Design of a Bionic Arm Using Rapid Prototyping Technology

Ph.D. **Ștefan Adrian ȚÎMPEA[1],** S.L.Dr.Ing. **Cristian COSMA[2],** Conf.Dr.Ing. **Cosmin CODREAN[3]**, S.L.Dr.Ing. **Aurelian MAGDA[4]**

[1]University Politehica of Timisoara, Piata victoriei nr. 2, 300006 Timisoara, Romania, stefantimpea@gmail.com

[2] University Politehica of Timisoara, Piata victoriei nr. 2, 300006 Timisoara, Romania, cristian.cosma@upt.ro

[3] University Politehica of Timisoara, Piata victoriei nr. 2, 300006 Timisoara, Romania, cosmin.codrean@upt.ro

[4] University Politehica of Timisoara, Piata victoriei nr. 2, 300006 Timisoara, Romania, aurelian.magda@upt.ro

Abstract: *This paper presents a 3D printable design for a myoelectric prosthetic arm which is electronically actuated and controlled by a user flexing muscles. The prototype has the potential to be used by an amputee or person born without a limb. In these days, a rapid prototyping (RP) technology as Fused Deposition Modeling (FDM) allows individuals to become small-scale manufacturers. Using RP technology to obtain physical parts for the bionic arm has a high impact due to the final price. The main purpose of this project is to design a low-cost bionic arm controlled by EMG signals.*

Keywords: *Bionic arm, rapid prototyping, additive manufacturing, fused deposition modelling FDM*

1. Introduction

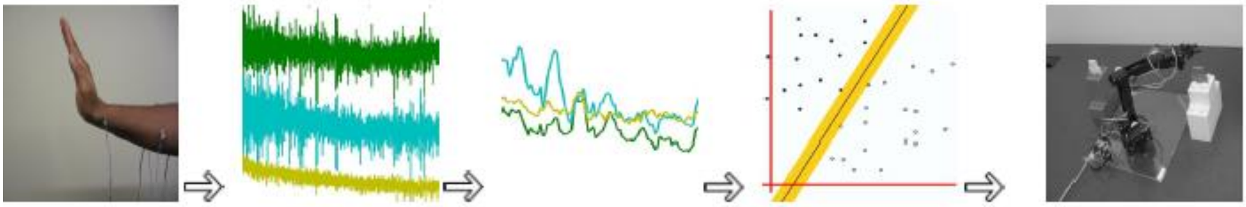
In medicine, a prosthetic implant is an artificial device designed to replace missing parts of the body, which may be lost through trauma, disease, or congenital conditions [1]. The prostheses are intended to restore the normal functioning of the missing parts of the body. The replacement of a part of the body, especially replacement of an arm, is indeed a challenging task, which makes the person truly appreciate the complexity of the human body. For centuries innovators have tried to replace lost limbs with various devices. Several prosthetic devices have been discovered by ancient civilizations around the world, which demonstrate the continuous progress of prosthetic technology [7]. For many people, an artificial limb can improve mobility and the ability to manage daily activities, and to be independent. Rapid prototyping technology has a major impact on low-cost bionic arms. RP gives a big chance to test the prototypes and upgrade them, to create the plastic parts of the bionic arm I took in consideration a field of RP called fused deposition modeling, FDM is one of the most popular technology on the market. Nowadays RP is used in medicine, especially in implantology area. Many implants for e.g. hip are made by selective lase sintering (SLS) technology using biocompatible materials as Titanium alloy Ti-6Al-4V [2].

2. The current state

In this moment, the price of a bionic hand is relatively high. A bionic hand with different functions costs between 20,000 - 30,000 $. An advanced bionic hand can cost up to $ 100,000. More than that, the price of a bionic hand is closely linked to the degree of amputation [3]. The price of a bionic hand with a myoelectric arm up to the shoulder is three times higher than a bionic hand which replace a partial part of hand.

2.1 EMG signals. Electromyography

Myoelectric signals are electrical impulses located inside the body produced by muscles fibers when they are contracting, base of this generate a change in electrical potential and can be measured of the surface of the skin by an electromyogram (EMG). The amplitude of the EMG signal is directly correlated with the force generated by the muscle. Most of prosthetics are using the amplitude of the steady state (Fig 1) EMG signal where the subject exerts constant effort with a chosen muscle, the device has a single degree of freedom such as a gripper for grasping and releasing objects [4].



a) Static gesture b) steady-state EMG c) extracted features d) SVM classification e) robot arm control

Fig. 1. Schematic for EMG-based robotic control [4]

Medical electrodes placed on the user's skin (Fig 2) can detect these small signals and can be used to control the device. The electrical signals are very small, myoelectric sensors pick up signals generated in the muscle tissue that are amplified filtered and undergo signal processing to control artificial hand. [5], [6]. The figure 3 shows standard model of myoelectric hand functionality.

