POLITECNICO DI TORINO

Master degree course in Mechatronic Engineering

Master Degree Thesis

Design and development of a prototype of cost-effective myoelectric prosthetic hands in Uzbekistan

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January 2022

Abstract

This thesis is a development project for a myoelectric prosthetic hand. That means a mechanical hand that is controlled and actuated by the user’s own muscles on the residual limb. The development of cost-effective prosthetics is needed since users are not fully satisfied with current mechanical prosthetic hands. Many people in Uzbekistan are dissatisfied or cannot afford functional prosthetics at all.

According to user feedback, the current models of myoelectric mechanically actuated prosthetic hands are not functional enough for the user, and many users choose to use a passive prosthetic instead even if they own a mechanically actuated one due to the low functionality. The price of these advanced prosthetics is also an issue, especially in Central Asia countries, Uzbekistan where the need is larger, and the economy is lower.

The idea had been around for many years, and this thesis together with the home university and resources made it possible to start the development of it. At the end of 2021, I participated in the Start-up competition which held by Ministry of Innovative Development of the Republic of Uzbekistan. After 6-month acceleration program I won a $50,000 grant to implement this Starup project in Uzbekistan. Now we are working on our first MVP model.

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1. INTRODUCTION

1.1 Background

The development of prosthetics is needed since users are not fully satisfied with current mechanical prosthetic hands according to our user needs study, and this project is attempting to improve user satisfaction. Many people in the world are dissatisfied or cannot afford functional prosthetics, and many more cannot afford prosthetics at all because of price.

According to the statistics in Uzbekistan in 2021 year, 670,866 people with disabilities, of which 100,827 (15%) are children under 18 years old. 21,742 people received recommendations from the medical-labor expert commission for the provision of technical means. 4,654 people are recommended to have hand prosthetics.

Nowadays, there are many prostheses that are more or less like actual hands and can do about half of their activities; the most recent can be moved by mental or nerve signals. Furthermore, the price of them cannot be afforded by most people with a basic salary. Therefore, this project is about creating a prototype of an orthopedic hand that can be made at a low price. Using the technology of the 3D printers and the movement will be performed by muscle signs.

1.2 Goals

This project aims to design and development of a prototype of cost-effective myoelectric prosthetic hands in Uzbekistan which can be placed on the forearm of the body, this hand would achieve the basic movements of graving an object in two different ways:

- Impingement, with the index, middle finger, and thumb for smaller objects and more precision.
- Enclosure, with the whole fingers for standard objects.

The main point of the project is the performance of the movement, it will be moved by the signals of force read at the biceps with some electrodes, amplified by an electronic device self-created and interpreted by Arduino UNO. Arduino will move five servos each one pulling some strings attached to the hand to make the fingers shrink or extend depending on the force you make with the biceps. The design of the hand will be taken from the network (opensource) by Gael Langevin www.inmoov.fr, Inmoov is an open-source 3D printed life-size robot, it has been decided to take hand from this project.

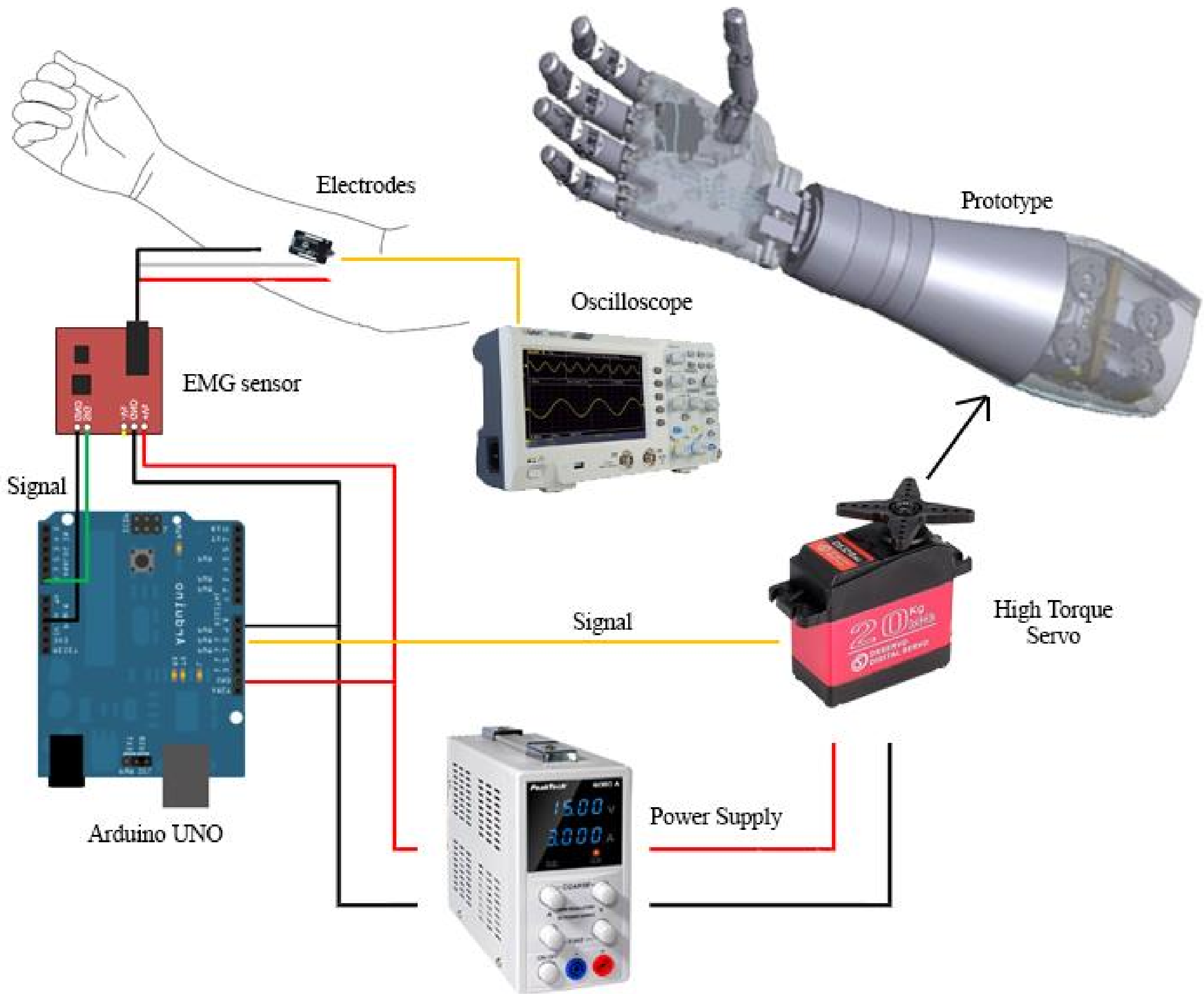

Figure 1: Scheme of prototype

2. PROSTHETIC HANDS: STATE OF ART

In medicine, a prosthesis (plural: prosthesis; from Ancient Greek "πρόσθεσις" prósthesis) is an artificial device that replaces a missing body part, which may be lost through trauma, disease, or congenital conditions. Prosthetic amputee rehabilitation is primarily coordinated by a prosthetist and an interdisciplinary team of health care professionals including psychiatrists, surgeons, physical therapists, and occupational therapists, one and mostly concerning this thesis, occupations such as engineers, program and software developers and finally the field of biomedicine.

2.1 Passive upper limb prostheses

This type of prosthesis is a passive solution that is designed solely to seem like a human hand. The similarity is incredible, however they are unable to move, which is a disadvantage.

Figure 2: Passive aesthetic prosthesis

2.2 Mechanically powered prostheses with strings

In this method, simply knot a thread or fishing line around the tips of the fingers and link the same thread to the wrist or someplace on the forearm. The threads are then drawn back and the fingers are folded as a result of wrist rotation.

You must have wrist movement to perform this approach; otherwise, you will not be able to pull the strings. Even so, it's an excellent answer because it's cheap to make with the new 3D printers, and the pieces are simple to create; you can also find them for free on the Internet.

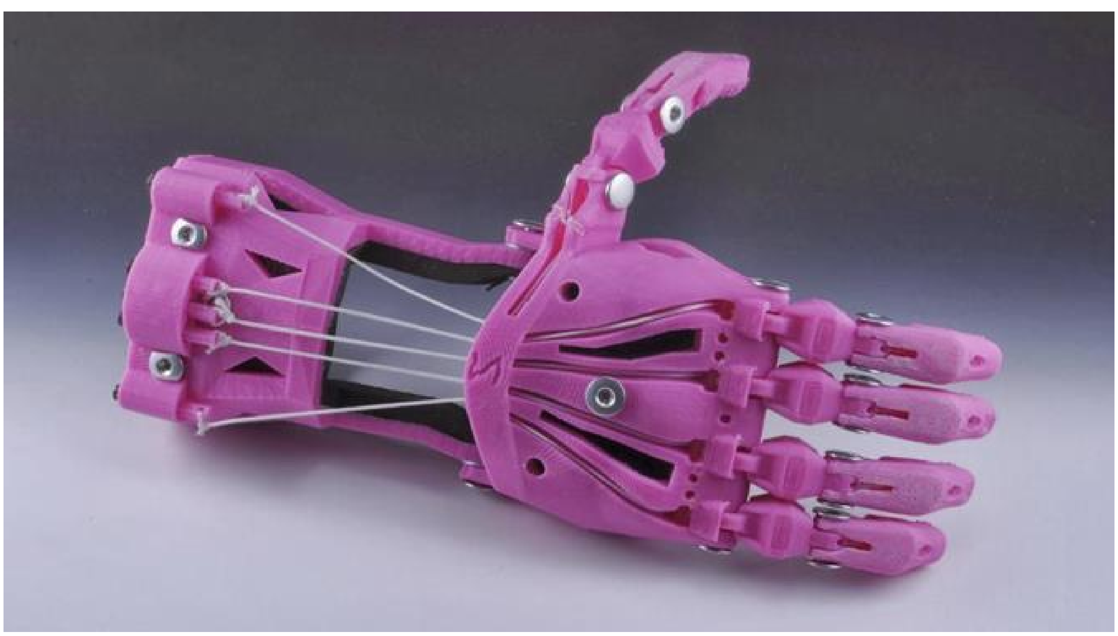

Figure 3: Mechanical powered prostheses with strings

2.3 Electric prosthesis

Electric motors with rechargeable batteries are used in the terminal device, wrist, or elbow of these prosthesis. These prostheses can be operated in a variety of methods, including using a servo control with a push button or a button switch harness.

It is more expensive to buy and repair, and there are other evident drawbacks like as environmental exposure and the weight of the prosthesis.

Figure 4: Electric prosthesis

2.4 Myoelectric prosthesis

Myoelectric prostheses are electric prostheses that are controlled by a myoelectric external power source. They are currently the most rehabilitation-friendly prosthetic limb.

Figure 5: Bebionic myoelectric prosthesis

Combine the best aesthetic look, grip strength and quickness, and a wide range of combinations and enlargements. The most popular control scheme is undoubtedly myoelectric control. It is founded on the idea that when a muscle in the body contracts or flexes, a tiny electrical signal (EMG) is produced in the body due to chemical interaction. This signal is extremely weak (5-20µV).

The EMG signal can be recorded using electrodes that are placed on the skin's surface. Once recognized, the signal is amplified and processed by a controller, which then turns on and off the engine in your hand, wrist, or elbow to provide movement and functioning.

The advantage of this form of prosthesis is that it simply requires the user to flex his muscles to operate. One problem of employing a battery system is that it needs to be recharged, discharged, discarded, and eventually replaced.

2.5 Mechanical prosthesis

This kind of hands are prosthesis that open or close voluntarily using a harness of user that is fastened over the shoulders, chest of the user-controlled arm. Its operation is based on the extension of a league through the harness to open or close, and closing or opening is accomplished merely by a spring performing a pressure force or pinch.

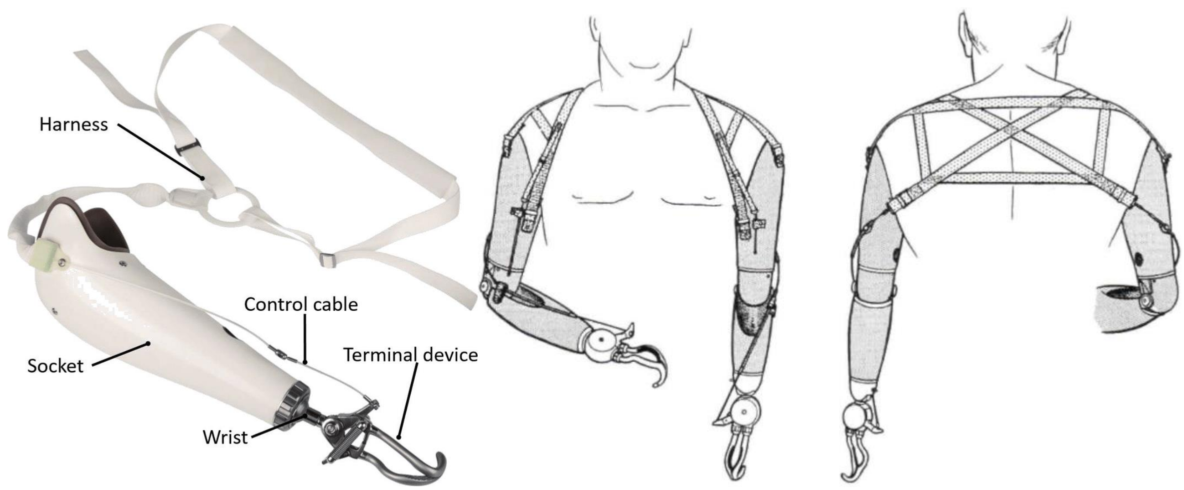

Figure 6: Mechanical prosthesis

Because these prostheses are powered by the body, they require at least a basic range of motion: chest expansion, depression, and shoulder elevation.

3. <u>MECHANISMS</u>

The movements of the articulations in the hand are implemented through mechanisms that stretch and fold the fingers. Transmission bars, driving pulleys, motors connected to each articulation, and simply pulling strings are all employed.

3.1 Toronto mechanisms

The bars are set up such that they fold at the same moment as you move one bar forward or backward; this system does not require motors, and production is simple and inexpensive.

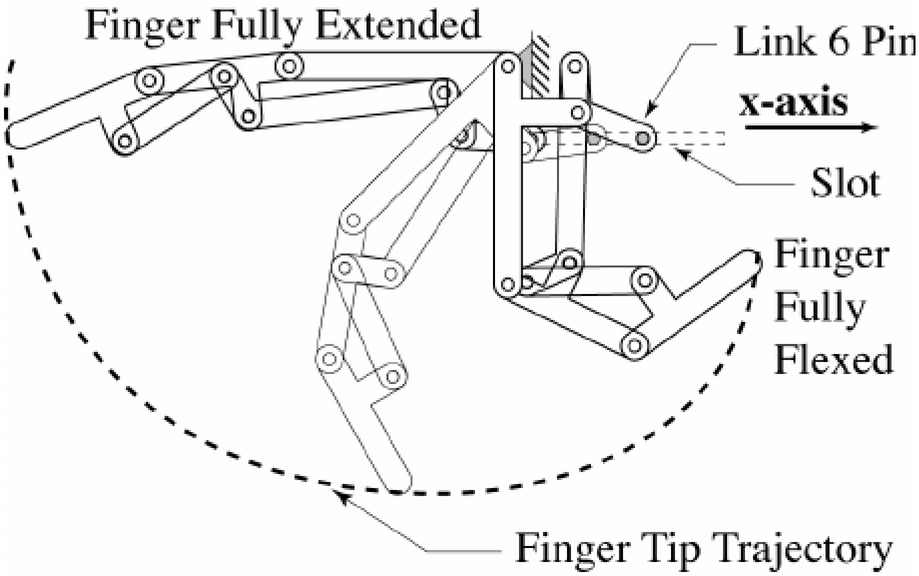

Figure 7: Toronto mechanism

This is an example of this technique, which is known as Toronto's mechanism.

