Design and Manufacture of 3D Printed Myoelectric Multi-Fingered Hand for Prosthetic Application

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Abstract— **Multi-fingered robotic hand plays a very important role as it is required to hold and place the object at the desired location. Extensive research work is under way in the design of Multi fingered or anthropomorphic hand. Exhaustive survey of all such hands convey the idea of higher and higher sophistication with innumerable components and elaborate controls with programmable ability has been the outcome of research. In this paper, we present an innovative design, simple to manufacture and low cost 3D printed myoelectric multi-fingered hand for prosthetic application. Servomotors coupled with pulleys and strings are used for actuation of fingers. This prosthetic hand is developed to study trans-radial amputees. The hand features human like fingers along with thumb roll mechanism which is driven by low weight servo motors. The hand is controlled by Arduino nano whose signal is powered by myoelectric sensor and the whole circuit is powered by 12V rechargeable battery. The fabricated hand is tested to study some of the human grasps by imitating the human actions and the results are presented.**

Keywords—Multi-fingered hand, myoelectric sensor, 3D printing, prosthetic application.

I. INTRODUCTION

Now a days robotics has greatly penetrated the field of Bio medicals especially surgery and prosthetics. It has proved very useful in autonomous navigation where human beings find it difficult to find the way. Haptic Robotics has also been major development in industrial applications which has helped not only in resource management but also in accuracy and precision. Field prosthesis means artificial replacement and to replace a body part anthropomorphically is a difficult task. Myoelectric or electromyogram (EMG) signals that may be acquired using suitable sensors from the human body are widely used in actuating prosthetic devices [1]. Many companies have tried and excelled in this field such as Be Bionics and Ottobock, USA. But these companies have come up with high cost prosthetic devices. The prosthetic hands actuated by pneumatic artificial muscle are costly and difficult to miniaturize [2]. Also in a prosthetic hand there is hardly any space left in the socket that covers the stump of the forearm of a handicapped person to keep the contracting artificial muscle which provides force to the movement of hand joints. Researchers have developed a EMG acquisition system with reduced noise and interference effect to acquire the EMG signal through surface electrode, but still they are using motor coupled with linkage mechanism [3] or drivetrain mechanism [4] in the construction of prosthetic arm. The existing 3D printed hands are costly due to use of many parts in the hand such as ball bearings, miniature epicyclic geared motors, stainless steel tendons with nylon coating, bolts and nuts and feedback sensors etc,[5]. The recent trends in prosthetic arm industry are fingers actuated by servo motors at each joints where rotation is required which itself makes the design complex and heavy [6-7]. Hence the elimination of extra servo motors itself made our design lightweight.

The present 3D printed hand is designed to lift 2 kg as we have used a polymer string or fishing line along with metal gear servo motors instead of stainless steel tendons and epi-cyclic geared motors. These are highly efficient and not only grasp delicate objects but also hold day to day household objects firmly. The design can be improved further by many ways which will open up new areas for innovations in robotics as well as medical field. This novel technique can prove to be boon to pick and place robotics, Haptics etc., and can be automated with least power consumption. Our design has 5 degree of freedom compared to commercial hand having 20 or more since they use servo motors at each finger joint. In the present design, each motor bends all the finger joints of each finger and hence only 5 servo motors are provided in the arm. This reduces the weight and cost of the hand drastically.

II. DESIGN OF 3D PRINTED HAND

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We used 3D printing technique for printing the whole skeleton of the hand and arm and assembled it after the manufacturing. So in order to 3D print the hand and arm chassis we have to make a 3D model into the machine recognizable format. We used solidworks software for designing the hand and finger chassis based on real shape and size of human hand. Figure 1 shows the design of hand and arm which resembles a human hand on an average basis. We have also incorporated thumb roll mechanism in to the design. Hence a better grasp can be invoked. The material chosen for printing was ABS plastic keeping in mind the finish that needs to be achieved for multi-fingered or anthropomorphism and also the cost and availability in the local market. The technical data of ABS plastic used is shown in Table 1.

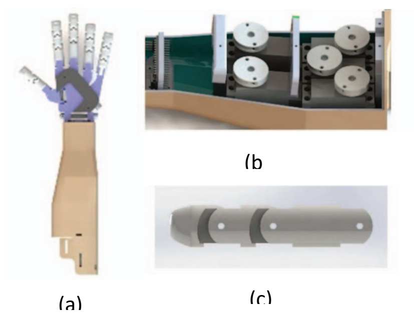


Fig.1. Computer aided design of (a) Prosthetic hand assembly (b) servo motor assembly inside the arm (c) Finger assembly

TABLE 1. Technical Data Of ABS Plastic

Density	Melt Flow	Tensile Strength	Max. Elongation
1.04 g/cc	18-23 g/10 min	42.5 - 44.8 MPa	23-25 %

A. Selection of Material

Any component design starts with material which will suit its situation and bear its load. Material plays an important role in adding to weight as well as other physical properties to the material. The model is made with ABS plastic due to the following reasons:

- Good strength to weight ratio.
- Easy to manufacture since the design is quite complex.
- Economical compared to other molding and forming process.
- Satisfactory aesthetic finish.

