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Design and fabrication of a 3d printed myoelectric prosthetic arm

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Abstract*- For the past decade 3D printing has become very popular as it has become much more accessible due to the availability of low cost 3D printer such as XYZprinting da Vinci Mini, LulzBot Mini, RepRap and Fab@Home. The main objective of this project is the design and fabrication of a low-cost 3D printed myoelectric prosthetic arm. The main challenge was to design an ergonomic prosthetic arm. The designed arm is almost totally 3D printed, electrically actuated and responds to EMG signals from the muscles. The parts were designed in SolidWorks and printed using the Prusa i3 3D printer. The whole project cost a lot less than the commercial prosthetic arms which are available in the market, making it a lot affordable for the low income people. There are quite a few limitations to this design as well. Such as low grip strength, low response time etc. which can be improved upon with further research.This topic covers a wide range of engineering fields the core of which is an innovative design.*

Keywords: PLA, EMG signal,Sensors, Arduino Uno, Electrode

1. INTRODUCTION

There is an increase in the number of traumatic and congenital hand amputation or reduction. Being a developing nation, the options for prosthetics are very limited. The cheapest widely used prosthetics here are hand molded and are simple and don't provide any flexibility in use. These prosthetics are passive devices which offer little in terms of control and movement. The more complex commercial ones are very expensive and not affordable for many. With the recent development in 3D printing technology it is possible to print prosthetics which can be electrically actuated. This can be a great low cost solution. This project is aimed to mimic the human arm closely as possible with cost reduction kept in mind.

3D printing is any of various processes in which material is joined or solidified under computer control to create a three-dimensional object, with material being added together (such as liquid molecules or powder grains being fused together), typically layer by layer. In the 1990s, 3D printing techniques were considered suitable only for the production of functional or aesthetical prototypes and a more appropriate term was rapid prototyping [1]. The most commonly used 3D Printing process is a material extrusion technique called fused deposition modeling (FDM). It is a 3D printing process that uses a continuous filament of a thermoplastic material. Filament is fed from a large coil through a moving, heated printer extruder head, and is deposited on the growing work. The print head is moved under computer control to define the printed shape. A wide variety of filament materials are extruded, including thermoplastics such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), high-impact polystyrene (HIPS), thermoplastic polyurethane (TPU) and aliphatic polyamides (nylon). PLA filament was used in this project as it is widely available, cheap and more environmentally friendly.

Prosthetics arm can be controlled different ways. One of the most popular is myoelectric control. The user controls the prosthetic arm via minute amount electric signals (EMG) that is generated in the arm due to the arm muscle flexing. This signal is picked up by sensors and amplified. This process is far less complex than some of the other method such as EEG control which uses signals from the brain. This project is based on EMG (electro-myography) signal control. Myoelectric control is less accurate and provide less control than EEG based control. But as the main objective of this project was to design a low-cost prosthetic arm, it was decided to use EMG signal based control.

The design of the whole arm was done in SolidWorks which is a popular CAD software. It has a modular design. So it can be taken apart and reassembled easily. If any of the parts or components get broken, it can be easily replaced. One of the advantages of 3D printing prosthetic arm is, anyone can customize the design to their own liking.

2. METHODOLOGY

To produce a functional 3D printed prosthetic arm, there were a lot of design and manufacturing challenges to overcome. As there was a limit to how much we can spend on this arm, the design won't be too complex. But the prosthetic arm is able to do some basic functions like picking up light object or holding an empty bottle. The design is modular, so if a part gets broken it is easily replaceable.

2.1 Required Hardware

The few basic components that was necessary for this project are

1) 3D Printer
2) PLA filament
3) 3 servo motors
4) Arduino Uno
5) Strings
6) EMG sensor
7) LiPo Battery
8) 7805 IC
9) Two 9V batteries
10) Bread Boards
11) Connecting Wires

2.2 Required Software

The softwares which was required to do this project are:

1) Arduino IDE
2) Prusa Slicer
3) SolidWorks

2.3 System Design

The system can be broken into three stages. Figure 1 shows the control scheme.

