Affordable Myoelectric Prosthetic Arm

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Acknowledgement

This project has been a great learning experience for the group. We extend our immense gratitude to Prof. P. V. M. Rao for believing in our idea and providing us this opportunity, along with constant guidance. Equal gratitude to our project supervisor, Dr. Ravi Krishnan E. who had been a constant source of motivation and criticism during the development of the product.

1. Vision & Motivation

India is a great nation with a very large population. And the per capita Income of $5530 (PPP) is much lesser than that of the developed nations. A similar picture is seen in the Prosthetic Industry. The Jaipur Foot and ALIMCO products are the well-known and affordable mass-manufactured prosthetic supplies in the nation. But when it comes to state-of-the-art prosthesis, the nation lags far behind both in terms of indigenous research and development and production. When focusing on prosthetic arms and legs, one can realize that very primitive and low-functioning products are manufactured.

We decided to focus on something more than just solid mechanical prosthetic arms available in the nation. While artificial limbs with cutting-edge technologies such as myo-sensing, brainwave-sensing, etc. being developed in EU, the West, etc. are either inaccessible to Indians or are available at extremely high costs ranging from $10,000 to $50,000 and beyond, we decided to create an arm which could be affordable by the Indian population. Maintaining the quality and technological efficiency along with cost-reduction has been the headline of our aim. We discovered that cost-reduction would be possible when we could omit the profit-orientation aspect, replace expensive parts and tech with cheaper ones.

There was indeed a trade-off between features and affordability. Thus we researched and came up with some essential features which are expected by an amputee for regular operation, plus a price that would be affordable.

2. Features at a Glance

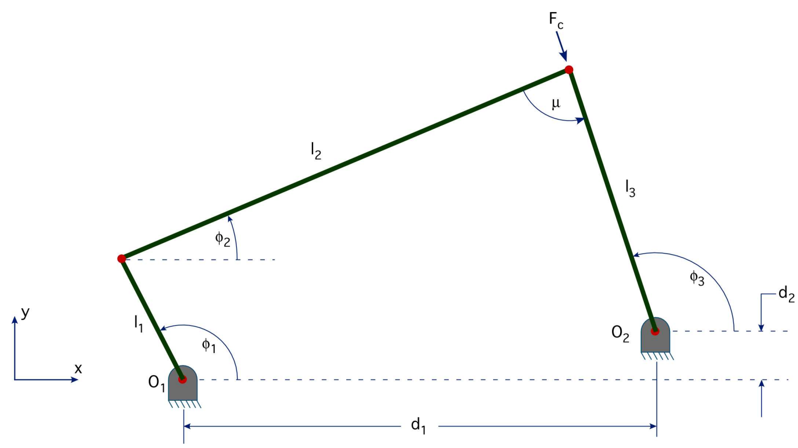
The hand is a congregate of most features expected from an artificial hand for regular functioning. Performing a trade-off between features and cost was performed post-research of the features expected from amputees and present technologies. Some salient features of the hand are as follows:

- Affordable by the Indian – product price approximated at $250
- 7 distinct Grip Patterns
- Voice switching of patterns
- Flexible, strong and water-proof PLA material
- Easy replacement of damaged digits and other parts
- Impact damage protection for digits

