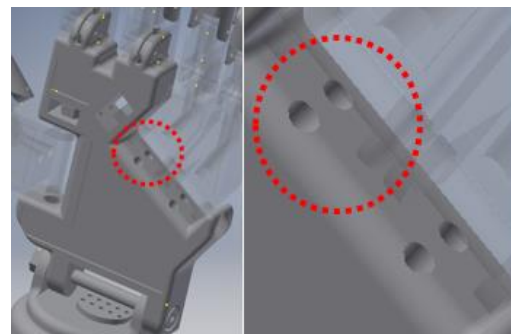


Fig. 2: Structure for cable routing.

To perform the printing of this 3D model of the prosthesis, the AnetA8 printer was used, as seen in Figure 1. This equipment comes from the factory with some limitations, such as: it does not have depth sensors to detect the approach of the extruder nozzle to the table and the sensors present are of the limit switch type. This feature, when not manually adjusting the table, can cause a collision between the extrusion nozzle and the table. Also, after the first impression, there may always be a mismatch of the side butterflies that attach the platform to the lower Z-axis carriage. In view of such measures, it is deemed necessary to carry out the automation of these calibration processes in order to increase the print quality and reduce the amount of adjustments between each print.

As a measure for the level switch with end-of-stroke characteristics, an inductive sensor was implemented due to its characteristic of detecting metallic materials, due to the printing platform having metallic characteristics. With the change of the Y axis sensor, it was necessary to update the firmware of the printer itself, modified to Merlin version 1.1.9. This version provides table calibration at 4, 6 and 9 points of precision. This calibration also allows that during printing the first layers are well adhered to the table avoiding deformation or poor filling of the initial layers. Based on the unevenness of the table, supports of the lock type were printed in the printer itself, in order to avoid loosening the butterflies that hold it, these modifications were made available on the website Thingiverse - Digital Designs for Physical Objects.

The filament adopted to compose the prosthesis in this first phase was the PLA. Its use was due to the assumption that this component suffered less impact on its structure during the sudden change in temperature, as the anetA8 printer has no control against external changes in temperature. This aspect, the material can be altered by a low intensity breeze and contribute to the solidification of the melted material. The PLA has a melting point of approximately 190°C, its adhesion to the table is much simpler, so it is unnecessary to apply substances to improve the adhesion of the filament in the first printing layer (MACHADO, 2018).

The software used for printing and configuring AnetA8 parameters was simplify3D V4.1. This software allows you to estimate how much filament will be consumed in each piece and its printing time. With these parameters it is also possible to assess how much energy will be spent to keep all and equipment up and running.

To perform the movement of the prosthetic fingers, high torque 13 kg / cm servo motors were used when powered at 4.8v, with 4.8 - 7.2 V operating capacity. The gears that make up the MG996R model (Figure 6), are made of metal which allows less wear between the gears and allows greater reliability in torque during the movement of the fingers, which can prevent wear on the gears and loss of efficiency during the movement of the prosthetic fingers.

The electrodes used were surface and EMG Advancer sensors to collect the electrical activity present in the muscle ventricle during contraction. They will be distributed over the biceps brachii muscle 1 in its medial part (muscle ventricle), one at its insertion (radial tuberosity) and the other on the brachioradial muscle. The EMG Advancer sensor (Figure 3) works directly with an amplified (rectified) signal, which allows direct use in a microcontroller.

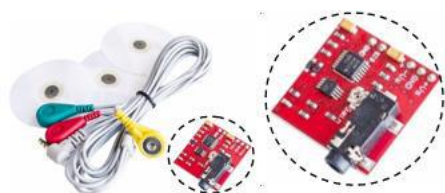


Fig. 3: Sensor EMG Advancer V3.

<http://qqtrading.com.my/electromyography%20sensor-muscle-activity-monitor-kit> acesso em 08 novembro 2019.

To measure the pressure of the fingers on the surface of the palm, the use of a force sensor with a measuring range between 100grams to approximately 10kg was adopted, with a detection area of 15mm in a circular format. They were conceived to interact motors and fingers, being the best option for the use of DAIYAMA fishing line MAX force model of diameter 0.62mm with capacity to support up to 40kg.