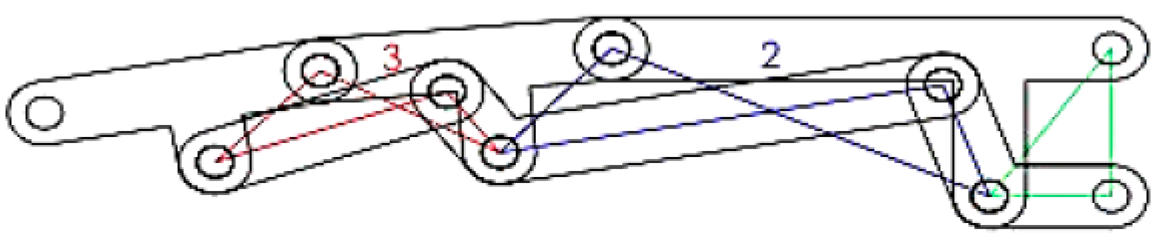

Figure 8: Toronto mechanism scheme

3.2 Mechanisms with drive pulleys

The concept behind this mechanism is similar to that of the bars, in that you must execute one action, in this case turning one pulley around with a motor, and the configuration of the pulleys will cause the others to accomplish the necessary movement. This method reduces the weight of the hand and is simple to use.

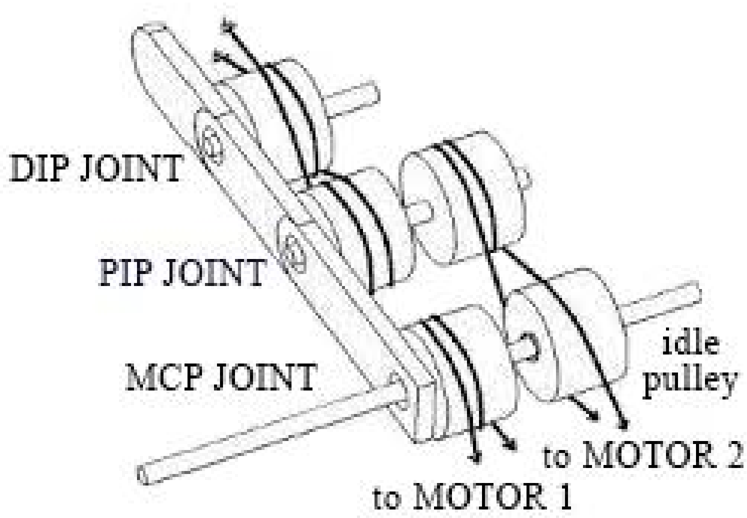

Figure 9: Driving Pulleys System scheme

In this figure we can see the way to configure this basic system to achieve movements like this.

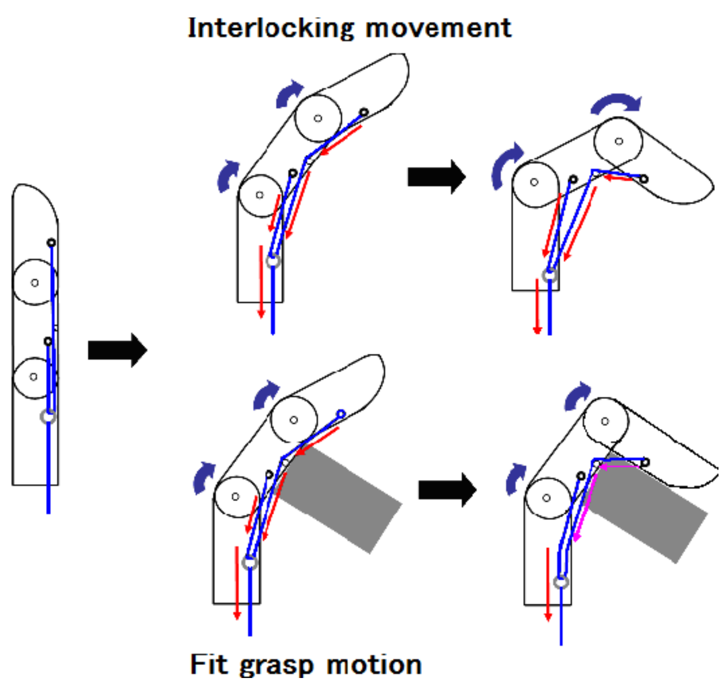

Figure 10: Adaptation of the finger with objects

If the motor is one directional and you want the finger to go back, you may add another motor like in figure 9, or you can add a rubber to the top of the finger and when it folds down, the rubber will become under tension, and when the motor stops, the rubber will cause the finger to move back.

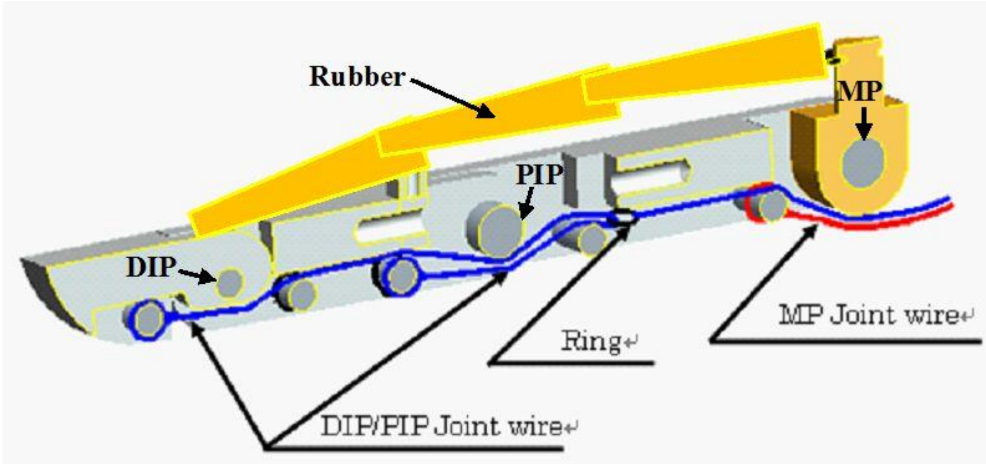

Figure 11: Mechanism of driving pulleys with rubber return

3.3 Mechanisms with motors in each joint

Mechanism with motors in each joint is mostly employed in robotic hands since the movements can be complicated and sophisticated when programmed. You may move any component of the finger independently and to any degree you want using this method. Of course, the weight of the hand has increased significantly, and moving any of these parts with muscle signals or body parts becomes quite difficult. As a result, these types of hands are typically used by robots or to be moved electronically, rather than as human prosthesis.

Figure 12: Computer simulation of robot hand

Recently, some new study on mind control in prostheses has been published. If technology keeps progressing, we'll be able to move every single finger in some way merely by thinking about it.

3.4 Servomotors and PWM

A servomotor is a specific type of motor that is combined with a rotary encoder or a potentiometer to form a servomechanism. This assembly may in turn form part of another servomechanism. A potentiometer provides a simple analogical signal to indicate position, while an encoder provides position and usually speed feedback, which by the use of a PID controller allows more precise control of position and thus faster achievement of a stable position (for a given motor power). Potentiometers are subject to drift when the temperature changes whereas encoders are more stable and accurate. Servomotors are used for both high-end and low-end applications. On the high end are precision industrial components that use a rotary encoder. On the low end are expensive radio control servos (RC servos) used in radio-controlled models which use a free-running motor and a simple potentiometer position sensor with an embedded controller. The term servomotor generally refers to a high-end industrial component while the term servo is most often used to describe the inexpensive devices that employ a potentiometer. Stepper motors are not considered to be servomotors, although they too are used to construct larger servomechanisms. Stepper motors have inherent angular positioning, owing to their construction, and this is generally used in an open-loop manner without feedback. They are generally used for medium-precision applications. RC servos are used to provide actuation for various mechanical systems such as the steering of a car, the control surfaces on a plane, or the rudder of a boat. Due to their affordability, reliability, and simplicity of control by microprocessors, they are often used in small-scale robotics applications. A standard RC receiver (or a microcontroller) sends pulse-width modulation (PWM) signals to the servo. The electronics inside the servo translate the width of the pulse into a position. When the servo is commanded to rotate, the motor is powered until the potentiometer reaches the value corresponding to the commanded position.

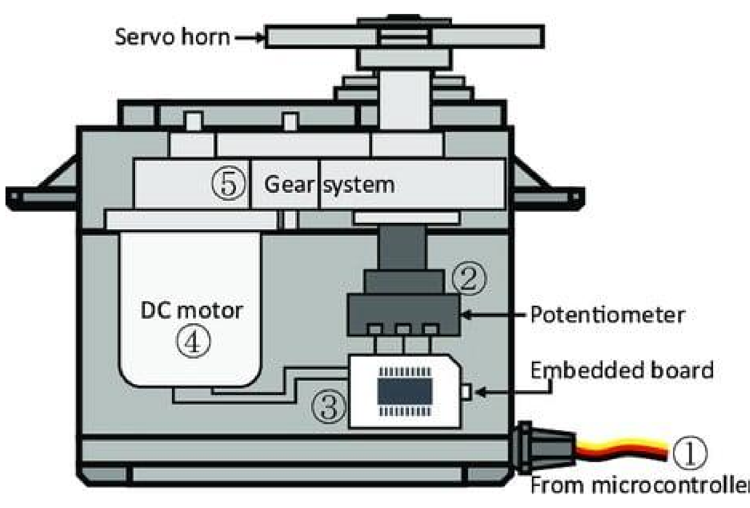

Figure 13: Exploded picture of servomotor

It is a type of modulation used to modify the load which arrives at the device connected to control its potency.

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load.

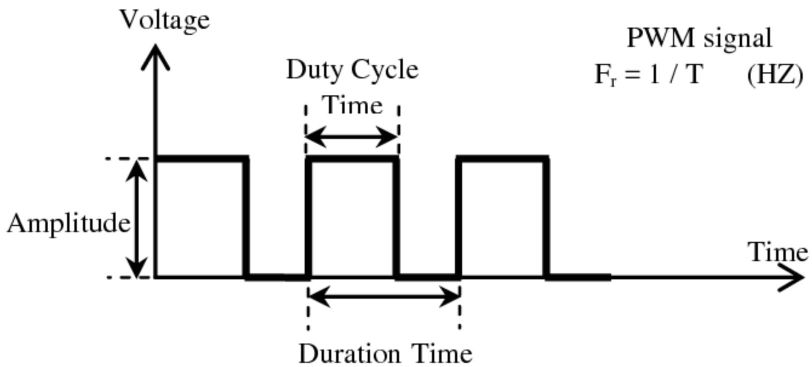

Figure 14: PWM graph of voltage with time

The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. The duty cycle is expressed in percent, 100% being fully on. When it is half time “on” and half time “off”, then it supplies 50% of the power, and so on.

4. INMOOV OPEN SOURCE ROBOT PROTOTYPE

4.1 3D design of the prototype

InMoov is the first life-size humanoid robot you can 3D print and animate. Gael Langevin is a French model maker and sculptor. He works for the biggest brands for more than 25 years. InMoov is his project, it was initiated in January 2012. InMoov is the first Open Source 3D printed life-size robot. Replicable on any home 3D printer with a 12x12x12cm area, it is conceived as a development platform for Universities, Laboratories, and hobbyists, but first of all for Makers.

Its concept, based on sharing and community, gives him the honor to be reproduced for countless projects throughout the world.

Figure 15: Inmoov Robot in Uzbekistan

Taking use of this open-source project, the hand of its robot has been picked.

The following are the key reasons:

- The resemblance to a real hand is more than acceptable
- The positions that can be attained are adequate for basic functions
- It can be printed at home with a 3D printer
- It can be moved easily fishing lines

The 3D modeling of each part is shown in the following figures:

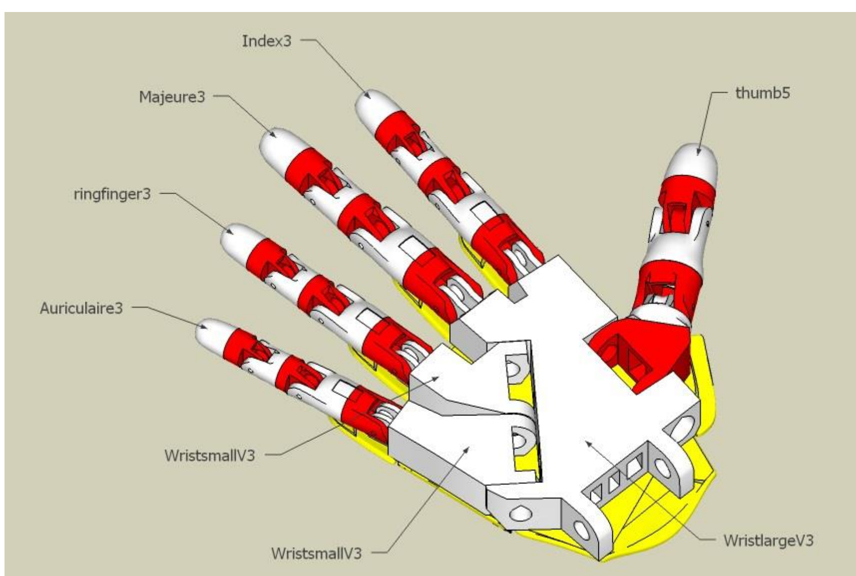

Figure 16: Inmoov right-hand bottom

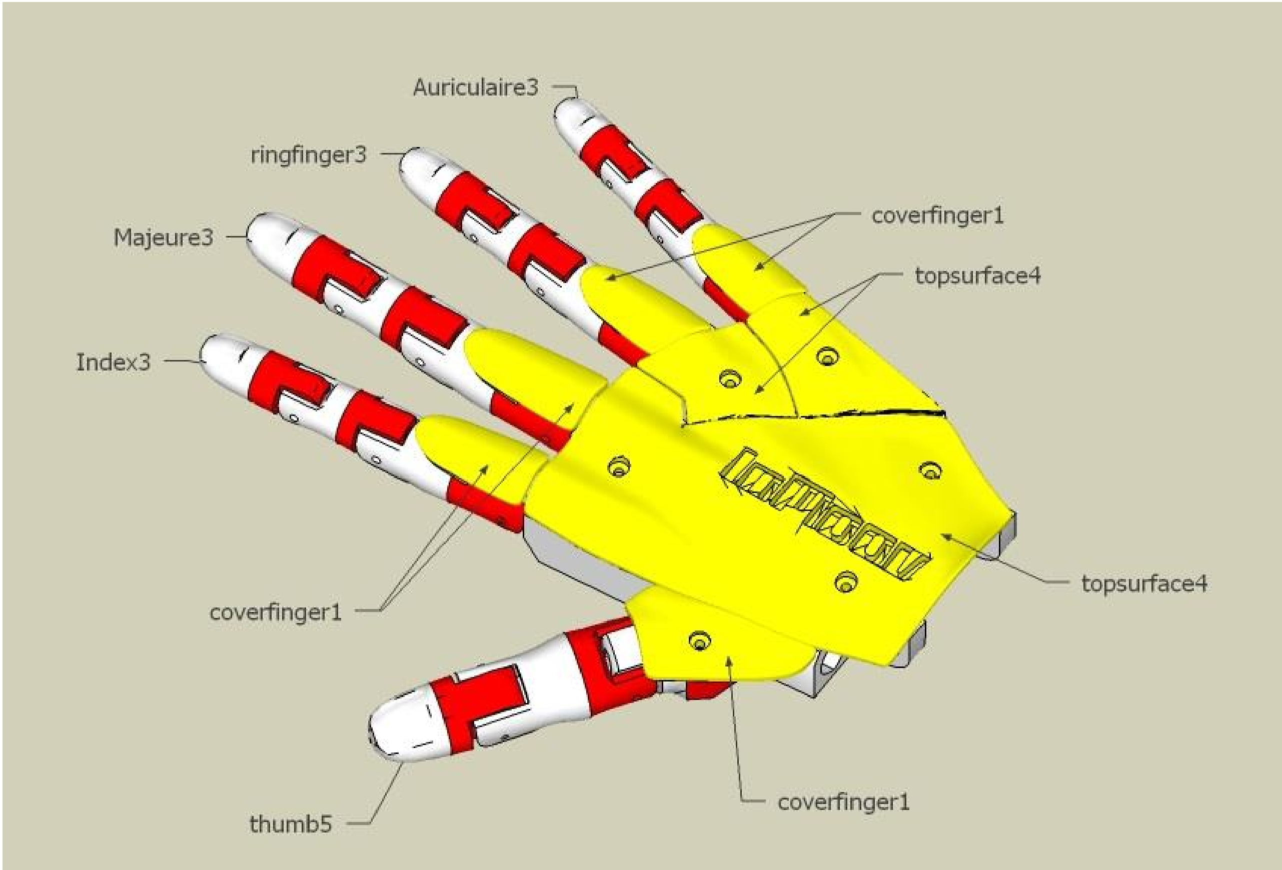

Figure 17: Inmoov right-hand top

Here are some illustrations of how it should be put together:

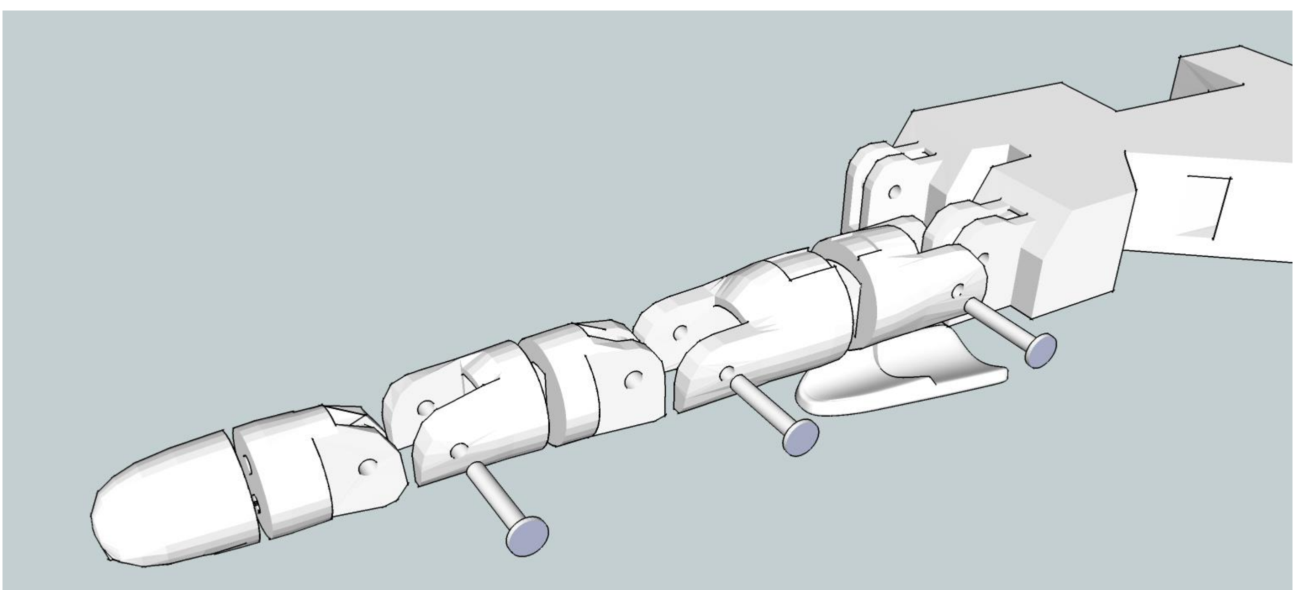

Figure 18: Middle finger assembly

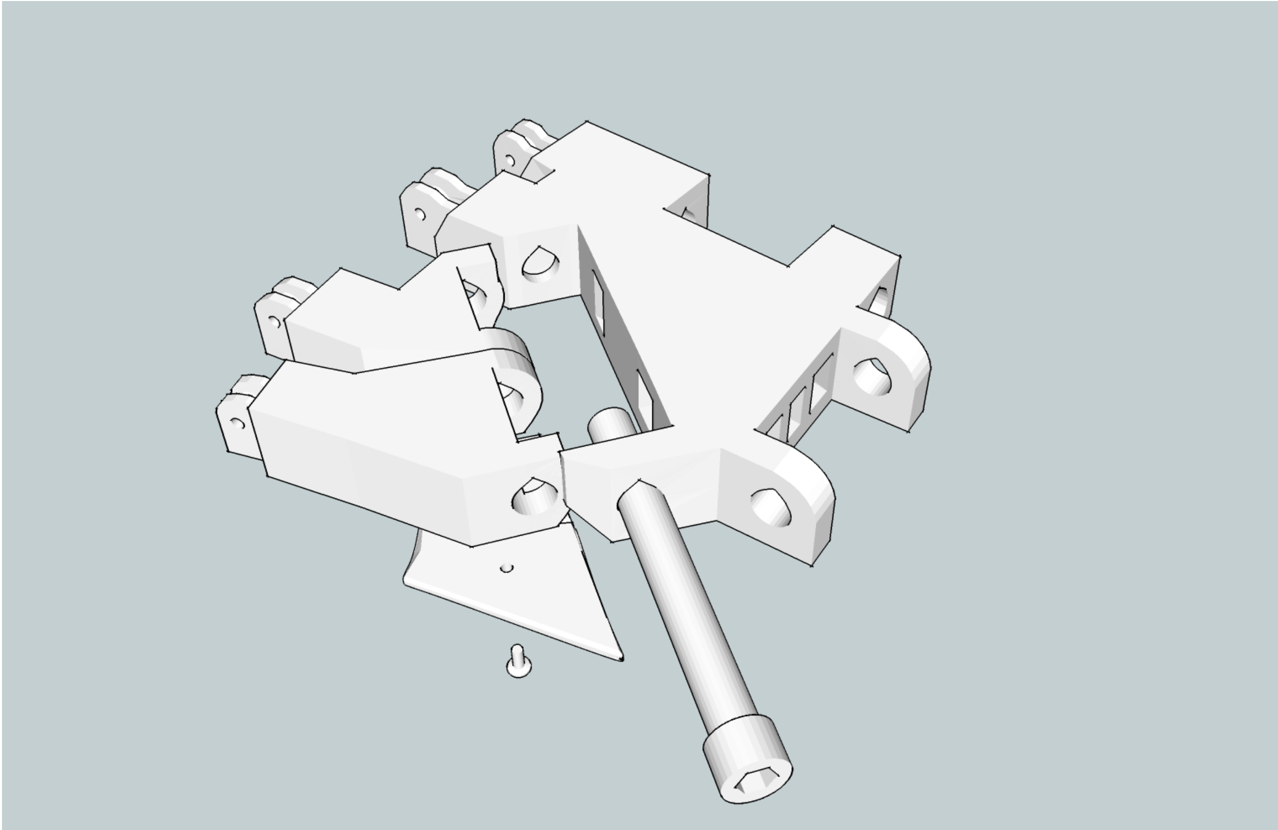

Figure 19: Wrist small with wrist large assembly

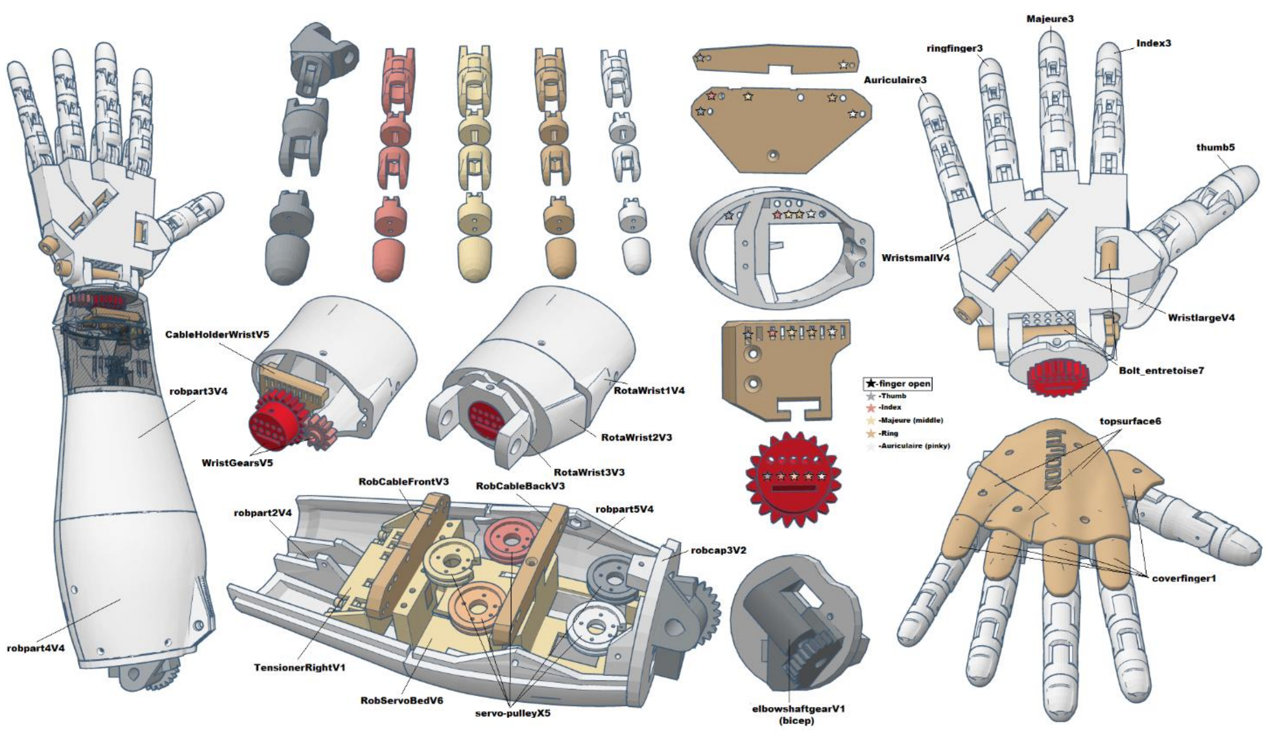

Figure 20: Fully assembled hand

4.2 3D printing of prototype

A Creality Ender 3 3D printer was used to print all of the 3D parts.

Machine model	Ender 3	**File format**	STL OBJ AMF
Molding technology	FDM	**Slicing software**	Cura, Simlpify3D
Printing size	220*220*250mm	**Power supply**	AC230v/DC 24V 270W
Printing speed	30-180mm/s	**Filament**	PLA, ABS, TPU
Printing precision	+-0.1mm	**N.W**	6.62kg
Nozzle diameter	0.4mm	**Machine size**	440*440*465mm
Hotbed temperature	100C	**G.W**	8.1kg
File transfer	SD card	**Package size**	570*380*205mm

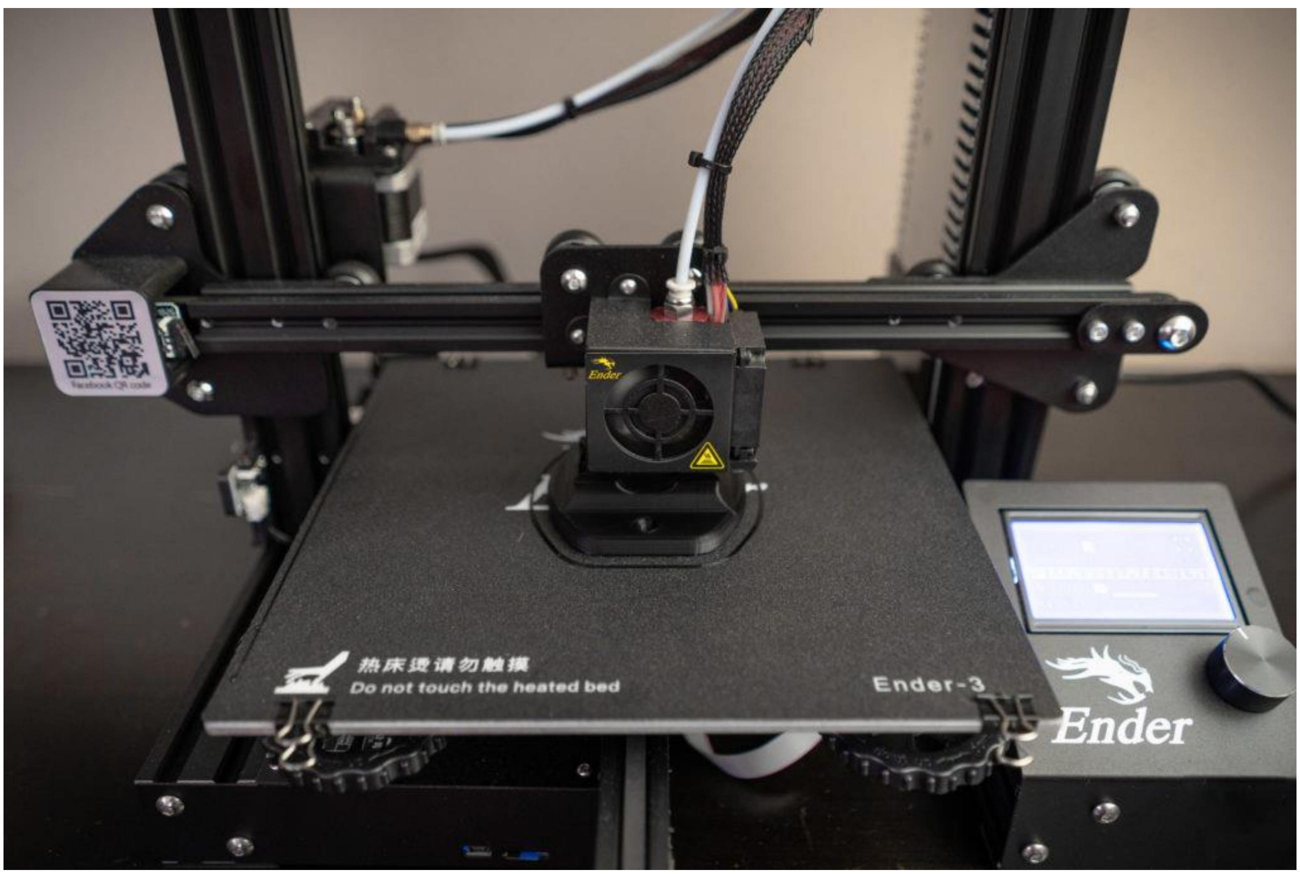

Figure 21: Creality Ender 3 printer

4.3 3D printing material

The material used for printing all the pieces is PLA.