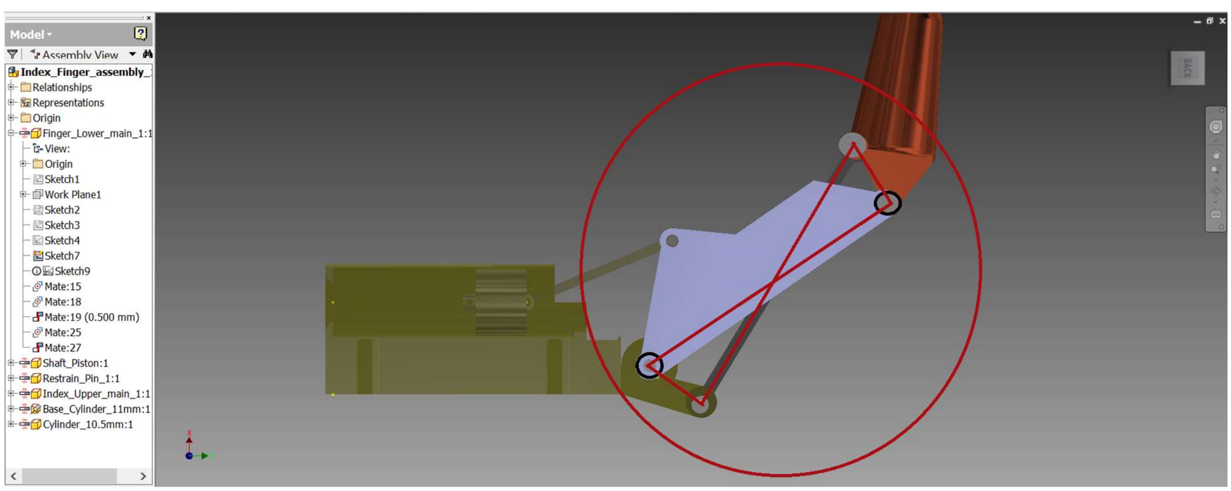
3. Design of the Hand

A. CONCEPTS :

1. Four-Bar Linkage



The coordinated opening and closing of the digits has been achieved through single actuator and a four-bar linkage mechanism. This mechanism ensures the angular motion of the finger joints always at a particular ratio.



2. Degrees of Freedom

Every digit in the hand consists of TWO degrees of Freedom. Complex movements such as wrist rotations, adductions and abductions have not been included. A total of 10 DOF can be achieved in the design.

3. Actuation using Strings

The linear actuation in the palm region (resulting in finger movement) is achieved using high-strength polymer strings which partially work like tendons in the human hand. These strings are pulled by servo motors in the forearm region. The strings are the ones used in fishing lines and nets. They are both inextensible and flexible.

B. COMPUTER AIDED 3-D DESIGNING :

The 3-D model for printing and simulation has been prepared in Autodesk Inventor Professional 2015. The 3-D printing files were furnished using the MakerBot Replicator Software. The individual digit designs and their features are shown below:

1. Thumb & Fingers :

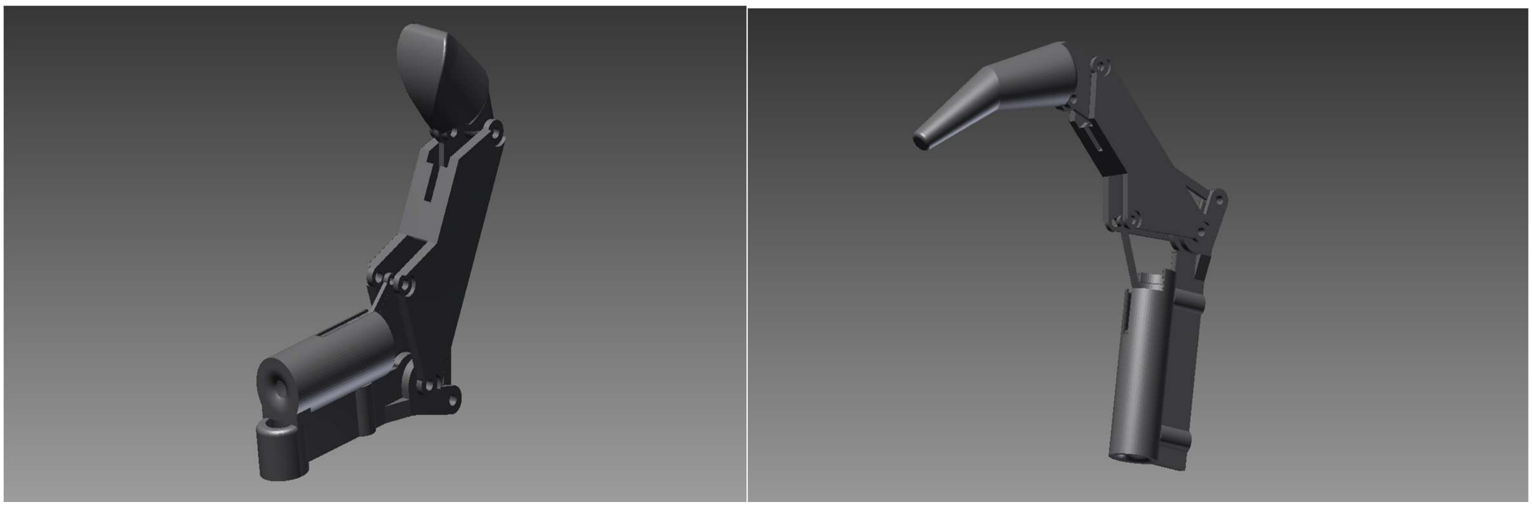


Fig. 3D development of Thumb (L) and Fingers(R)