The mechanical properties of the material used are given in Table 1.

B. Selection of Mechanism

The mechanism used is to enable curl the fingers by string tension technique. This technique uses strings. The option used for string tension here is fishing line which is attached on servo motor at one end and to finger at the other end. The tension of the string is controlled at the time of fixture. Using of strings requires the knowledge of the tension that is imparted by the servo motor. Hence the design calculation of drive starts with servo motor. The servo motors are used as the prime mover of the prosthetic hand. The servo motor should provide adequate torque at the required RPM so that the fingers are adequately powered. The commercially available ones do have a variety of options to choose with. Sometimes one characteristic is sacrificed at the expense of other. Here speed (RPM) is compromised over torque since this gives adequate tension that can subsequently result in curl motion. The chosen servo motor is of make Robokits India Std. Servo Economy. While selecting servo motor from the manufacturers catalogues, first consider the maximum load that needs to be lifted. Table 2 shows the properties of the selected servo motor.

TABLE 2 Specifications of Servo Motor

Name	Voltage V	Torque kg-cm	Mass, g	Size mm	Cost Rs.
Metal Gear Servo	6	16	120	41 × 20 × 36	550

We have selected Metal Gear Servo motor since the dimensions were compact and also light weight being the added advantage. Servo motors of higher capacity are also available for commercial use but these cannot be accommodated into the provided space.

Load Calculations:

As mentioned, the curl of the fingers is due to the servo action of the motor. The torque which provides the right tension is calculated as follows:

Max. Torque (T): 16 kg-cm.

Armature Radius (r): 1.2cm

Hence, Max. Force(Tension): $T/r = 13.33$ kg

So it has capability to pull a weight up to 13.33kg with armature mounted. Hence the maximum tension that can be transmitted is also the same.

$$\text{Tension} = 13.33\text{kg} = 29\text{lbs}.$$

Hence the string chosen should have 29lbs strength. The string can be anything which can handle tension above 29lbs. Normal string can handle usually about 25lbs of force and very rarely the 30lbs variety is found. But the strength can be doubled by

twisting a string with another. The string so produced is called as Flemish string. This can be strengthened by making bundles of strings just like manufacturing of steel cables or commercial ropes. The strings can either be combined to multiple strands or used alone if it has sufficient strength to handle the force. Either way it produces the same effect whereas second one adds to weight too. Hence a fair sacrifice is made to find a 30lbs variety which has by default an ability to carry 37 lbs force. Factor of safety:
37/29 = 1.3 This factor of safety is the least considered since bundling of strings can further lead to increase in strength of the actuation. For commercial purposes, better steel alternatives can be tried.

C. Electronics

It is necessary to handle the complex signals[4]. Arduino Nano v3.0 has made it simpler to analyze these signals and come with a motion technique that can imitate that of humans. The carrier of muscle signals to Arduino used is Advancer Technologies LLC Ltd. which is a myoelectric sensor that can intake macro motions and to some extent micro motions of muscle fibers. This sensor will measure the filtered and rectified electrical activity of a muscle; outputting volts depending the amount of activity in the selected muscle. Power supply voltage: min. +3.5V. The microcontroller takes feedback from the myoelectric sensor[5] which in fact senses signals from muscle fibers upon movement and also it has an internal circuit which will amplify the signals received and also filter its envelope as follows. Electromyography[6] is measuring the electrical