Evaluating situations where the contraction stops performed by the engines were necessary, strain gauge sensors were inserted in the palm of the prosthesis. The purpose of this sensor was to prevent structures from being detected during the closing movement of the fingers, and during contact, it prevents the fingers from closing irregularly, causing damage to the structure. The sensor has a circular shape with approximately 10 cm in diameter and is located on the palm of the prosthesis.



Fig. 4: Sensor Strain Gauge.

<https://www.robocore.net/loja/itens-eletronicos/resistor-sensivel-a-forca-redondo> acesso em 16 novembro 2019.

### III. RESULTS

With the positioning of the EMG sensors on the biceps musculature, it was possible to observe the signal propagated in the muscle ventricle at the moment when the muscle fiber is stimulated. Thus, Figure 6 shows peaks above 200 mv for contraction of the muscle ventricle. In this step, the EMG sensor, in addition to measuring the information, enlarges it so that it is possible to read through the analogy input of the arduino nano 3.0 (Figure 6).

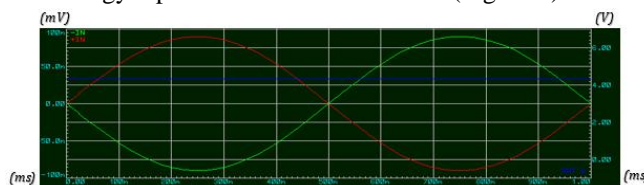


Fig.5: Graph 1 Stimulus 1: Biceps brachii.

The signal measured by the sensor is measured and amplified by operational amplifiers included in the EMG advancer V3 sensor. Still in Figure 5, on its left side we will have illustrated the input of the signal emitted in the muscle ventricle, where it has alternating AC characteristics with voltages from -90mv to + 90mv, and so that the signal can be interpreted by the controller analog input, the signal needs to be rectified to continuous DC, in this specific case 4.15V shown on the right side of the graph in Figure 6.

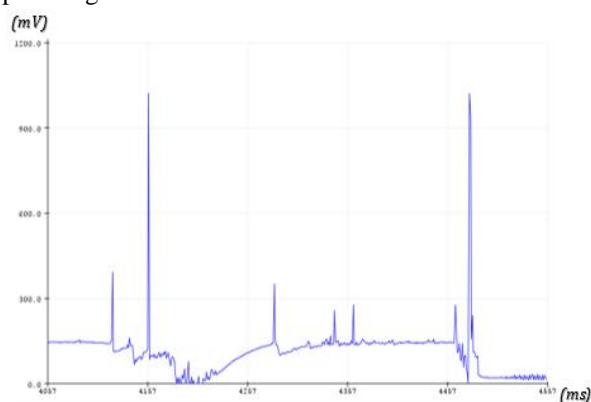


Fig.6: Graph. 2 Stimulus 1: Biceps brachii.

During execution of the opening and closing functions of the prosthetic fingers, specific values were set that could be easily interpreted by the logic implemented in the micro

controller, in other words the Setpoint used was  $\geq 200\text{mv}$ . Thus, when reaching the setpoint, the prosthesis will perform the function of closing the fingers.

In the same way, Figure 7 shows the contraction, but with regular periods of isometry of the biceps. That is, not to changes in the stimulus that may cause noise during the execution of the function that will close the prosthetic fingers.

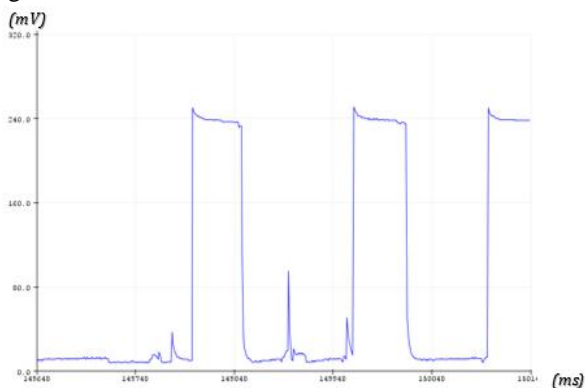


Fig.7: Stimulus 2: Biceps brachii.