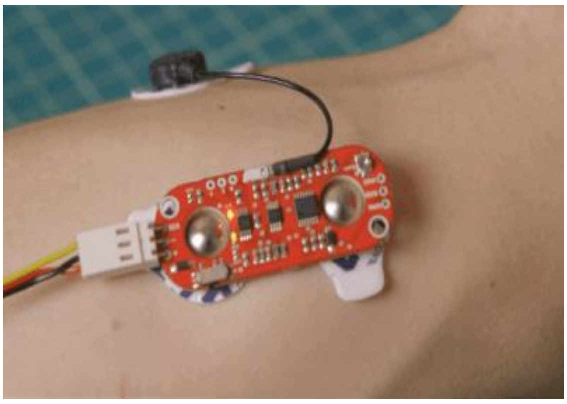


Fig. 2. Location of electrodes

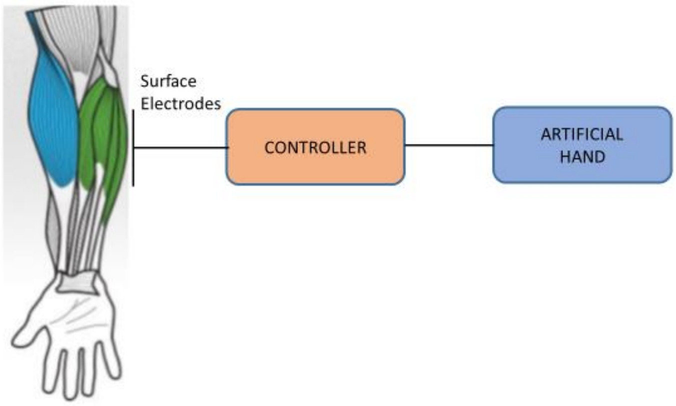


Fig. 3. Myoelectric hand [5]

2.2 Rapid prototyping. Fused deposition modelling FDM

To create the physical parts of the bionic arm is taken into consideration a field of rapid prototyping (RP) technology, called fused deposition modeling (FDM).

In RP, the term "rapid" is relative, it aims at the automated step from CAD data to machine, rather than at the speed of the techniques. Depending on the dimensions of the object, production times can be as a few days, especially with complex parts or when long cooling times are required. The manufacturing process is slow, but compared to traditional production techniques it can provide the physical parts in a very short time. This relatively fast production allows analysing parts in a very early stage of designing, which decreases the resulting design cost [6].

''Additive manufacturing AM is the generic term for the collective advanced manufacturing technologies that build parts layer by layer. The layers are produced by adding material instead of removing it as opposed to subtractive manufacturing such as machining. The material addition or fusion is controlled by G-codes generated directly from 3D CAD models. FDM, one of the AM technologies, builds parts layer by layer by heating a thermoplastic filament to a semi-liquid state and extruding it through a small nozzle per 3D CAD models usually in STL format as shown in Figure 4. The filament is usually of circular cross section with specific diameters for each FDM system. The most widely used diameters are either 1.75 mm or 3.0 mm. Due to the nature of FDM process, many advantages arise, such as the design freedom to produce complex shapes without the need to invest in dies and molds, the ability to produce internal features, which is impossible using traditional manufacturing techniques. FDM enables the reduction of the number of assemblies by producing consolidated complex parts [7].''