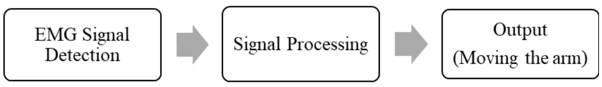

Fig.1: Control Scheme

Figure 2 shows how the sensor is connected to the power supply, Arduino and the muscle. There are three electrodes (red, blue & black). The red and blue (in some cases green) need to be placed closed to each other on the

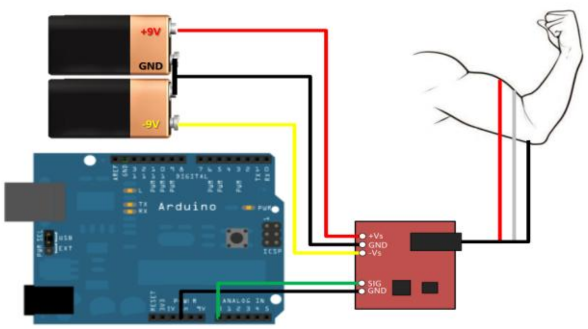

Fig. 2: EMG sensor pin lay-out [2]

muscle targeted. The black electrode is the neutral electrode which needs to be placed on a place with less muscle such as the elbow.The sig pin of the sensor is connected to the analog pin of the Arduino. When muscle is relaxed it gives a value smaller than when the muscle is

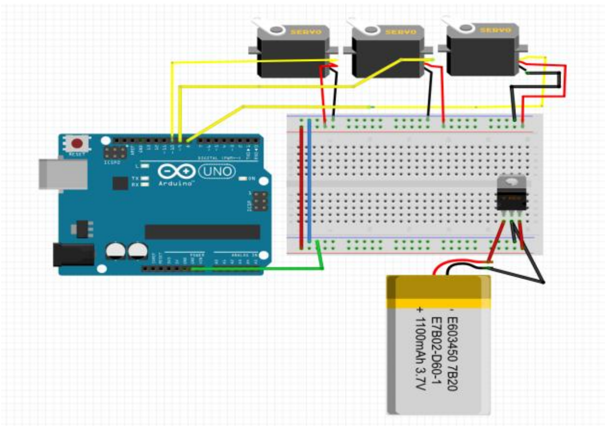

Fig 3: Servo motors pin layout

contracted. The magnitude of the signal depends on how hard the muscle is flexed. If the muscle is flexed really hard then the value will be greater. In figure 3 we can see the interface between the servo motors, power supply and Arduino.

2.4 Computer Aided Design

To 3D print the first thing needed is the 3D design of the object. All the parts are designed in SolidWorks.

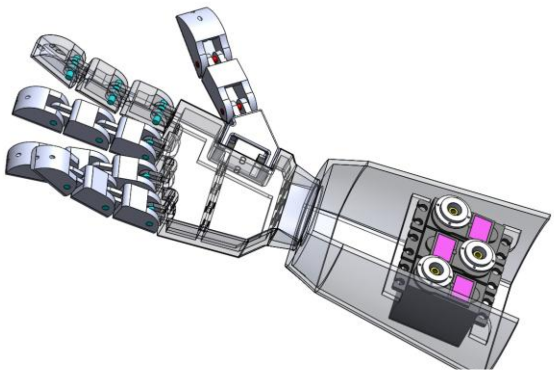

Fig 4: CAD design of the arm

Figure 4 shows the assembled arm design. The top four finger (index, middle, ring & pinky) are all designed the same way with same dimensions to reduce complexity. The thumb has also been designed in a similar fashion. Most commercial and research prosthetic hands aim to provide at least two degrees of freedom in the thumb. This thumb however only provides a single degree of freedom as it can only open/close in a single way. As the thumb only closes it does not move like the opposable thumbs that humans have. Due to this, this thumb doesn't provide the necessary refined grip. This is why it is not possible to hold many large objects. All of the fingers are connected to the palm with the help of pins. The top part of the palm is kept hollow to have an easy access to the strings. There are two guide bridges with holes in them inside the palm to guide the strings. The palm is printed with the wrist. This is why the wrist has no movement. The wrist is then attached to the forearm. The forearm was kept as short as possible to reduce the material cost.

To attach it to someone's arm, it needs to be extended and some sort of harness has to use to attach it to the arm.