To control the excessive closing of the fingers, in addition to the rotation control of the servo motors limited to  $180^\circ\text{C}$ , also with the close function, parameters were included to control the strain gauge force sensor inserted in the palm of the hand, where the same when measuring equivalent force at 300g, the function closes and pauses and after 5 seconds the function opens, responsible for returning the fingers to their initial position.

Regarding the Strain Gauge sensor, the resistance variation when different from "0", the controller will use the analog port reading stored in the variable (fsrADC) named (FSR\_PIN) to perform the voltage calculations (fsrV). The VCC values were predefined with the value of 4.98, a voltage similar to the Arduino analog port defined in a datasheet equal to 5V.

Then the resistance (fsrR) is calculated with values of R\_DIV equal to 3230.0 (3.3k Ohms). Then the estimated force calculation will be given based on the change in resistance as mentioned above to define the electrical conductance, then estimate the force exerted on the pressed area, where the resistance values (fsrR) less than or equal to 600 must perform the expression  $F = (\text{fsrG} - 0.00075) / 0.0000032639$  and greater than 600  $F = \text{fsrG} / 0.00000642857$ . Finally, uniting all the components, the prosthesis is finalized.

#### IV. DISCUSSION

During the initial tests with a force sensor positioned in the palm of the hand, there were satisfactory results,

however, there is a need to implement a larger group of sensors allocated to the fingers and palm. In this way, a single sensor is capable of capturing the pressure exerted by the objects during the closing of the fingers, since when implementing the 3.3k Ohms resistance, it was observed that even before the object touches the surface of the sensor, the same detects the approach of the object, taking then a pre-detection of the structures that come close to the contact surface of the sensor.

The EMG sensors adopted for the development of the project have some limitations, namely: measurement of only one muscle EMG stimulus and noise and setpoint readjustments for all moments. For this reason, there was a need to reposition the target musculature. The results in the graphs of figures 6 and 7 were made with gain adjustments in the measured signal, providing a clean image of the signals, there was also the need to control the measurement environment, being then adopted as a protocol the superficial cleaning of the skin where they were the electrodes were fixed with 70% alcohol, also the removal of hair in the measurement area.

The results showed that, based on the implementations performed, the sensory application proved to be satisfactory in view that the results measured between the prosthesis and the target musculature, were measured and converted into movements for the equipment. Thus, the force sensor was able to stop the movement, preventing the fingers from closing in such a way as to damage the joint structure of the prosthesis. The structures printed in PLA filament are also sufficiently controlled during the assembly steps, considering that they were able to withstand a force exerted by the servo motor equivalent to 13kg in the process of pressing the fingers. On the other hand, when closing and opening the fingers, it was observed that the cables were loosened overtime, this phenomenon occurred because the line had a smooth surface, so the moorings overtime loosened, to heal this problem was adopted for the practical purpose of securing the moorings in such a way as to be permanent.

Based on the development of the project, it was possible to obtain the final acquisition value of the project with investment costs equivalent to R\$ 2,000.00. Based on similar research, when compared to the current one, it was well known that many authors reached values between R\$ 2,000.00 to R\$ 10,000.00, which when compared to the current market average of approximately R\$ 200,000, 00, makes the construction of the mechanism viable with investments of approximately 1% to 5% of the current market value, thus enabling the acquisition by people less financially favored.

## V. CONCLUSIONS

The objectives proposed in this research were achieved. The projected prosthesis responded well to the expected stimuli, and the costs were low in the order of R\$2,000.00. Aiming at future studies involving the improvement project of mechanical prostheses, sensors that may simulate the touch of a surface similar to human skin may be provided, as well as the insertion of new force and EMG sensors to better treat the stimulus signals dissipated in the muscle ventricle. In this way, the project should pass through new structural dimensions such as modeling and printing of new parts that can reduce limitations of the current structure, for example, the non-displacement of the fingers on the Cartesian x axis. As a means of providing greater flexibility through the printed structures of the prostheses, the use of filaments such as TPU (polyurethane thermoplastic), total or partial, is estimated for items that may require multidirectional behaviors, such as pre-rotation of the fingers.

The servo motors used in the arm structure take up too much space to the real needs, aiming at the use for people with only hand amputations, it will be necessary to use smaller motors, and also the space needed for their allocation in the prosthesis structure.

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