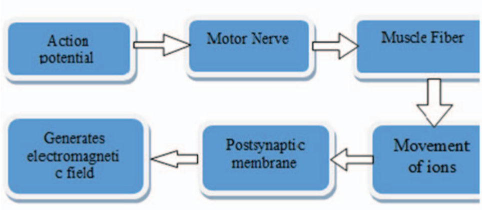


Fig.2. Working of Myoelectric sensor

signals associated with the activation of the muscle. This may be voluntary or involuntary muscle contraction. The EMG activity of voluntary muscle contractions is related to tension. The schematic of the working of a myo-electric sensor is shown in Fig. 2. The functional unit of the muscle contraction is a motor unit, which is comprised of a single alpha motor neuron and all the fibers it enervates. This muscle fiber contracts when the action potentials (impulse) of the motor nerve which supplies it reaches a depolarization threshold. The depolarization generates an electromagnetic field and the potential is measured as a voltage. The depolarization, which spreads along the membrane of the muscle, is a muscle action potential. The motor unit action potential is the spatial and temporal summation of the individual muscle action potentials for all the fibers of a single motor unit. Therefore, the EMG signal is the algebraic summation of the motor unit action potentials within the pick-up area of the electrode being used. The pickup area of an electrode will almost always include more than one motor unit because muscle fibers of different motor units are intermingled throughout the entire muscle. Any portion of the muscle may contain fibers belonging to as many as 20-50 motor units. The detailed functioning of sensor can be found out from schematic succeeding this and also by visiting the parent site of Advancer Technologies Ltd.[7].

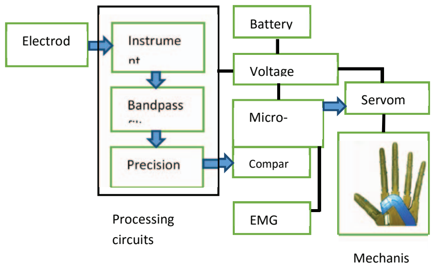


Fig.3. Internal circuitry

The micro controller used in the process was Arduino Nano v3.0 since it consumes very low power and can handle signals from almost 8 ports with analog signals. Fig. 3 shows the internal circuitry of the Arduino Nano board. The Arduino Nano 3x version used has ATMEGA 328 chip as its core microcontroller. It has 8 analogue pins and 14 digital I/O pins of which 6 has PWM output. Analogue signals are engaged for operation of analyzing the input. These signals coming from the sensors are processed according to the high and low frequency of the wave form and the corresponding action is initiated depending on the code compiled.

III. MANUFACTURING

Manufacturing consists of three phases namely design, assembly and testing. The main aspects of design were explained in the earlier section of design which included basic designing from solid works based on average human finger size and shape. Later on it was decided for the right prime mover and also the medium through which the prime mover does the work (direct or indirect contact). The connection of the myo-electric sensors with the Arduino board is shown in Fig. 4.

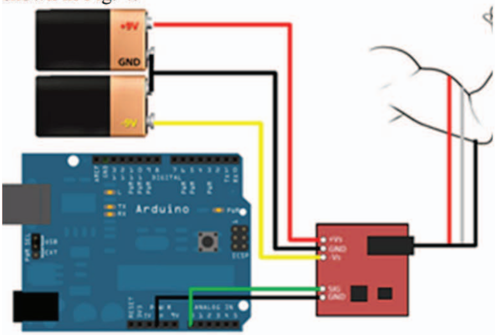


Fig.4. External circuit with micro controller

The basic design[8] is based on design consideration which was explained above. The procedure is followed by manufacturing it using 3D printer. In order to use 3D printer for manufacturing it has to be converted from the standard design format in Solid works to machine readable format which is .g code. Cura Software, basically a freeware, is used exclusively for this purpose. Solidworks file was saved in .stl format which was further converted to .g code followed by printing of the design. Printing almost takes a couple of weeks.

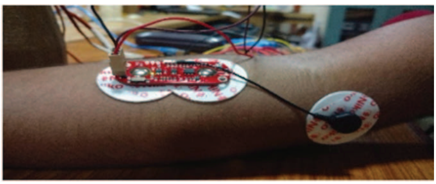


Fig.5. Hand being tested with sensor

After printing, the finer works like polishing and rectification of printing defects are done. Now the assembly starts with manufactured printed parts being assembled with the required fasteners. After the fasteners are fixed, the string or the fishing line is tied to the phalanxes at the fixtures manufactured.

IV. TESTING

The testing phase constitutes of electrical connections, troubleshooting and also checking the ability to grasp an object. Different objects are tried and the activities are noted and compared to that of humans. Fig.5 shows the testing of a human hand with sensor. Fig.6 and Fig.7 show various mimicking postures and grasps respectively. Fig.8 shows the assembled 3D printed hand.