2.5 Manufacturing

All the parts were printed by Prusa i3, an open-source fused deposition modeling 3D printer. It has its own development environment. This lets us fine tune various printer options such as density, support configuration etc. PLA was used as the material for all the parts. Figure 5 shows the printer 3D printing a part

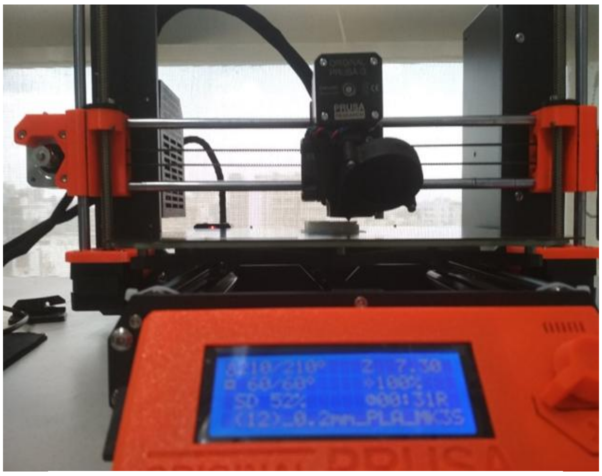

Fig. 5: 3D printing parts

The Prusa development environment Prusa slicer can control the density of the infill of the print. The density of the infill of the parts is 15%.

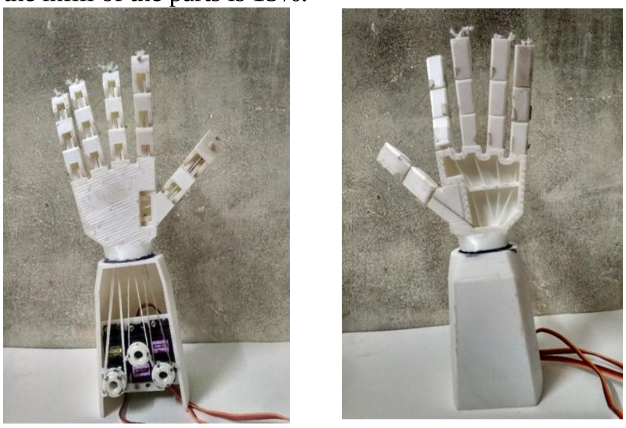

Fig. 6: Front and back of the prosthetic arm

Figure 6 shows completed assembled arm. Due to the lack of tolerance, it was very difficult fit the parts. Most of the parts needed some sanding to be done in order to properly fit. Threading the strings through the guide holes, tensioning it and tuning it required a lot of time and was very difficult to do.

2.6 Working Principle

Figure 7 shows how the strings are attached to the servo and the arm. When the servo motor turns clockwise, it pulls the bottom string which closes the finger. And when the servo motor spins anti-clockwise, it pulls the top string which opens the finger. There are 3 servo motors, not 5. Because the index finger and the thumb is controlled by two separate motors and the other three fingers are controlled by a single motor. When the muscle in the arm is flexed, it generates an EMG signal which is picked up by the sensor. The sensor gives an analogue voltage reading. The harder the muscle is flexed the greater the amplitude of this value. This value also depends on the placement of the electrodes of the sensor on the arm.

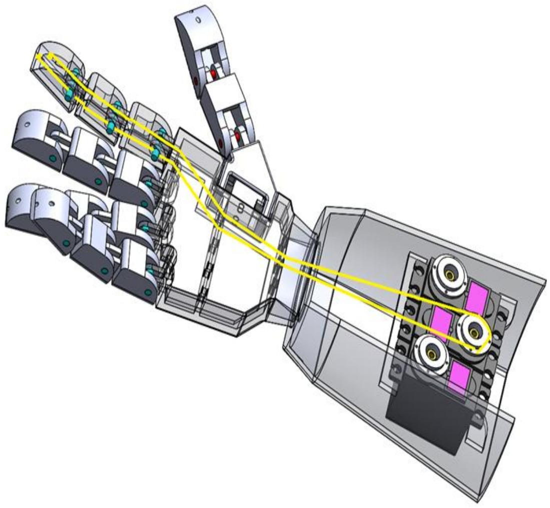

Fig. 7: Prosthetic arm working process

Normally the arm is kept in the open position. When the muscle is flexed and the EMG value reaches a certain threshold, the servo motors are instructed to turn 180 degree. Meaning that the arm has only two positon. Open and close position. So it has only one degree of freedom and grip light objects. Keep in mind that the value of the threshold has to be changed if the position of the electrodes changes.