Polylactic acid or polylactide (PLA, Poly) is a biodegradable thermoplastic aliphatic polyester derived from renewable resources, such as corn starch, tapioca roots, chips or starch, sugarcane.

It is harder than ABS, melts at a lower temperature (around 180°C to 220°C), and has a glass transition temperature between 60-65 °C, so is potentially very useful material. It does exhibit higher friction than ABS however which can make it difficult to extrude and more susceptible to extruder jams.

4.4 Configuration of the printer

As a result, the Creality Ender 3's configuration has been as follows:

- Base Temperature: 65ºC
- Extruder Temperature: 220ºC
- Resolution: 100µm

4.5 Ultimaker Cura Software

Once the printer is well configured and the pieces have been modeled in a specific format to be printed (.stl), the next step is to upload them to Ultimaker Cura, a free program for Creality Ender 3.

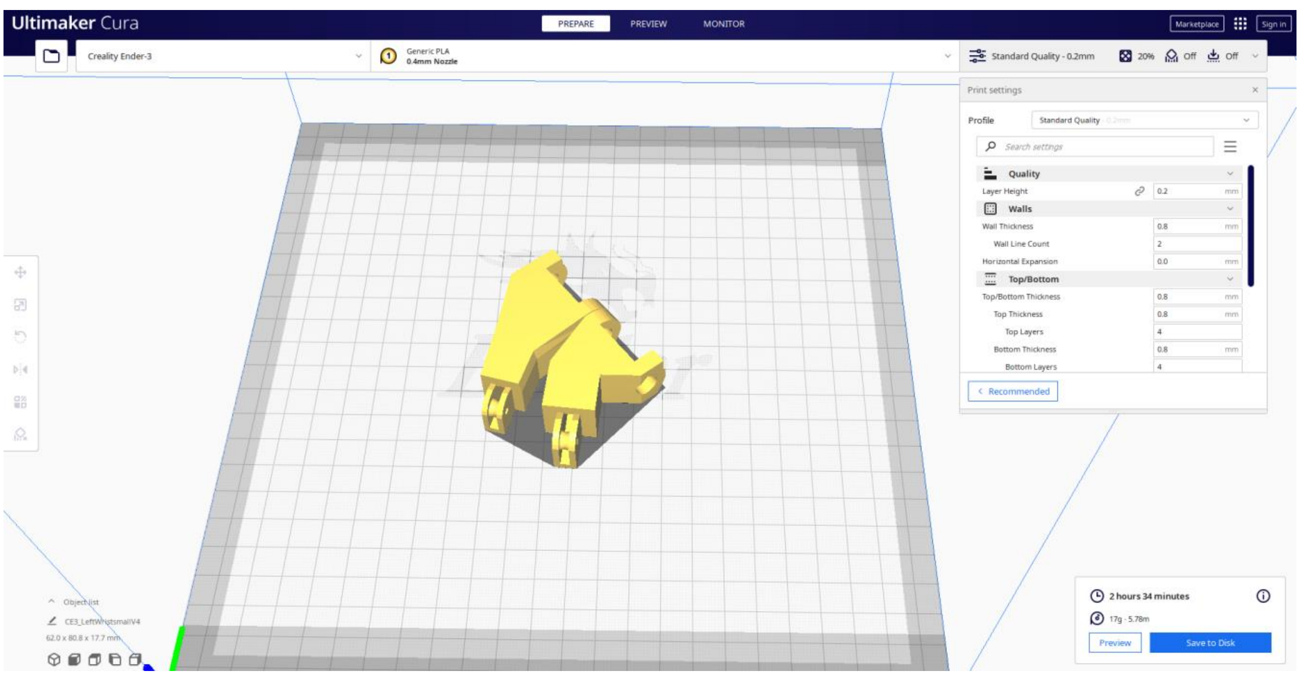

Figure 22: Ultimaker Cura software

In figure 22, On the base, the size of the components and how they will be printed may be seen.

Ultimaker Cura is a program that generates a code full of coordinates (x, y, and z) in order for the extruder to move around them and complete the component layer by layer.

Some of the items were printed.

Figure 23: Printed handpieces

4.6 Assembly process of the prototype

Details are not ideally printed, after printing all of the 3D models remove the anti-warp supports and trim with a knife. First of all, fix details with pliers to hold the parts together while gluing them with AkFix.

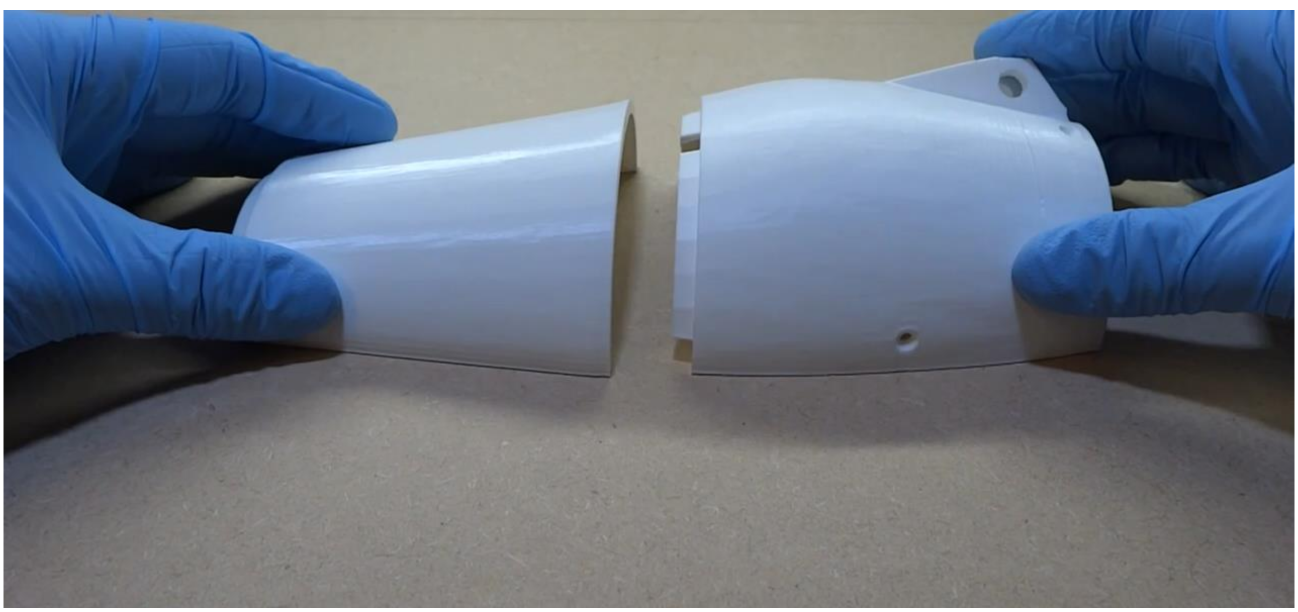

Figure 24: Trimmed details before glue process

Step 2, I trimmed the holes of the servo bed and mounted it on the bottom of the hand. I fixed servo bed to the bottom of the hand with glue.

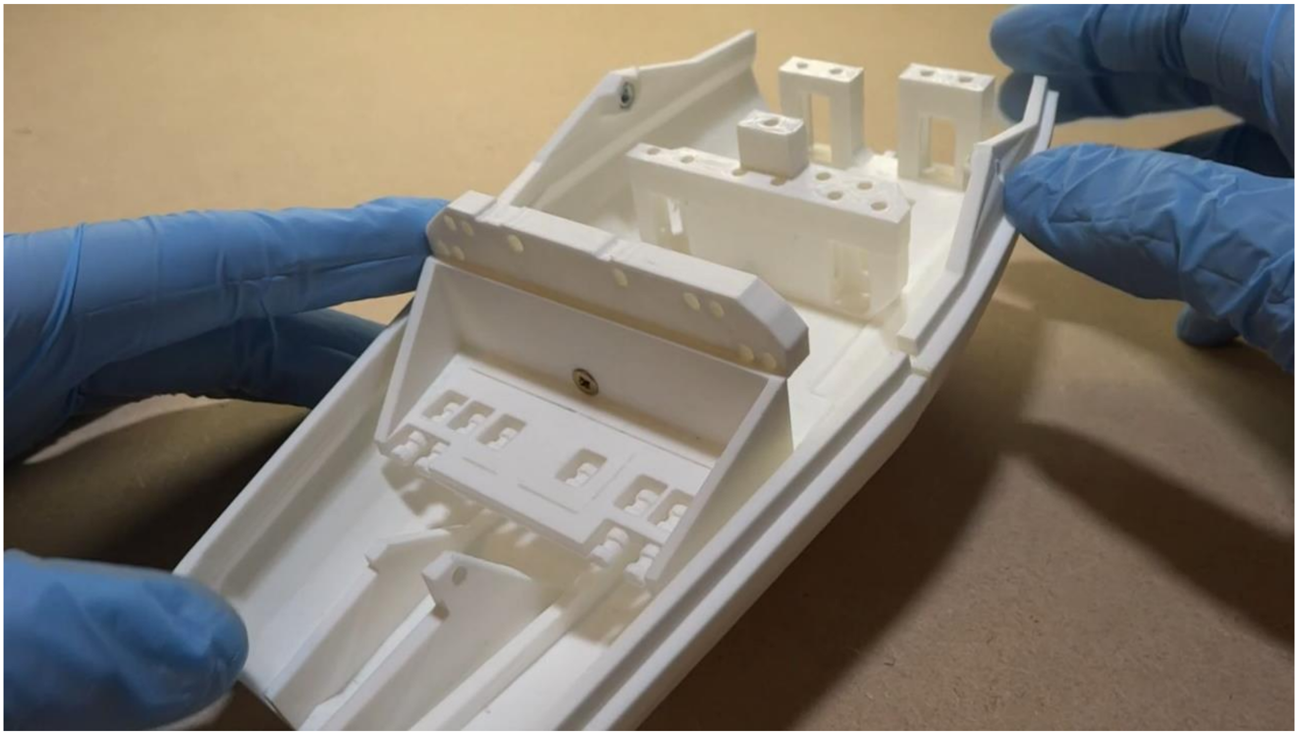

Figure 25: Mounted servo bed

I'm using MG996R 5 servo motors and I mounted to the servo bed with screws.

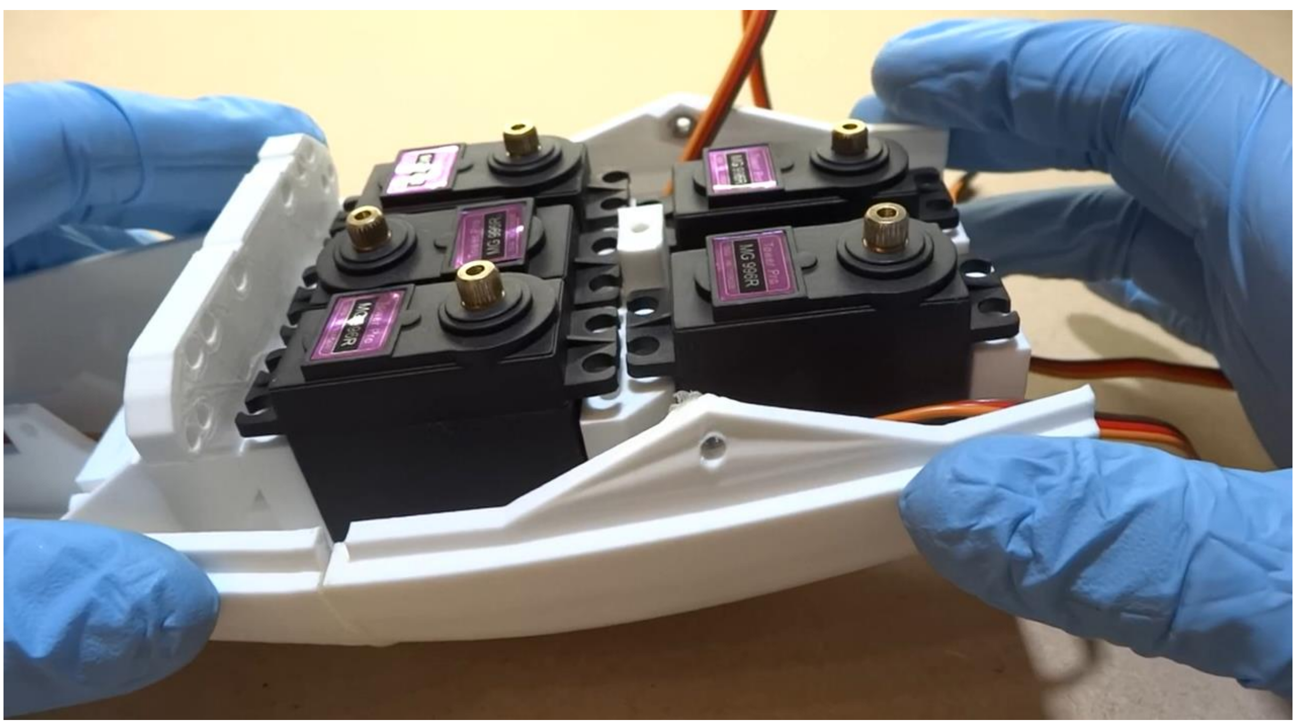

Figure 26: Mounting of the servo

3D models of the robrings and servo pulleys which I downloaded from Thingiverse and I maked the holes wider with a 3mm drill to pass the screws easily through.