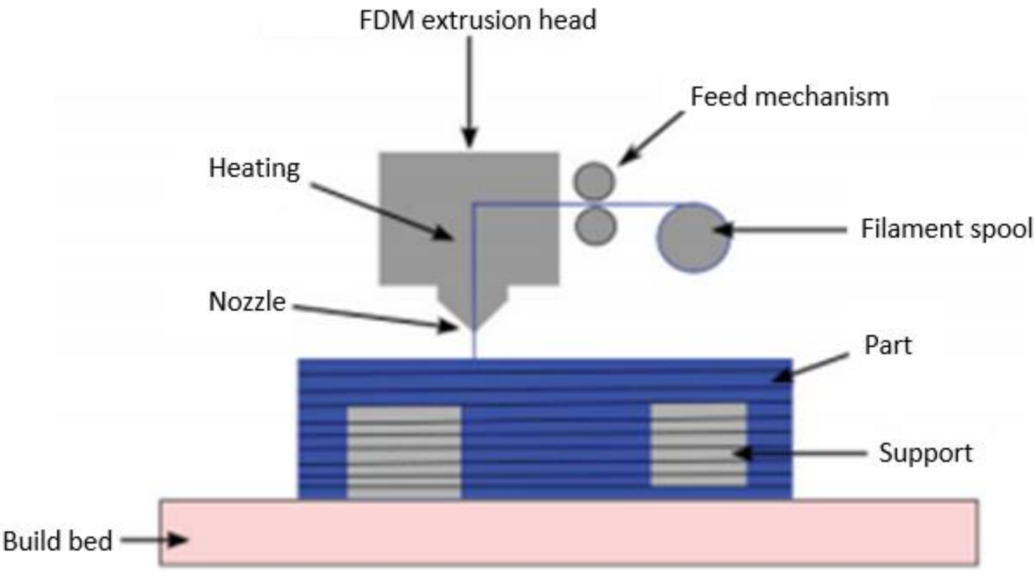


Fig. 4. FDM process schematic [5]

3. Description of the bionic arm

In order to design a bionic arm (Fig. 5), it is important to have a well-designed mechanic that mimics the functionality of the human arm as good as possible. Among many other aspects, the mechanical scheme involves how joints are operated, what type of linear motors used for fingers actuation, the centering and fixing of the components. The design of the bionic arm presented in this sketch can be entirely made with a 3D printer and basic tools. The bionic arm can be used in many applications like a human arm, this requires a high speed of response from the sensors to make a certain task.

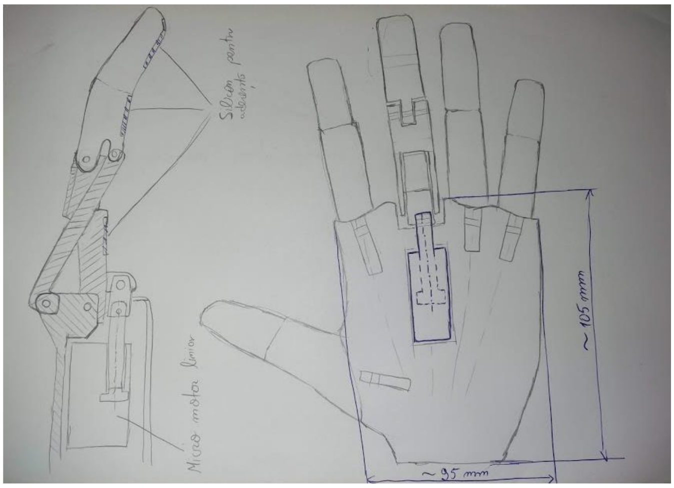


Fig. 5. Isometric view and schematic of the bionic arm

Figure 6 represents an isometric view of the finger assembly, the only piece that differs from one finger to another is the tip of the finger that is longer or shorter depending on the position of each.

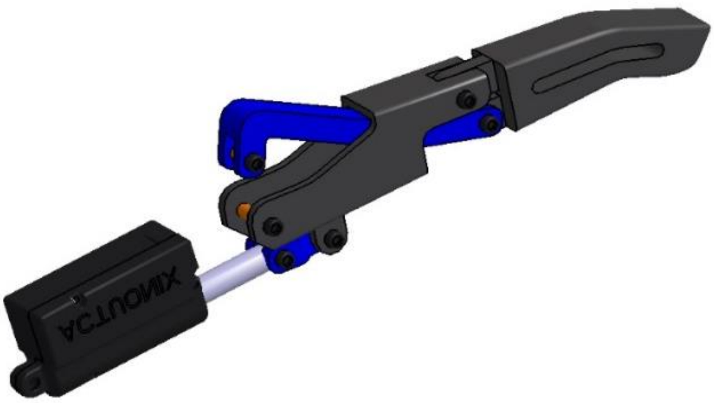


Fig. 6. Finger subassembly

In the figure 7 the Kinematic model for prosthetic finger is presented. The finger incorporates own mechanism to mechanically couple joints together. Rotating the metacarpal joint (knuckle) simultaneously rotates the higher phalange joint [8].

Fig. 7. Kinematic model for prosthetic finger [6]

Figure 8 shows an exploded view of the finger assembly, the assembly steps can be observed as well as the name of each component of the finger. In order to avoid damage to the plastic parts is used brass bushing. Also, to avoid the unscrew process is chosen self-locking nut.