2.7 Signal Flow Diagram

A user flexing generates an analogue signal which is amplified, rectified and smoothed by the EMG sensor board. The microcontroller uses this analogue signal to generate a pulse width modulated signal. This drives servo motors which tension the tendons causing the fingers to curl up.

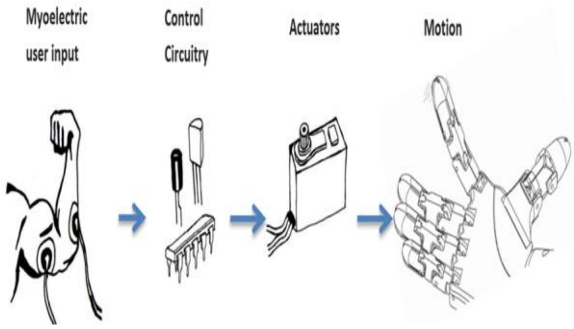

Fig. 8: Signal Flow Diagram [3]

Figure 8 shows the signal flow of the whole system. Many prosthetic hands incorporate multiple EMG sensors, taking input from multiple muscle groups. This allows the user to have greater control of the movement of the arm.

3. RESULT AND DISCUSSION

The main hurdle of this project was the design process. The coding part was relatively easy as there was no need to do any signal processing and the movement of the arm was kept simple.

3.1 EMG Signal Plot and Hand Position

In figure 9 we can see where the electrodes were placed while taking value of the plot in figure 10. The electrodes were placed in several places of the forearm.

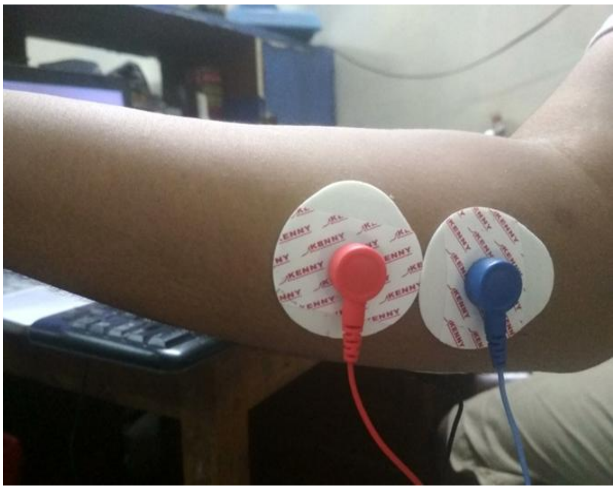

Fig. 9 Electrode position

The electrodes have been placed in several places of the forearm. Areas where there is more muscle present tends to give values which can be differentiated easily. Meaning the difference between the voltages reading from relaxed to that from the flexed is much greater there. This is why the electrodes were put on to the side of the forearm as there is more muscle there.

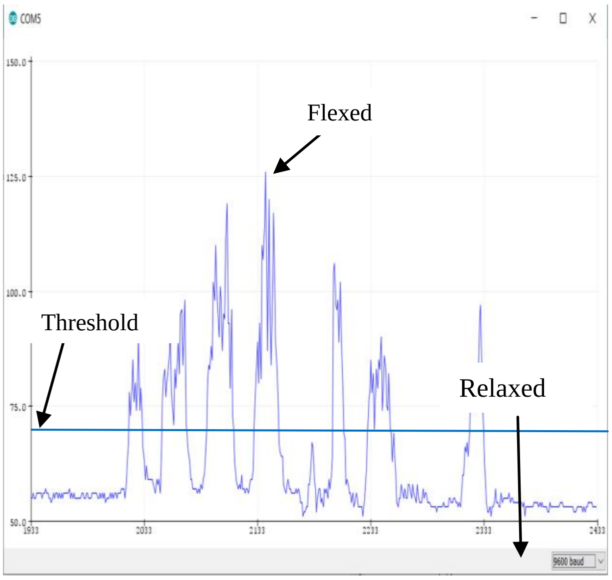

Fig. 10: EMG signal plot

In figure 10, the value of the EMG sensor is plotted against the Y axis with respect to time along the X axis. The spikes in the graph is when the muscle is flexed which gives a maximum value around 125. And when the hand is relaxed, we get a reading around 50. So am average value of this two value is taken as the threshold point. When the value of the sensor crosses this threshold, the Arduino sends the signal to the servo motors to rotate 180 degrees. This pulls the strings and closes the fingers. When the arm is relaxed, the value from the sensor goes down below this threshold and the servo motors goes back 0 degree which closes the fingers. One thing to keep in mind is that the gain of the sensor can be adjusted. The bigger the gain, the noise amplification. The gain needs to be adjusted to get values that you can work with.