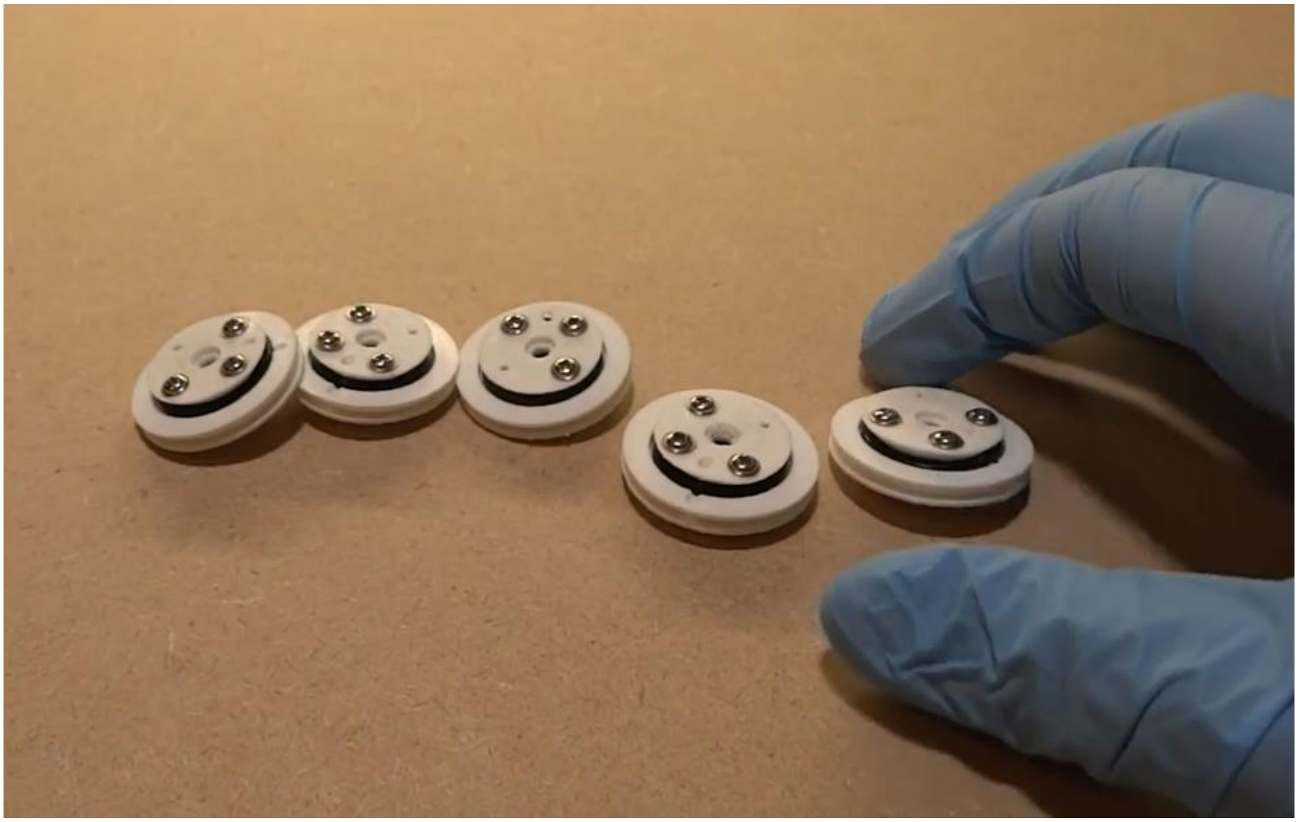

Figure 27: Robring and servo pulleys

I redrilled all of the finger holes with a 3mm drill and fixed them with AkFix glue to connect each other. I putted 3mm metal bolt to mage pegs between parts. I cutted with a knife anti warp places to take smooth surface

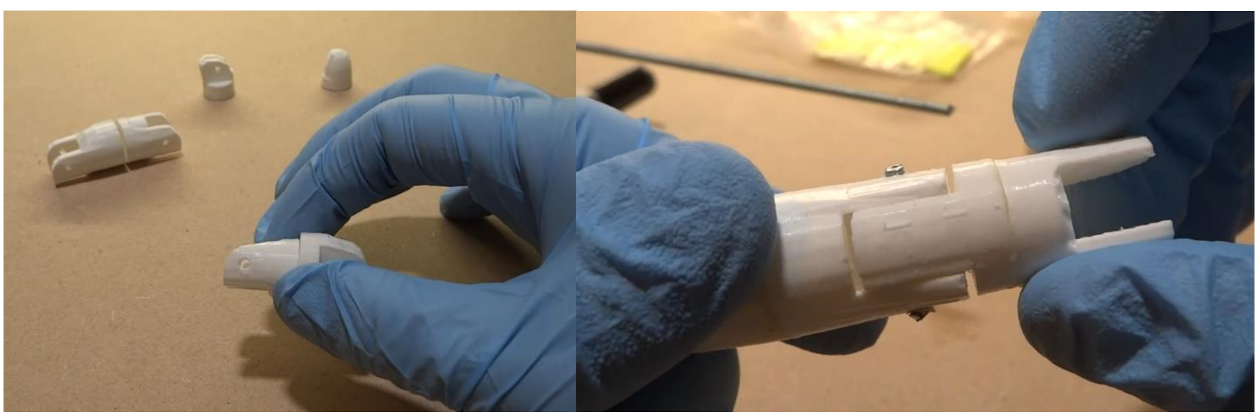

Figure 28: Finger assembly

I cutted 10 pieces 75cm long of fish line. I didn't use standard nylon because it stretches. I inserted the fish lines in the hole of the wrist.

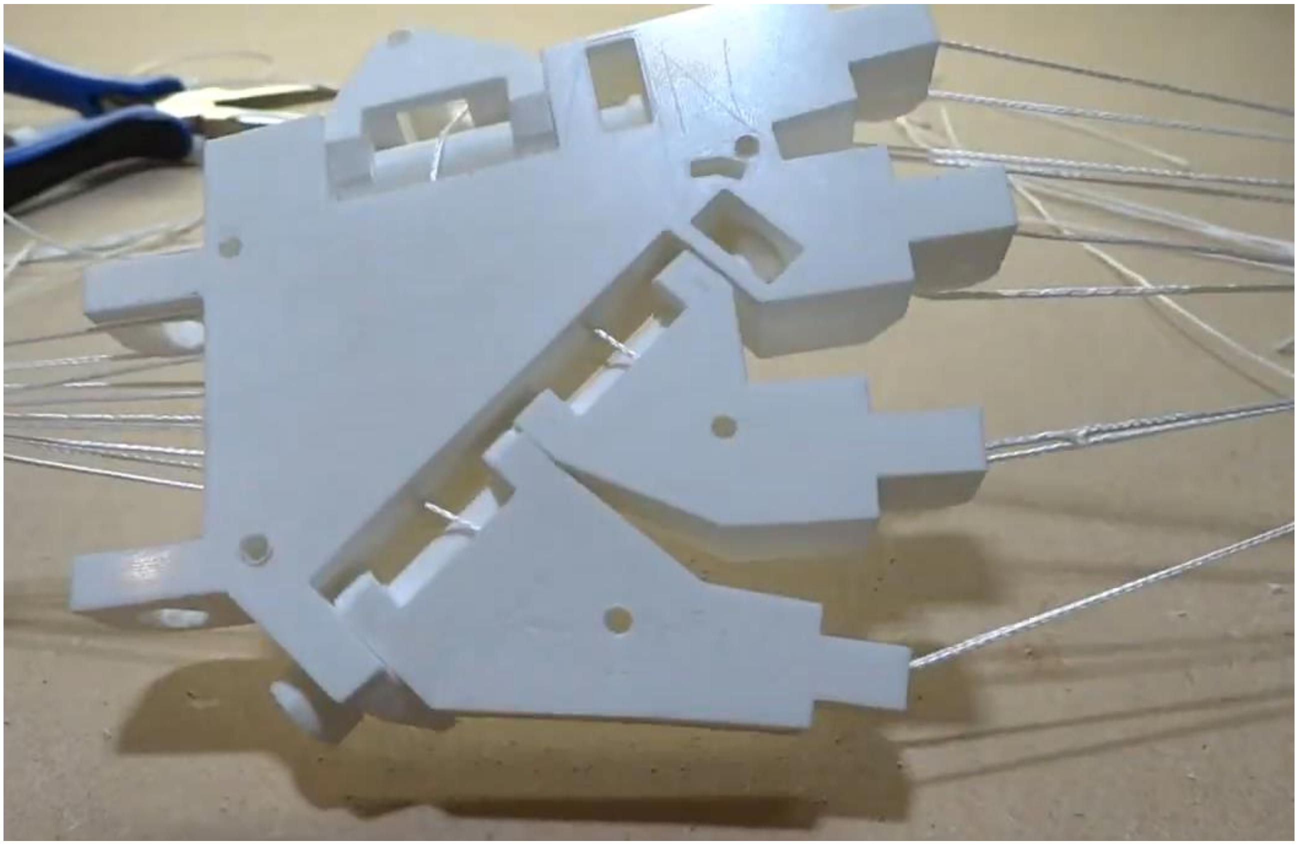

Figure 29: Hand wrist

After assembling all the parts, i tested the movement pulling the fishing lines, the result most shows flipping of the fingers. I passed the bolts to attach the fingers and tighten the screws with nuts.

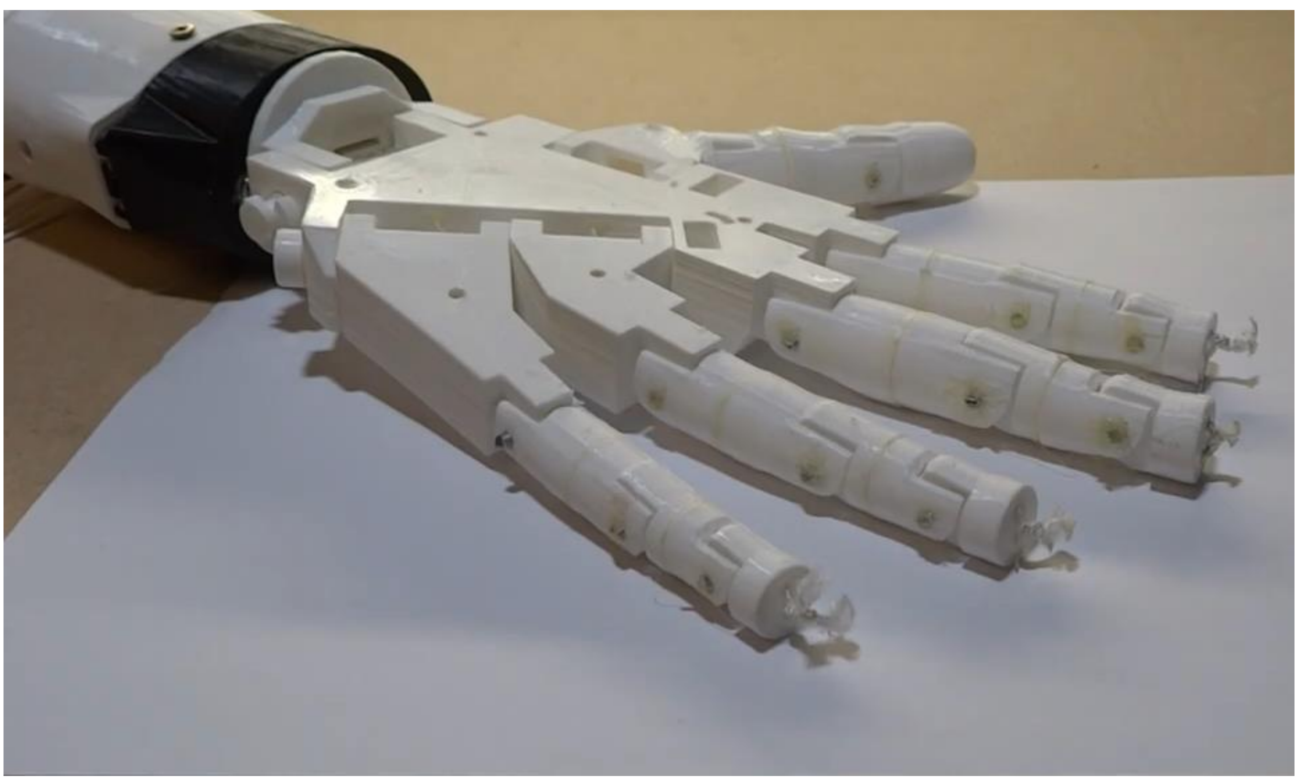

Figure 30: Assembled finger and wrist

I tied the fishing lines to the pulley of the servo, then it's been held each line with an improvised system of screws and threads to maintain the tension.

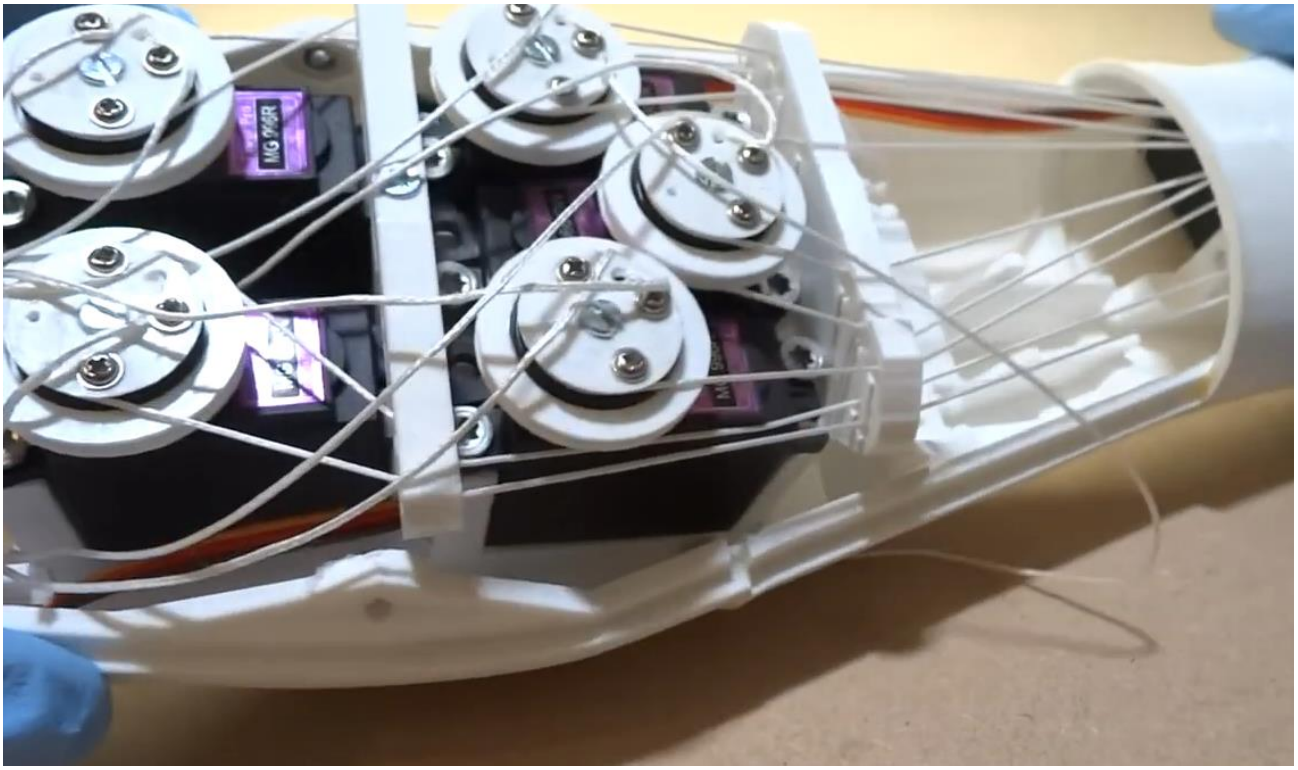

Figure 31: Holding system of the strings

Figure 32: Fully assembled hands

5. HARDWARE AND SOFTWARE

In this part the main idea is to read signals from the muscles, actually from the biceps, send them to Arduino and through it moves five servos in the function of the force, from 0 to 180 degrees.

For the prototype design, the electronic system was kept fairly simple. In this design, one microcontroller, EMG sensor and servo motors were used and connected up to a power source.

5.1 Electromyography sensor (EMG)

Sensors are needed in the hand to measure the EMG signal coming from the remaining muscles of the amputee's stump, to position the fingers.

Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles. EMG is performed using an instrument called an electromyograph to produce a record called an electromyogram. An electromyograph detects the electric potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect abnormalities, activation level, or recruitment order, or to analyze the biomechanics of human or animal movement. Needle EMG is an electrodiagnostic medicine technique commonly used by neurologists. Surface EMG is a non-medical procedure used to assess muscle activation by several professionals, including physiotherapists, kinesiologists, and biomedical engineers. In Computer Science, EMG is also used as middleware in gesture recognition towards allowing the input of physical activity to a computer as a form of human-computer interaction.

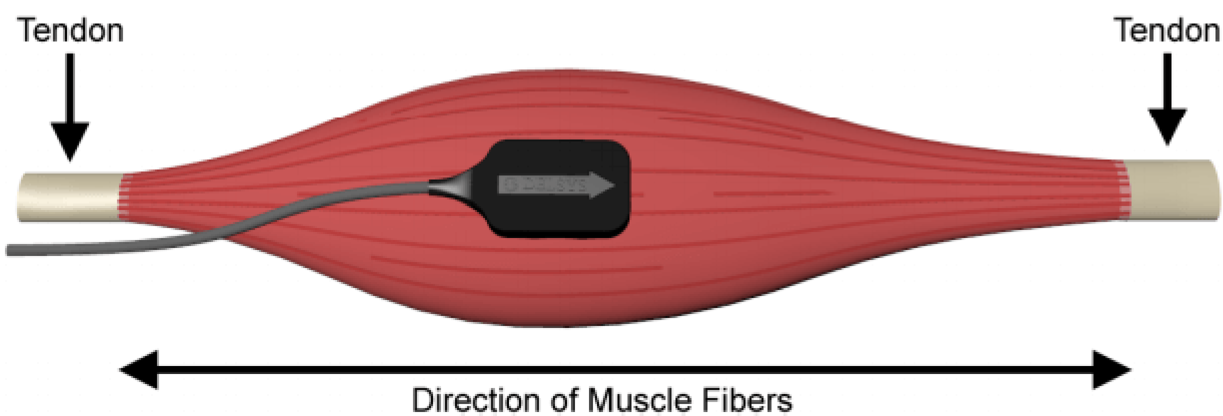

Figure 33: EMG sensor placement

The process begins with EMG sensor placement; where it's placed in the innervation zone of both tendons for better detection quality. Electrodes begin to detect electrical activity generated by muscle movement/contraction. Electrical activity detected is then displayed via the form of waves on a monitor or in an oscilloscope.

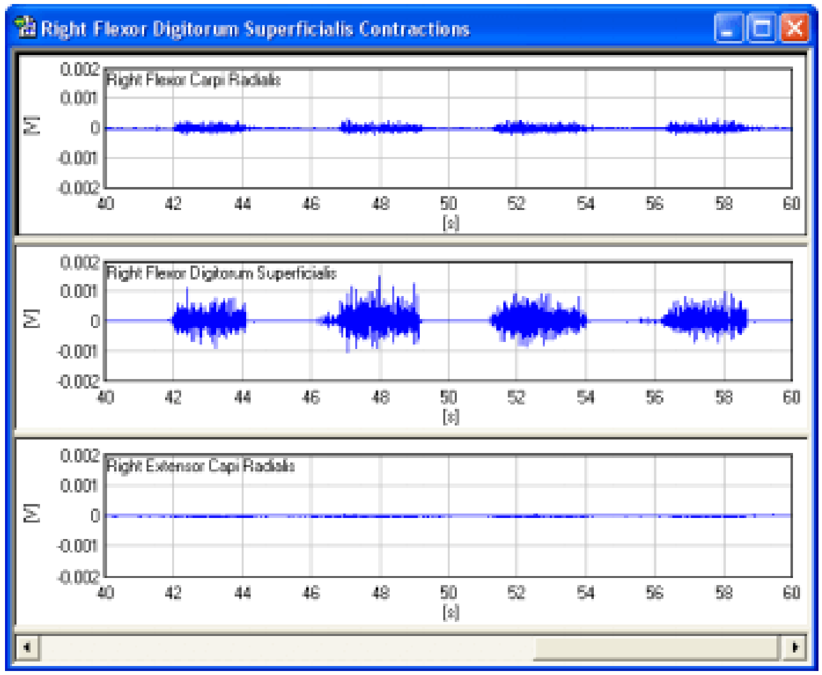

Figure 34: EMG sensor output display

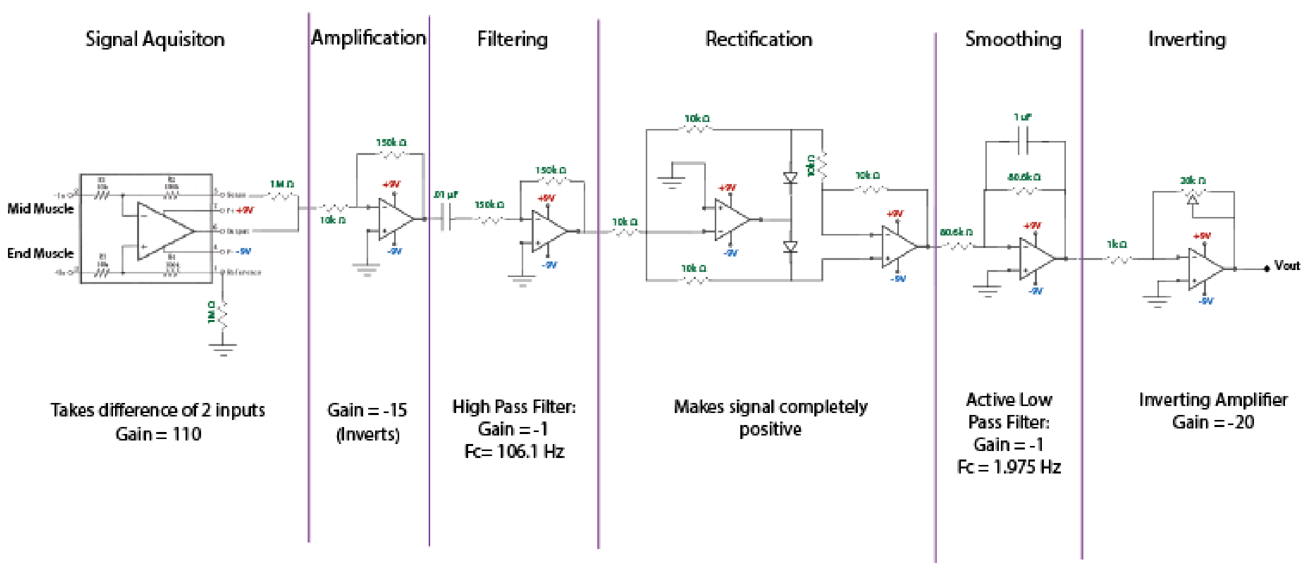

Figure 35: Electromyogram EMG circuit diagram

In my project, I'm using an AD8226 amplifier-based EMG sensor from Aliexpress. An EMG Sensor required positive and negative reference voltage. Therefore two power sources are required because the sensor has a maximum operating voltage of ±18V

Figure 36: AD8226 based EMG sensor

The EMG device used in this project is a 3-lead differential muscle/electromyography sensor. It comes with an onboard, 3.5mm cable port that can be used to attach regular EMG/ECG electrodes. Although the sensor is not an industry-grade EMG device, it is effective for measuring and monitoring muscle activation. It can be used for robotics, prosthetics, and a variety of control applications.

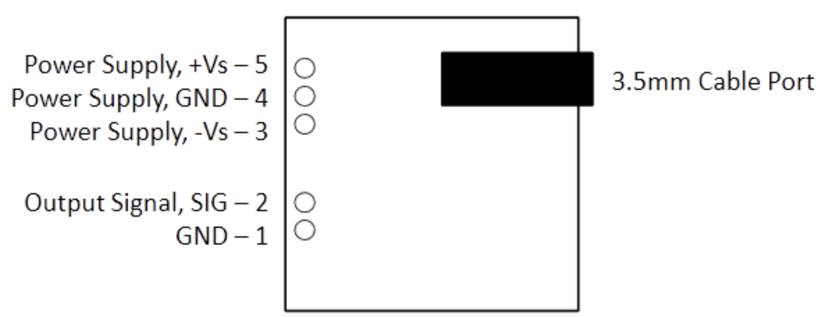

Figure 37: The sensor board has this pin configuration

The sensor is ideal for use with microcontrollers. Unlike industry-grade medical sensors, however, it does not output raw EMG signals. Rather, an amplified, rectified, and smooth signal is delivered that can be read at Arduino's analog input pin (or any other microcontroller).

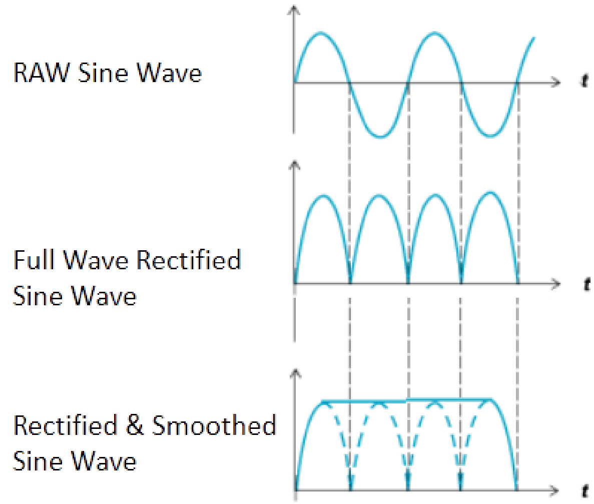

Figure 38: Wave of the signal

The sensor board uses an AD8226 instrumentation amplifier. It requires only one external resistor to set the gain from 1 to 1000. The amplifier operates on supplies, ranging between +/-1.35 to +/-18V (for dual supplies) and 2.2 to 36V (for a single supply). It can also handle voltages beyond its rail-to-rail voltage. For example, even with a 5V supply, the IC can withstand up to +/-35V. The AD8226 is a small form factor, multichannel, low-cost, and low-power amplifier.

5.2 Controller

As the brain of the automatic control equipment, a microcontroller is critical for the operation of any mechatronics device. A microcontroller is a single integrated circuit with a microprocessor, memory, and programmable input/output peripherals. It has a robust computational instruction set in a small package with low energy and low cost. This made applications of microcontrollers reach throughout every field, such as mobile phones, automobiles, industrial control, home appliances, and electric machine control. Therefore, a microcontroller is necessary for the control system of a bionic hand.

Arduino is a user-friendly popular microcontroller platform. It has open-source hardware with several types of boards and open-source software with hundreds of libraries. Therefore, Arduino can be used to complete numerous control functions, mainly since thousands of projects are published on the website and the worldwide community. People can use and modify code freely from another project because Arduino is licensed under the GNU Lesser General Public License or the GNU General Public License. Therefore, it is favored by, not only academics, but also hobbyists. Moreover, the price of an Arduino board is lower than other platforms. The highest cost of an Arduino board is under $30. Arduino software Integrated Development Environment (IDE) runs on many operating systems, like Windows, Macintosh OSX, and Linux. In conclusion, Arduino matches the hardware standard of this thesis.

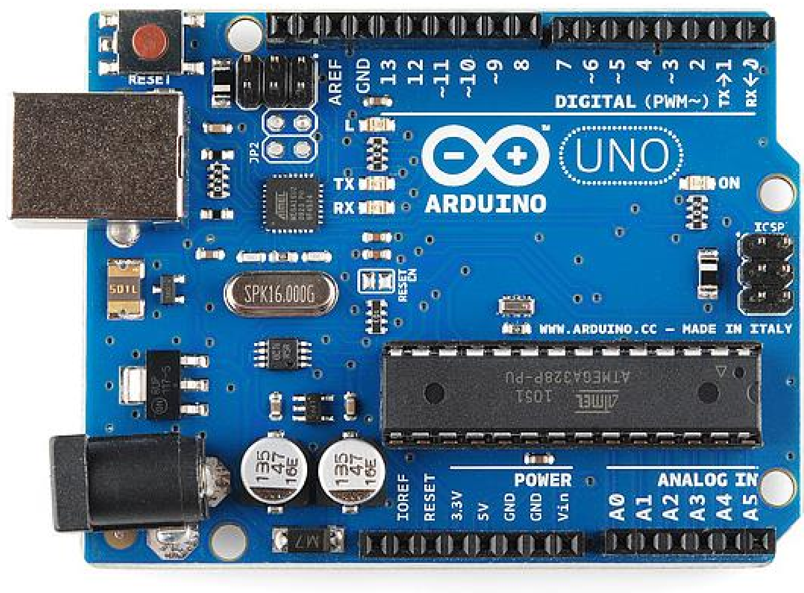

Figure 39: Arduino Uno shield

5.3 Circuit connection and diagram

The sensor board has two sets of pins:

- A 3-pin **set** that includes -+Vs, GND, and -Vs terminals. It’s used to provide a dual supply to the AD8226 amplifier.
- A 2-pin set that includes the signal and GND terminals. It’s used to interface the board with the microcontroller.

To begin, I used the two 9V batteries. Connected the positive terminal of one battery to the +VS pin. Then, connected the negative terminal of that same battery with the positive terminal of the second battery, joining it to the GND pin in the 3-pin header.

Then, connected the negative terminal of that second battery to the -Vs pin. This provides the +/-9V dual-supply to the sensor.

To interface with Arduino, connected the GND pin in the 2-pin header to any of the two ground pins on Arduino UNO. In the end, connected the signal pin to the analog input pin.

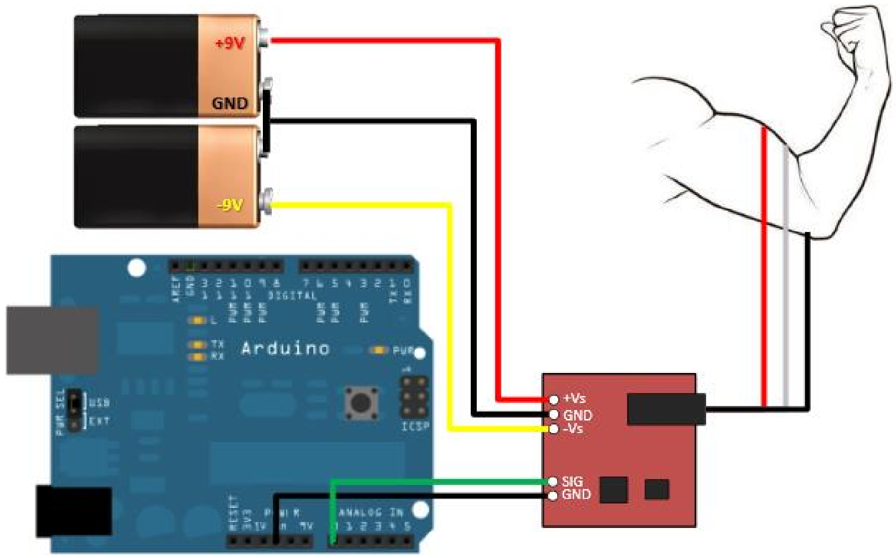

Figure 40: Circuit diagram

Ensure the 3-lead cable that's equipped with a 3.5mm jack, is connected to the sensor board. The EMG/ECG electrodes can, then, be attached to the cable.

Pick a muscle group to monitor, such as a bicep or calf. Place one electrode in the middle of this muscle group and attach the red cable's snap connector to this electrode. Next, place a second electrode at one end of this muscle group, attaching the green cable's snap connector to this electrode.