2. Wrist & Palm :

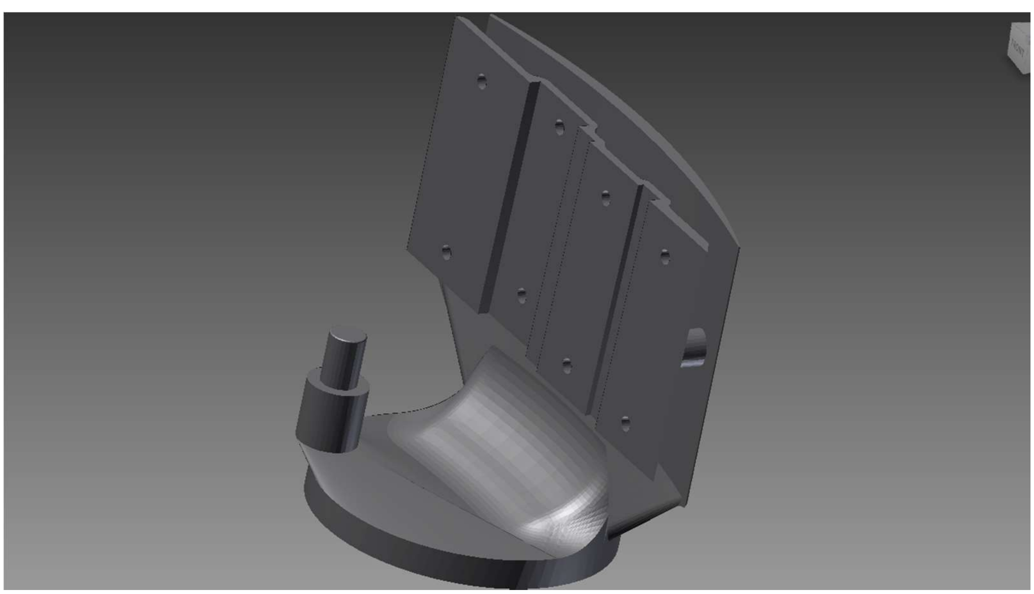


Fig. Wrist & Palm, along with mount platform for fingers

3. Assembly Overview :

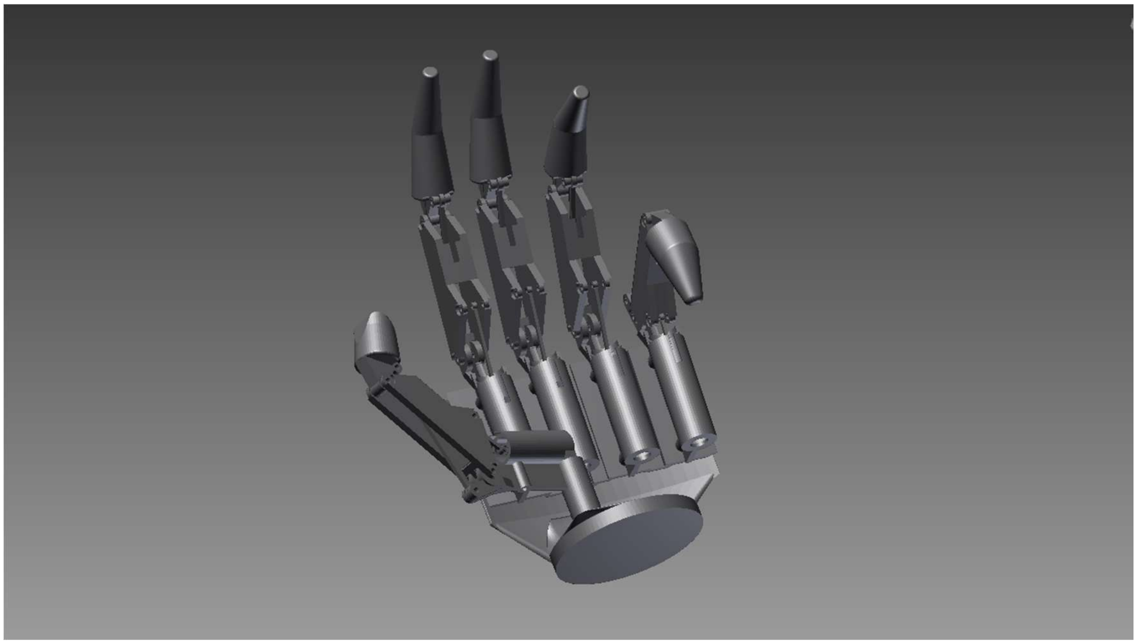


Fig. Assembly of hand with digits

4. The Electronics and Algorithms

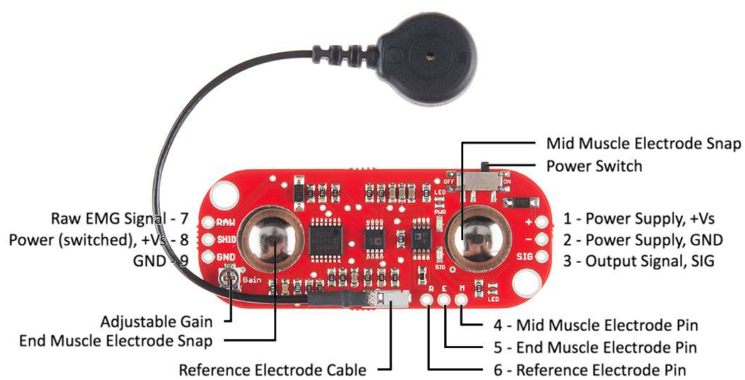
A. Brain – The Arduino Microcontrollers :

Arduino Microcontroller combinations have been used for deploying schemes and algorithms for the hand movements. The hand uses an Arduino MEGA for controlling the servo motors and the display screen, and an Arduino UNO for collecting and deploying algorithms using inputs from the Myoelectric Sensors, Force sensing resistors and the Voice Recognition Modules. Both microcontrollers communicate with each other during the process.

The primary codes have been uploaded on MEGA, the reason being more processing speed, cache and RAM. C++ codes uploaded in the microcontrollers dynamically analyze the analog data stream from the myoelectric sensor and the force sensing resistor, and send commands across the controllers to switch on/off the servo motors, and alter their angular speed.

B. Sense- EMG Sensory Feedback :