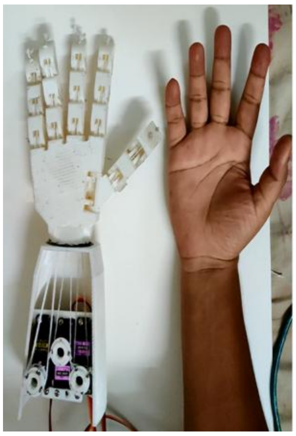

Fig. 11: Relaxed position

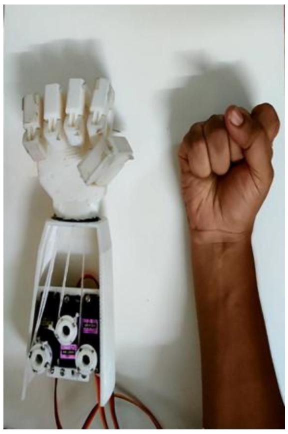

Fig. 12: Flexed position

In figure 11 and 12 we can see that when the signal from the sensor is below the threshold which in this case is 70, the hand is in open positon. And when the value of the sensor is above the threshold the hand is in closed position.

3.2 Cost and Other Specifications

Cost: The total cost of the arm is around 4000 taka. The majority of the cost is of two components:
1) Printing cost & 2) Sensor cost.
Weight: The weight of the whole arm is around 500gm.
Servo motor torque: 9.4kg/cm (4.8v); 11kg/cm (6.0v).

3.3 Discussion

The advantages of this prosthetic arm are:

1) The main of advantage of this prosthetic arm is its low cost. The commercial prosthetic hands on the market is quite expansive but this hands cost is low enough that a low income family can afford it.
2) One other advantage is its modularity and printability. The design of the arm can be downloaded by anyone who can then print parts themselves and it's really easy to assemble. If any part get broken, it can be easily replaced by printing a new one.

Even though there are few advantages to this prosthetic arm, there are many limitations as well.

1) The degree of freedom of this arm is only one. Some commercial prosthetic provides up to 11 degree of freedom.
2) The fingers can't be controlled individually.
3) The grip strength is quite low.
4) The material is not quite as durable as ones that are available in the market.

The cost of the arm can still be reduced as it cost 5 taka/gm to print even though the cost of normal PLA filament is around 2.5 taka/gm. If a printer was readily available then the print cost would reduce by half. There is room to improve upon the grip strength of the arm. As of now the grip strength is quite low and not very practical. The strings attached to the servo motor wear out quickly and slack. Due to slack the fingers are not quite as responsive as it should be. The design of the string attachment can be improved upon to reduce the slack of the string.

4. CONCLUSION

There are not many options in Bangladesh when it comes to prosthetics. They are usually hand molded and passive prosthetic. They don't provide much functionality. They are used for more of a cosmetic purpose. The commercial prosthetics that are available abroad are quite expensive and not affordable for the majority of the people of this country. 3D printing can be a great solution to this problem as it gives manufacturing capabilities to the individual. Now amputees can build prosthetics customized to fit their amputated arm with very low cost. Thus it will be very beneficial for all the increasing number of amputees in our country. The main objective of this project was to design and fabricate a low cost prosthetic arm. The design process of this arm can allow people to freely download the design, print and assemble it on their own at a very low cost. This work can still be improved upon with further research.

5. ACKNOWLEDGEMENT

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Finally, I am also very thankful to all my respected teachers and staffs of Department of Mechanical Engineering, CUET.

6. APPENDIX

Code for the prosthetic arm:

```
#include<Servo.h>
#define emgPin 0
int avg = 85;
Servo servoR;
Servo servoM;
Servo servoL;
void setup() {
  servoR.attach(8);
  servoM.attach(9);
  servoL.attach(10);
 Serial.begin(9600);
}
void loop() {
  int value = analogRead(emgPin);
  Serial.println(value);
  delay(5);
  if(avg<value){
    servoR.write(180);
    servoM.write(180);
    servoL.write(180);
  }
  else {
    servoR.write(0);
    servoM.write(0);
    servoL.write(0);
}
}
```

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