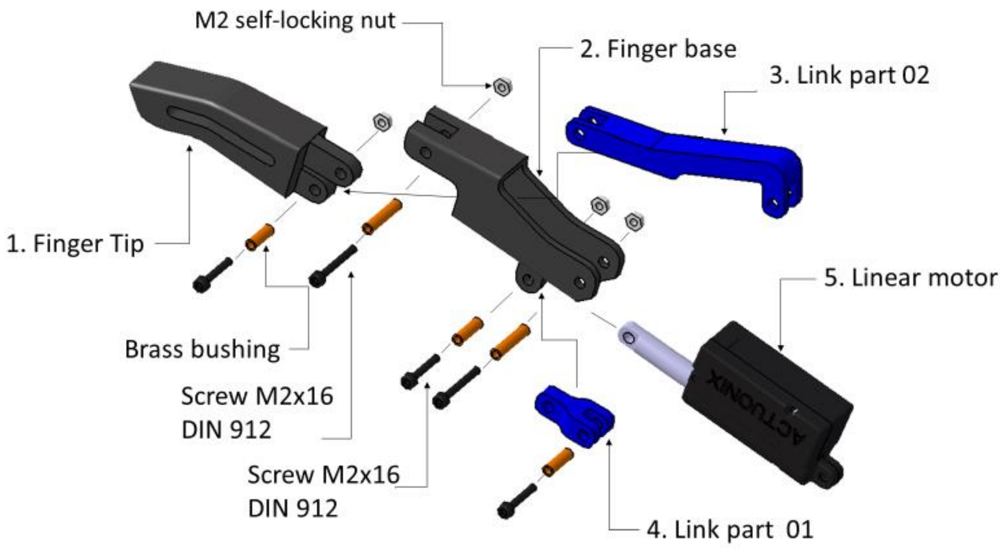


Fig. 8. Exploded view of the finger subassembly

In figure 9 one can see an exploded view of the palm assembly, the assembly steps can be observed as well as the name of each component.

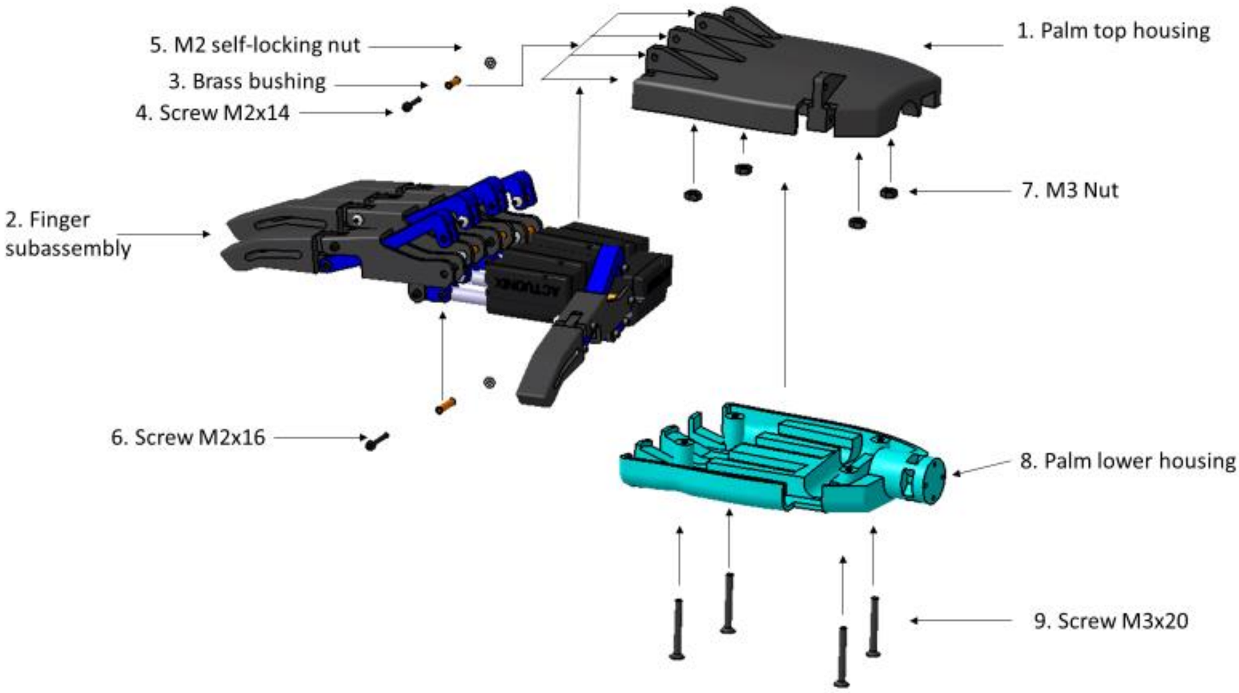


Fig. 9. Exploded view of the palm subassembly

Figure 10 shows an exploded view of the finger assembly; the assembly steps can be observed as well as the name of each component of the finger.