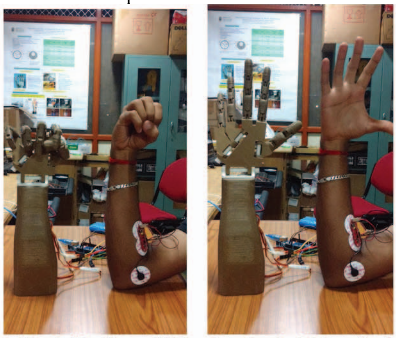
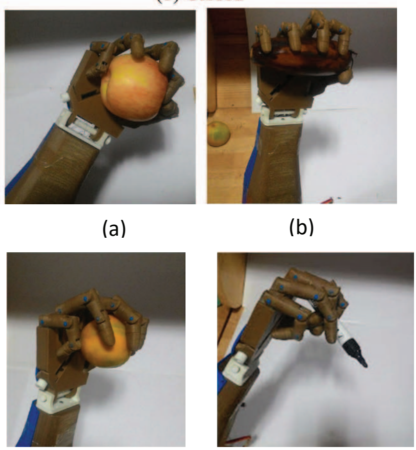


Fig.6. Testing of 3D printed mimicking the human hand grasp postures through EMG sensors (a) Open (b) Closed



(a) (b) (c) (d)

Fig.7. Various hand grasps (a) Spherical (b) Cylindrical (c) Power (d) Precision

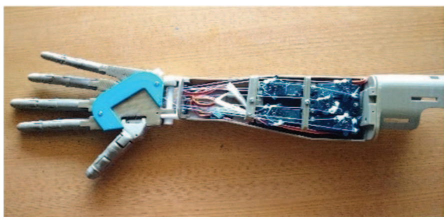


Fig.8. Assembly of 3D printed Multi-fingered hand

V. KINEMATIC ANALYSIS

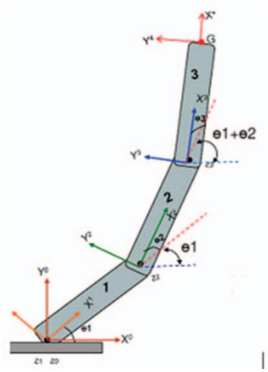


Fig.9. Schematic view of a finger

The kinematic analysis of the hand uses geometric approach for finding the position [9]. The phalanges are the three different parts of the finger which are manufactured separately and assembled using nuts and bolts. The distal phalange is the tip of the finger and the rest follows by the name. There are three parameters that change depending upon the motor rotation. These angles are depicted as $\theta_1, \theta_2, \theta_3$ respectively in Fig.9. These angles are interdependent. The middle phalange of the finger can only be active once the distal phalanx is at 90°. Similar is the case of proximal phalanx. Here $l_1 = 26\,mm, l_2 = 27\,mm, l_3 = 32\,mm.$

$$\begin{Bmatrix} X \\ Y \end{Bmatrix} = \begin{bmatrix} cos\theta_1 & \cos(\theta_1+\theta_2) & \cos(\theta_1+\theta_2+\theta_3) \\ sin\theta_1 & \sin(\theta_1+\theta_2) & \sin(\theta_1+\theta_2+\theta_3) \end{bmatrix} \begin{Bmatrix} l_1 \\ l_2 \\ l_3 \end{Bmatrix}$$

X and Y represent the coordinates of the tip of the finger. The origin is at the base of the finger.

Case 1:Distal phalange subjected to full rotation i.e., $\theta_3 = 90°, \theta_1 = \theta_2 = 0°,$

$$\begin{Bmatrix} X \\ Y \end{Bmatrix} = \begin{Bmatrix} 53 \\ 32 \end{Bmatrix} mm.$$

Case 2: Middle phalange subjected to full rotation, i.e., $\theta_1 = 0°, \theta_2 = \theta_3 = 90°,$

$$\begin{Bmatrix} X \\ Y \end{Bmatrix} = \begin{Bmatrix} -6 \\ 27 \end{Bmatrix} mm.$$

Case 3: Proximal phalange subjected to full rotation, i.e., $\theta_1 = \theta_2 = \theta_3 = 90°,$

$$\begin{Bmatrix} X \\ Y \end{Bmatrix} = \begin{Bmatrix} 0 \\ 21 \end{Bmatrix} mm.$$

Other positions are controlled mainly by the pulse of the arduino board. The position of the hand can be determined from the above equation.

CONCLUSION

This paper represents the design and manufacturing of anthropomorphic prosthetic hand using 3D printing technique. The hand was able to achieve 5 DoF with individually actuated fingers. EMG signal is made used for the control and coordination of 5 fingers. The pulses are generated by EMG sensors which are fed into the microcontroller and the respective motors are driven for movements of the hands, such as hand open, hand close. This paper represents progress towards more natural and more effective means of myoelectric control by providing high accuracy and an effective control interface to the user. The future work includes further allowing the hand to achieve more grasping mechanisms by analyzing strength variation in the EMG signals and implementing a feedback loop. But still humanoid robotic hand needs seamless integration of muscles fibers, sensors, structures and controllers for its closed loop functioning.

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