Then, place the third electrode on a bony or non-muscular part of the body that's near the same muscle group. Attach the yellow cable's snap connector to this electrode.

5.4 Arduino sketch

The EMG signals can range from 50u to 30 mV. The AD8266 sensor offers a gain of up to 1000, which can amplify the EMG potentials to the mV level. The "read" EMG signals are amplified, rectified, and smoothed by the AD8226 instrumentation amplifier.

When the electrodes are properly placed on a muscle group, their contraction and relaxation produce EMG potentials. These potentials are picked up by the sensor and amplified to a measurable range. The sensor board's gain can be adjusted by using an onboard potentiometer.

The output signal from the sensor board is read via Arduino's input pin. As the output signal from the sensor board is rectified (and in the mV range), Arduino can easily read it. Arduino is programmed to read the analog input at its A1 pin and print the readings to the serial port.

These EMG readings can be set and monitored as numbers, ranging from 0 to 1023, on Arduino IDE's serial monitor or as a graph on its serial plotter.

test §

```
//Firdavs Nematzoda Thesis work
//Design and development of a prototype of
//cost-effective myoelectric prosthetic hands in Uzbekistan.

int EMG_PIN = A1;
int THRESHOLD = 250;
#include <Servo.h>
Servo SERVO_1;
Serial.begin(115200);

void loop(){
   //The "Value" variable reads the value from the analog pin to which the sensor is connected.
   int value = analogRead(EMG_PIN);
   SERVO_1.attach(5);

   //If the sensor value is GREATER than the THRESHOLD, the servo motor will turn to 170 degrees.
   if(value > THRESHOLD){
    SERVO_1.write(180);
   }

   //If the sensor is LESS than the THRESHOLD, the servo motor will turn to 10 degrees.
   else {
        SERVO_1.write(0);
        }
   delay(500);
      //You can use compare the values shown when you open and close your hand.
      Serial.println(value);
      }
```

Figure 41: The code

The sketch begins by assigning A1 as the pin to read the EMG sensor's analog signals. A variable 'value' is declared to store the analog values that are received from the sensor. Annex 1.

In the setup() function, the baud rate for serial communication is set to 115200. In the loop() function, the sensor's analog voltages are read and stored in the 'value' variable.

The analog readings are printed to the serial port, where they can be monitored on Arduino IDE's serial monitor or serial plotter.

The position control of the servo will take place by Arduino. The results of the actuation are shown below.

When the arm is in Non-flex condition the servo motor position will be at zero degrees for the voltage depolarization in the forearm muscle giving the frequency rise up 162Hz.

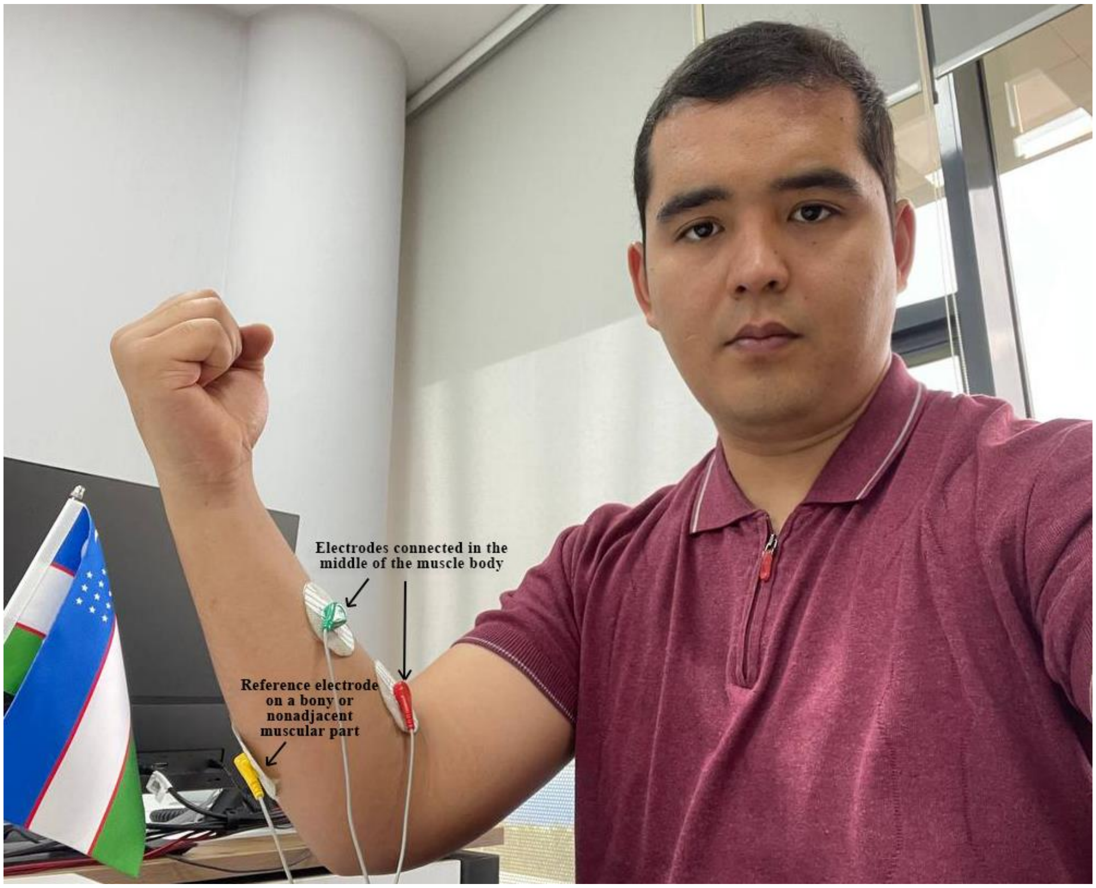

Figure 42: Connected electrodes

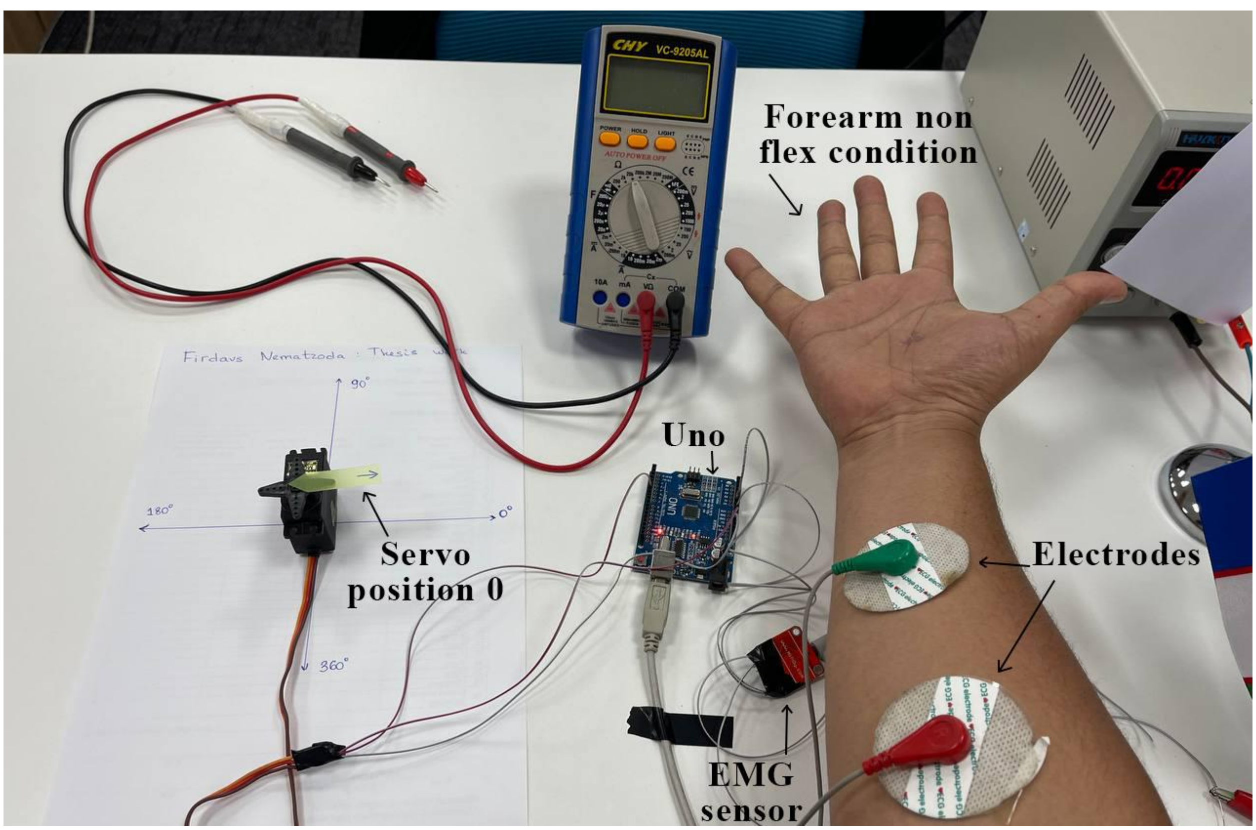

Figure 43: Servo Motor 0 degree position at forearm None flex condition

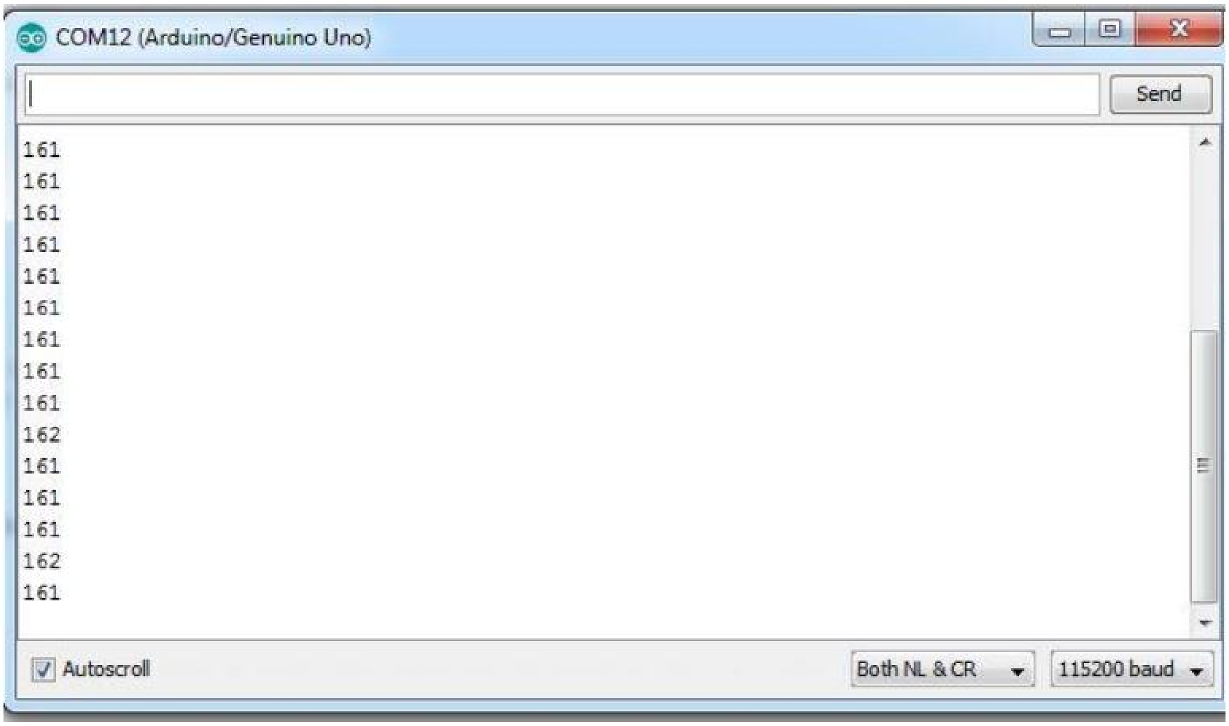

Figure 44: Serial monitor display 162 Hz frequency value during forearm None Flex condition