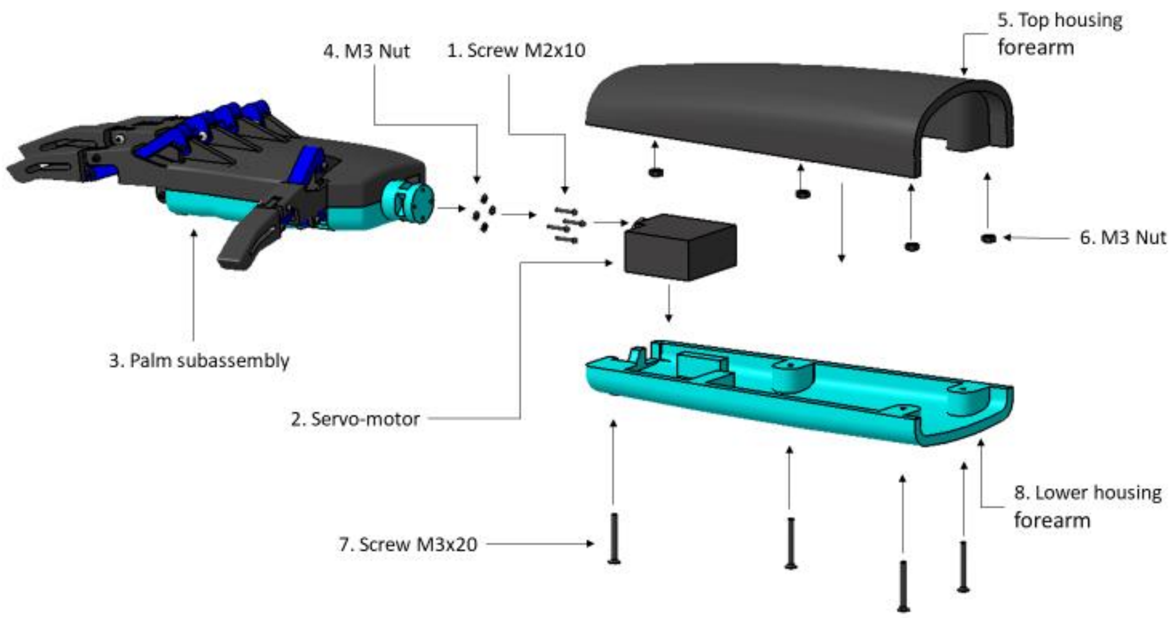


Fig. 10. Exploded view of the bionic arm

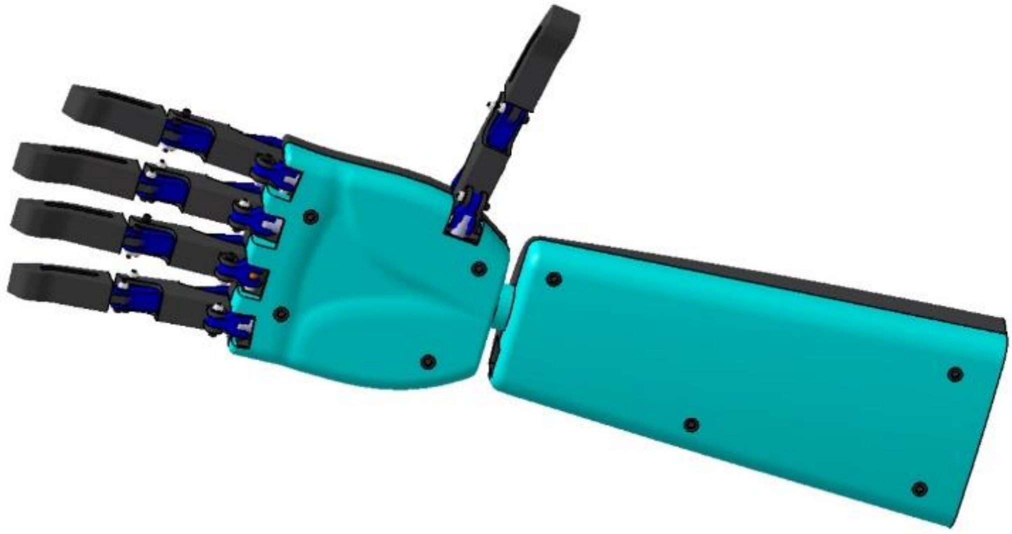


Fig. 10.1. Final assembly

3.1 Simulation of bionic arm movements

During the mechanical design I made a series of finger simulations (Fig 11 and 12), how they close, how much to close. Doing these simulations, a very well-structured concept has resulted. The following figures show the bionic arm movements.

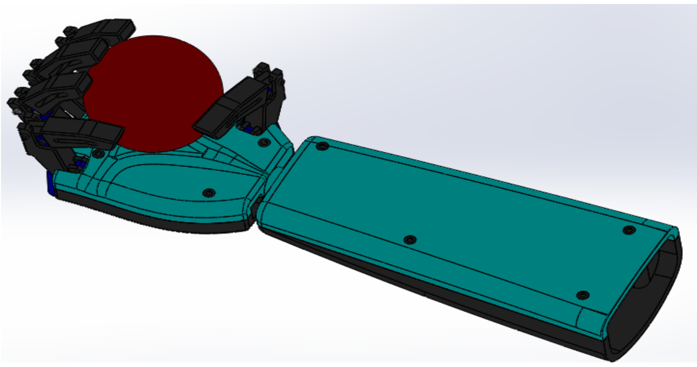


Fig. 11. Catching a sphere with diameter 70mm

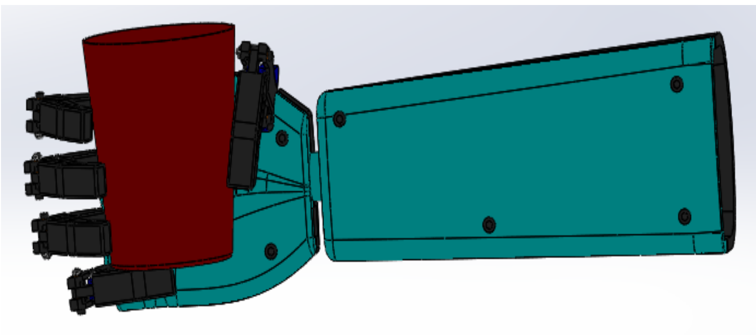


Fig. 12. Catching a glass with diameter ~70mm

3.2 Price of the bionic arm

One of the goals of the project was to design an affordable bionic arm for all patients. The hand developed within the project is still in the prototype phase. Therefore, a cost analysis is needed to estimate future costs and price per unit. The current cost of an arm is $ 503.38, and the costs are shown in Table 1. Compared to the myoelectric prostheses available on the market, which cost about $ 60,000, the goal of creating the bionic arm with reduced costs was achieved.

Table 1: Price of the components

Description	Nr Part	Price in $	Total price in $
Myo-Ware Muscle sensor	3	30.53	91.59
Linear Motor PQ12	5	65	325
Battery	1	19.34	19.34
Tower Pro MG996R Servo	1	7.45	7.45
Filament PLA	24	15$/kg	10
Other components	N/A	N/A	50
			503.38

Conclusions

The main purpose of this project was to design a bionic arm controlled myoelectric with low manufacturing costs, which can be made by 3D printing technology. The purpose of this project was achieved resulting a prototype controlled by EMG signals captured by the biomedical electrodes and converted into movements. The final prototype is designed to be user-friendly with a simplistic design. However, many aspects still require further work to develop a fully functional bionic arm.

The project shows the advantages of rapid prototyping technology, this have the potential to produce bionic arm parts personalized, cheaper and faster. The bionic arm is designed to be easy to assemble. For people who lost the upper limbs trough trauma, disease, or a condition present at birth, they may have a chance at a normal life. For a highest precision of the finger movements, a medical check is recommended to highlight the area where the biomedical electrodes are placed that capture the electrical signals from the movements.

During the development of the bionic arm, we made several finger actuation systems, one of the tried systems was to actuation finger using a tendon cord, the problem encountered in this system was to return to the natural position of the finger. To restore the finger to the natural state it was necessary to implement two or three springs depending on the system used, which was quite difficult for the small space of the finger joint.

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