A dedicated hardware is used for tapping the myoelectric signals from muscles in the upper arm of the amputee, and subsequently amplifying and normalizing the raw output.



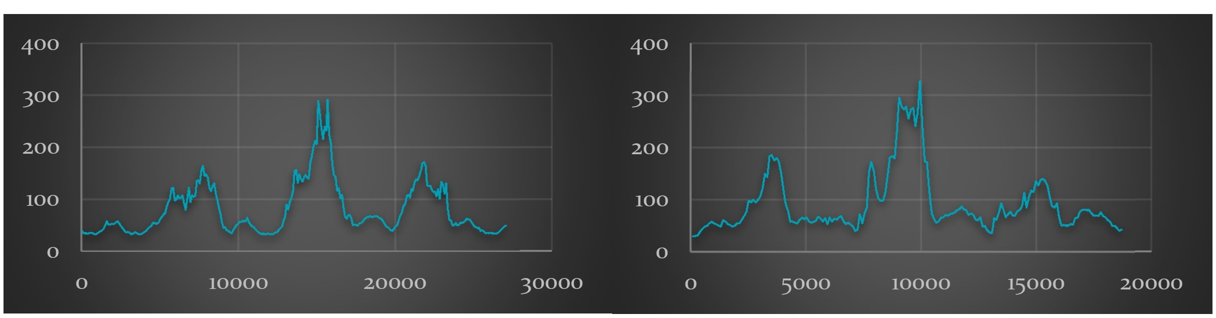


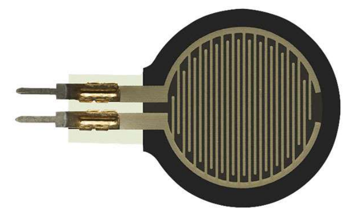
Fig. Normalized signal obtained from the sensor placed on forearm

C. Servo Motors :

The arm uses 4 servo motors for actuation. The angular velocities of these motors can be adjusted by microcontrollers. These motors consist of a circular rheostat which gives feedback of its angular position at any instant. The range of rotation is only 180 degrees.

D. Touch- FSR :

To control the gripping strength of the hand, Force-Sensing Resistors (FSRs) are used at the tips of two digits. These FSRs change resistance values linearly with applied force on their sensing surface. The dynamic monitoring of this resistance value helps to stop the digits from damaging the gripped object and from damaging itself.



E. Power :

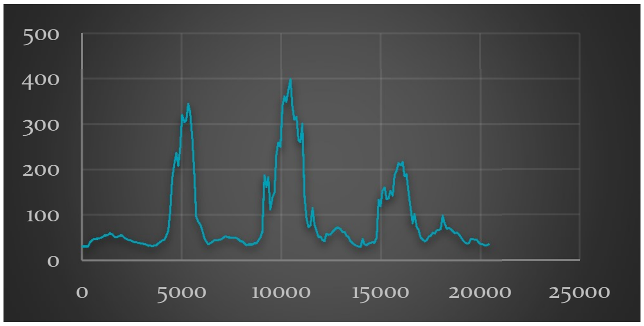
The hand currently works on a 5V DC supply from USB adapters. This can be conveniently replaced by rechargeable batteries. It is noteworthy that the power consumption of the arm is low enough to use a 1000 mAh battery for up to 2 days, with continuous operation for 3 hours per day.