When the arm is in flex condition the servo motor position will turn 180 degrees

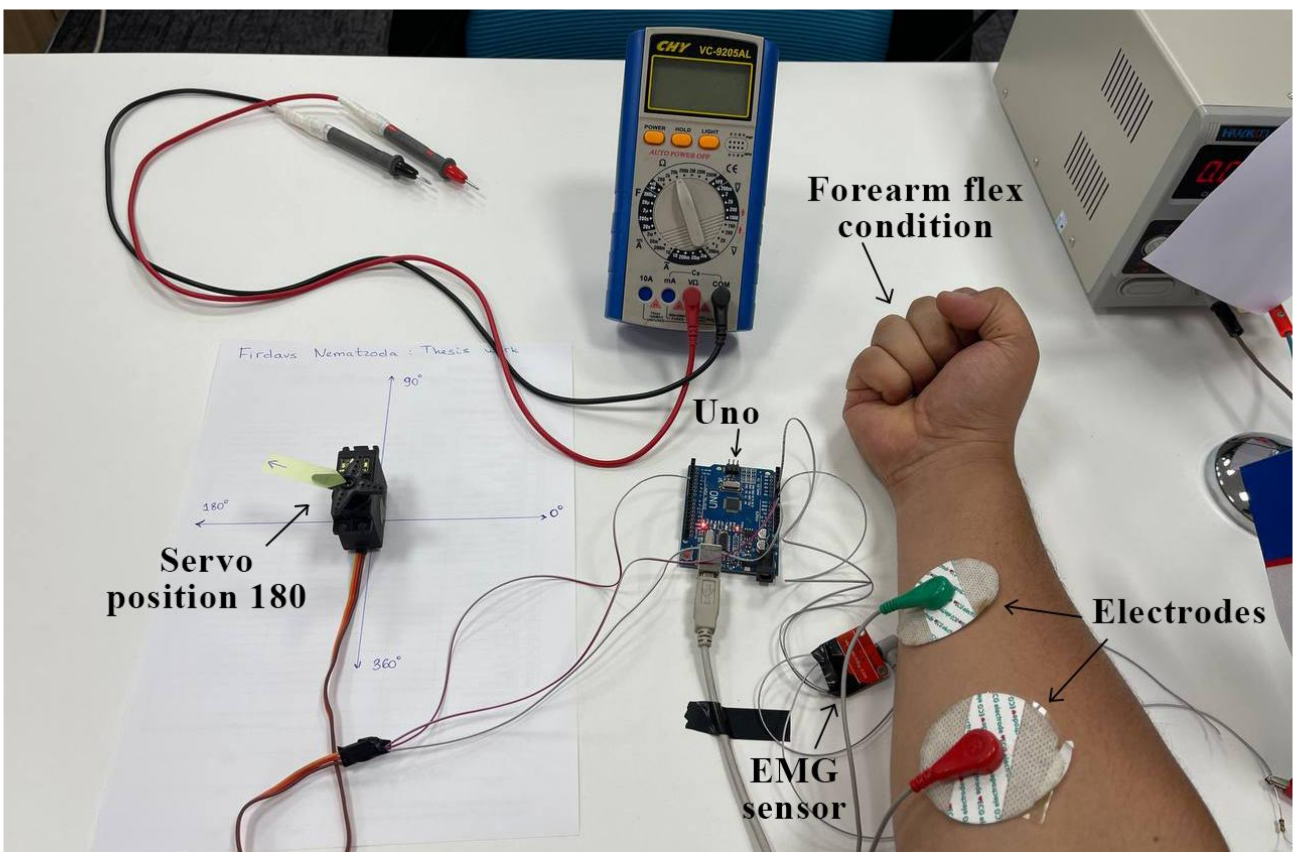

Figure 45: Servo Motor 180 degree position at forearm flex condition

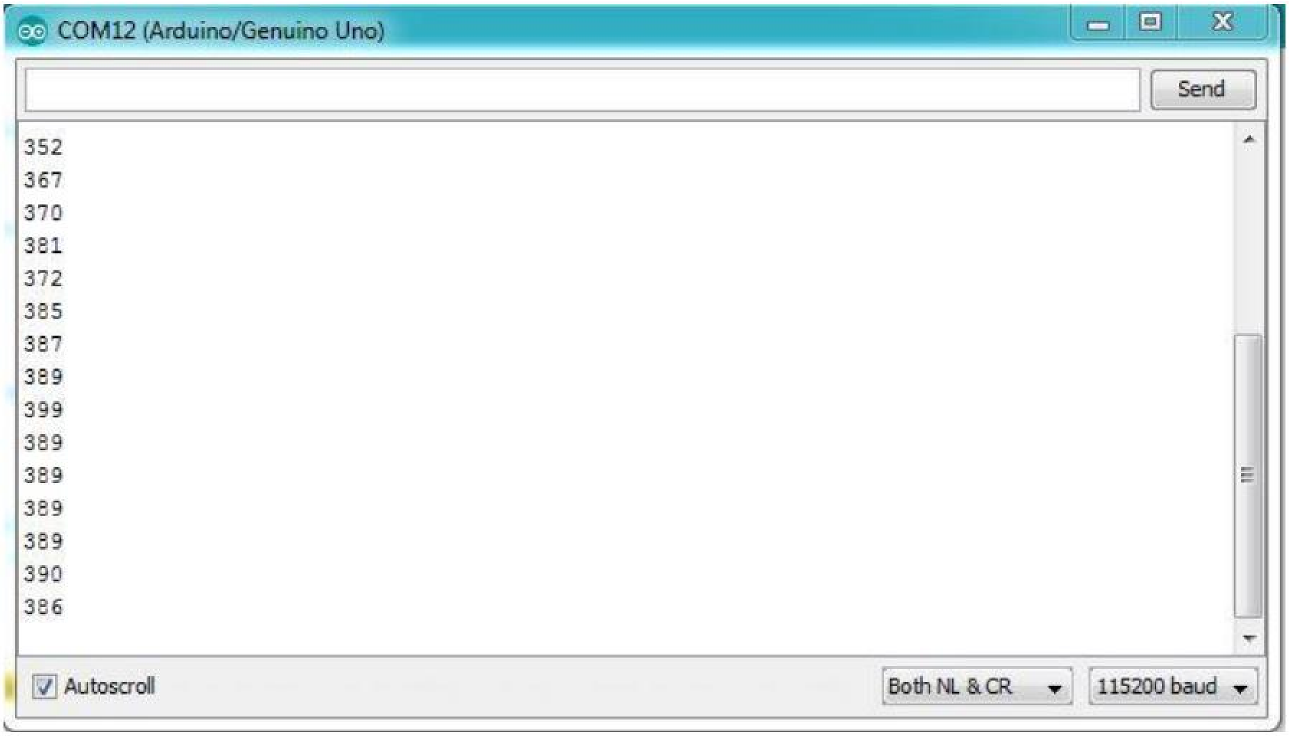

Figure 46: Serial monitor display greater than 350Hz Frequency value during forearm Flex condition

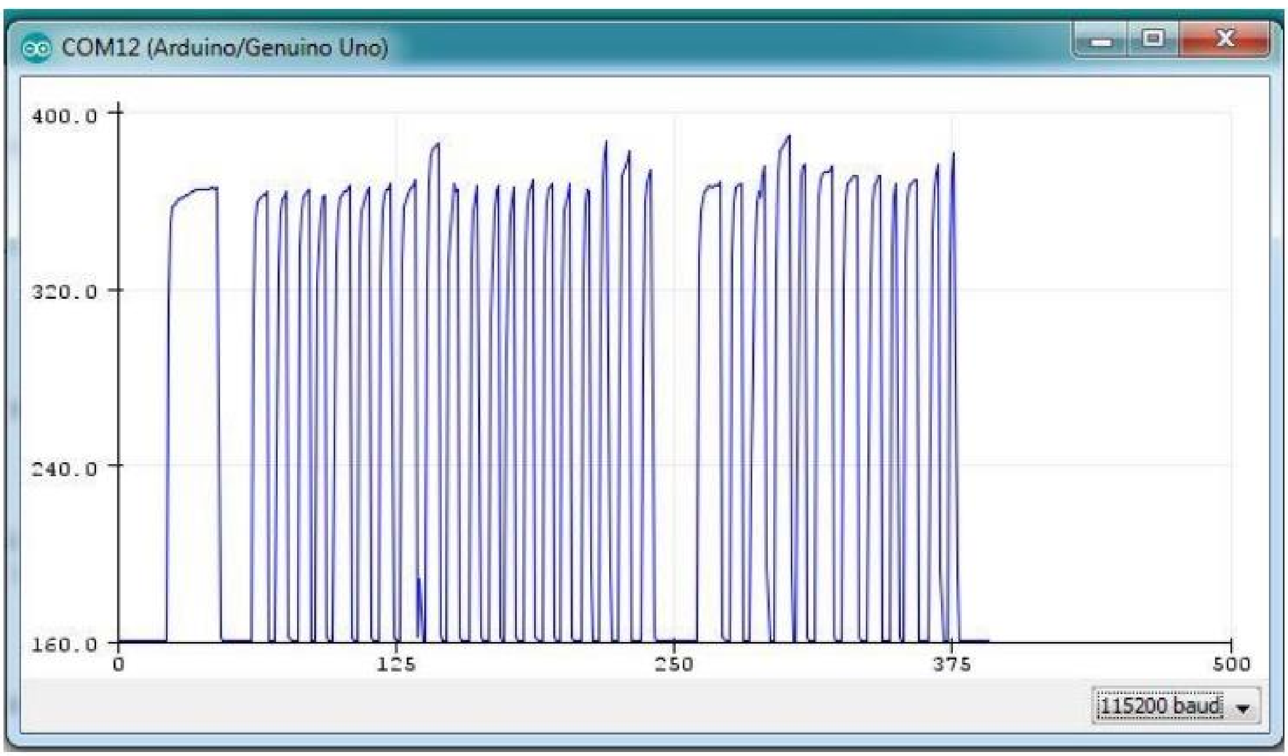

Figure 47: Serial plot display frequency oscillation between 162 to 400 Hz during forearm flex & none flex condition.

5.5 Calibration process of signal

It is needed to evaluate the output signal to make sure that the range of the voltages is between
0 - 5V because the analogical input of Arduino works between these values, also it is preferable to obtain a signal smooth to make the servos work properly later.

It has used various forces to test the signal's values. A variable resistance is used to alter the final gain of the pulses such that the signal does not exceed 5V.

It's time to connect the Arduino and run a quick test using the servomotors once the final signal has been well limited.

The analogical to digital converter of Arduino UNO goes from [0, 5] V, as it is been said, to [0, 1023] bits. First of all, calibrate the minimum value to make the servos start moving. Then, after overcoming this value the servos will start moving from 0 to 180 degrees.

150-160Hz the signal is stable at 0V because there is no force done. Afterward, is applied some force and the signal rises until more or less 5V is stable.

5.6 The prototype performance

Once the signal has been appropriately handled, it can be properly interpreted by Arduino's analog input. A program has been built, which can be found in Annex 2, to make the prototype act in response to the force applied.

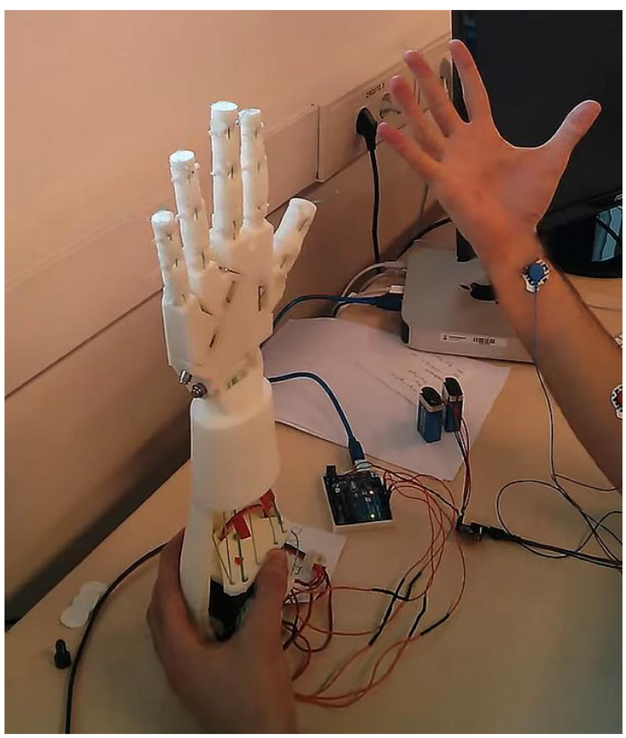

Figure 48: Prototype state without doing force.

The prototype is shown in its relaxed state without any force applied. The following one shows how the prosthetic hand shrinks when force is applied.

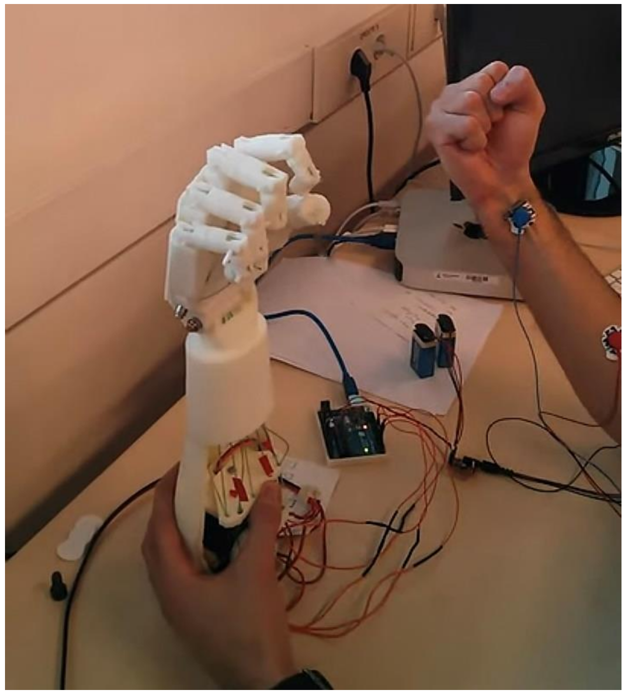

Figure 49: Prototype when force applied.

6. COSTS AND ECONOMIC ASPECTS

To show that this project is less expensive than existing myoelectric prostheses, all economic factors have been considered

Parts	Time (hour)	Price in USD
All printed materials 170 gr of PLA + electricity	53	18$
Servo motor MG996R 5 pcs	4	66$
EMG sensor AD8226	6	15$
Arduino UNO shield	1	6$
Fishing line 6m	1	3$
Bolts and screws 8mm 16mm	1	2$
Electrodes 3pcs	1	6$
7.4V LiPo Battery 1.6Ah	1	14$
9V battery	1	2$
Glue AkFix 2 component	1	4$
Other things	5	5$
Total amount	**69**	**141$**

7. CONCLUSION

Referring to the goals description's aims, both forms of movement—enclosure and impingement—have been accomplished using the prototype. The final design, which was created as a prototype, wasn't created to be properly matched to a person with an amputated arm; rather, it was created with the intention of being used by anyone, such as a prosthesis tester, and it meets the expectations.

Many obstacles had to be overcome throughout the project, starting with 3D printing because it is not as simple as it first appears. I've discovered that 3D printers are extremely sensitive to even the slightest temperature change, and if the base or the extruder are not set up correctly, it is very simple to obtain an imperfect piece. Additionally, every design created for this project has through multiple iterations due to issues such as a challenging design that cannot be printed using the 3D printer utilized due to its complicated geometry or because the shape has to be altered due to poorly planned physical attributes.

Particularly noteworthy is the growth in my understanding of 3D design using Solid Works, Ultimaker Cura and programming using Arduino Software, which is similar to Dev. C++.

An important outcome of this project is the demonstration of the economic viability of creating one's own prosthesis in comparison to the costs discovered online. The present project cost roughly 141 $, while a professional prosthesis can cost anywhere from 18,000 to 23,000 $ and even more. Price impossible to afford for many people.

The improvement or optimization of the finished prototype is another theme of the conclusions. There are undoubtedly many elements that may be improved, but for me, these are the most crucial:

•Including a pressure sensor to regulate how hard the grip is made when something is present.

• Refine the forearm pieces' design to give them a more realistic and natural shape.

• Attempt to increase the number of motors or actuators to each joint so that each finger may move independently.

• Continuous program and signal reading enhancements.

Goals are closer than they appear.

In conclusion, it can be said that myoelectric prostheses are extremely challenging to construct, but there are new innovative ideas emerging nowadays, such as 3D printing, which makes creating one's own devices simpler and less expensive. The open source designs on the Internet will make crafting simpler in the near future when these printers will be accessible and affordable for everyone.

The future is in our hands.

8. ANNEXES

8.1 Annex 1: EMG Sensor

```
int EMG_PIN = A1;
int THRESHOLD = 250;
#include <Servo.h>
Servo SERVO_1;
Serial.begin(115200);

void loop(){
  //The "Value" variable reads the value from the analog pin to which the sensor is connected
  int value = analogRead(EMG_PIN);
  SERVO_1.attach(5);
  //If the sensor value is GREATER than the THRESHOLD, the servo motor will turn to 170 degress
  if(value > THRESHOLD) {
    SERVO_1.write(180);
  }
  //If the sensor is LESS than the THRESHOLD, the servo motor will turn to 10 degrees
  else {
    SERVO_1.write(0);
  }
  delay(500);
  //You can use compare the values show when you open and close your hand
  Serial.println(value);
}
```

8.2 Annex 2: Source code

```
#include <Servo.h>
int EMG_PIN = A1;
int THRESHOLD = 250;
int value = analogRead(EMG_PIN);
//Naming the servos
Servo servo1;
Servo servo2;
Servo servo3;
Servo servo4;
Servo servo5;

void setup()
{
//Starting the serial monitor
Serial.begin(9600);
//Configuring servo pins
servo1.attach(10); // pinky
servo2.attach(11); //ring
servo3.attach(3); // middle
servo4.attach(6); //index
servo5.attach(5); //thumb
}
void loop()
{
```

```
//If the EMG data is greater than x the hand closes
  if(value > THRESHOLD) {
    servo1.write(180);
    servo2.write(148);
    servo3.write(89);
    servo4.write(180);
    servo5.write(180);
  }

//If the EMG data is lower than x the hand opens
  else if (value > THRESHOLD) {
    servo1.write(38);
    servo2.write(10);
    servo3.write(0);
    servo4.write(16);
    servo5.write(16);
  }

//A delay to slow down the process
  delay(100);
//You can use compare the values show when you open and
close your hand.
  Serial.println(value);
}
```

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