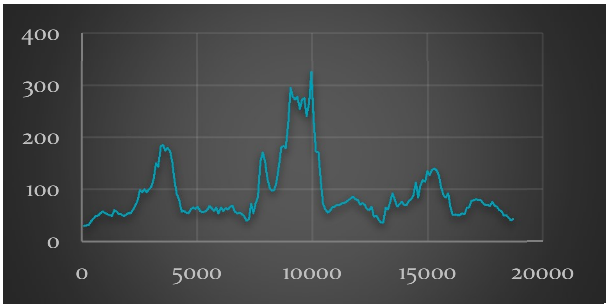
5. Testing and Results

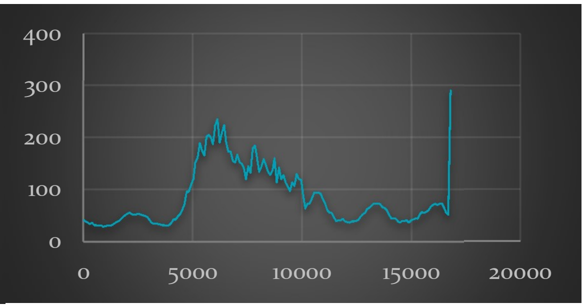
A. EMG sensor Feedback Patterns :

To understand the language of myo-electric signals, a large number of feedback data streams were recorded for different positions of the electrodes and different movements.

Since these signals are expected to vary from person-to-person, we created learning algorithms to analyze the signals during training sessions, so that personalized values could be set and deployed by the microcontroller. This will help the user to save time and effort on altering the code or tweaking the hardware repeatedly.







Sensory values from the EMG were recorded at the rate of 50 values per second, and plotted as shown above. A peak appears in the stream whenever a muscle flexes at the point of electrode attachment. The valleys are stationary states of the muscles, both flexed and relaxed. Thus it was necessary to analyze when the arm must be opened, and when it should be closed.

For patent/publication purposes, the software has been kept private. However, I've decided to completely open-source the designs. As an example, given below is a function in Arduino C++ which intakes dynamic data from FSR and EMG sensor and controls a servo motor:

```
/*
  AnalogReadSerial
  Reads an analog input on pin 0, prints the result to the serial monitor.
  Graphical representation is available using serial plotter (Tools > Serial
Plotter menu)
  Attach the center pin of a potentiometer to pin A0, and the outside pins to +5V
and ground.
*/

#include <Servo.h>

int Ar[15];
int servoWritePin = 9;
int pos=800;\

Servo servo;

// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
  servo.attach(9);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
   int sensor2Value = 0;
  // print out the value you read:
  Serial.println(sensorValue);
  if(sensorValue > 200 &&sensor2Value < 900 ){
    ::pos+=20;
    servo.writeMicroseconds(::pos);
  }
 if(sensorValue<=200 && sensorValue>80)
 {
    servo.writeMicroseconds(::pos);
 }
 else{
  if(sensorValue<=90){
    ::pos-=20;
 servo.writeMicroseconds(::pos);}
 }
  delay(30);        // delay in between reads for stability
}
```

6. Discussion

A. Reliability:

This device is meant to provide only some necessary features. The dexterity of a human hand was not possible to achieve. Some cases where the functioning could be compromised are:

- The EMG sensor may malfunction due to sweat, electrical activity on skin surface, under-flexing of muscles due to fatigue.
- FSRs work only when normal forces are applied on them. Any gripping forces applied at an angle may not return the actual force value.
- Functions such as writing, peeling,etc. could not be performed well.

B. Cost Estimates :

Since one of our primary motives is cost reduction,

Materials Used	**Cost** (INR)
Micro-Controllers	1200
Servo motors	1400
3D-Printing	7000
MyoWare™ EMG sensor	3800
Voice Recognition module	1900
Force sensing resistors	500
Strings	50
Total	**15850**

! Since the components were ordered in small quantities, and some sensors were imported, the price of the device is higher than when it is mass-produced using local technologies in bulk quantities.

C. Part Availability :

All the above listed materials are easily available except MyoWare EMG sensor which has to be imported from the States. 3D printed parts can be easily re-printed using .STL files. The servo motors are easily available in the local market.

The ARDUINO microcontrollers are open-source and readily available. The codes can be easily uploaded on a new board using a USB cable and a computer with Arduino IDE.

Also strings can be easily replaced.

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