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Design and Development of a 3D Printed Myoelectric-Controlled Prosthesis Hand Using sEMG Sensor

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***Abstract*—**Over the last decades, biomedical engineering prosthetics become one of the most essential grounds. Prosthetic hands are rapidly evolving. Therefore, for designing prosthetic components, it is essential to improve quality such as make it affordable and improve patient comfort and mobility by making them lightweight and easy to wear. In this paper, we proposed a myoelectric controlled prosthesis hand. We can fabricate and manufacture customized cost-effective, small volumes of 3D printed hand which is interesting. The total weight of an adult hand is about 1000 gm including a battery. The prosthetic hand is built up with low-cost materials and techniques, the cost of manufacturing will be approximately US$145. The hand can grip objects of different shapes and sizes. The 3D printed hand can rotate its wrist like a human hand. The prosthetic hand is capable of showing some types of human gestures.

***Keywords*—**Prosthetic Hand, sEMG, 3D printing, Arduino.

I. Introduction

IN Bangladesh many people are prone to accidents every year. Bangladesh Passenger Welfare Association said in its annual report that in 2019 at least 7,855 people were killed and 13,330 others are injured in 5,516 road accidents across the country [1]. Every year many people lose their limbs in several accidents. Once a limb is totally or partially lost it is very difficult for him to come back to normal life because every part of a human body is preciously important in terms of functionality for the daily life of human beings. To improve the life of a disabled person, it is essential to develop a prosthesic.

In the case of children to increase the acceptance rate it is needed to adopt prosthetic hands from a very early age, preferably under 2 years of age with upper limb [2]-[4]. According to various research surveys, if one gets a powered prosthesis just after his loss of a hand, the hand rejection rate is lower in the following years of their life [5], [6].

Despite several research works aimed at inventing prosthesis hand, a survey shows that 35-50% of amputees do not use their prosthesis hand regularly for lack of comfort, high cost, and degree of freedom due to low aesthetic appeal [7]. Due to these limitations, we have developed a hand prosthesis that can potentially address these limitations. The following design principles were taken into attention to avoid prosthesis rejection [7].

Our proposed prosthesis hand is

1) Low powered
2) Lightweight
3) Affordable for common people of Bangladesh
4) Comfortable
5) Scalable for every age of people

Our hand consists of a surface Electromyography (sEMG) sensor, Arduino Uno, and metal gear servo motors to provide specific movements. In this research, we used the Ninapro database for sEMG signals, which is a publicly available multimodal database to research prosthetic. The system components were implemented into a 3D printed hand. sEMG signals are captured via special EMG sensors from biceps brachia muscle through some surface electrodes. The signals are then filtered and amplified. The filtered and amplified signal sent to the Arduino is used for producing motorized work.

II. Literature Review

Recently, there are several kinds of research that describe the development and design of hand prosthesis. There also exists commercial hand prosthesis with high-tech features.

Manfredo et al. [8] characterize the Ninapro database and its use as a benchmark for hand prosthesis assessment. They present standard classification results using a variety of feature representations and classifiers. Their comparison shows that simple features such as waveform length and means absolute value and can achieve similar performance to the marginal discrete wavelet transform.

Pai [9] designed & printed a 3D printed multi-fingered hand that is capable to hold and place the object at a specific location. They represent an innovative design and simply manufacturable 3D printed myoelectric multi-fingered hand at low cost by using a kinematic solution. The hand was able to achieve 5 DoF with the individually triggered finger.

Ccorimanya et al. [10] implemented a design affordable, lightweight, and easy to wear prosthesis hand, especially for children. Commercial prosthetic hands for children are often too expensive, burdensome, and difficult to use. In their research, they attempt to address these issues with a novel design for a prosthetic hand for children. Their proposed prosthesis implements the use of sound biofeedback and a soft socket with in-liner electrodes. They improve the control

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performance and make the hand prosthesis easy to use, lightweight and affordable thus increase the acceptance rate.

Chalong et al. [11] present the development of a force-controlled 3D-printed prosthetic hand commanded by sEMG. The prosthetic hand used force control to pick up a 600-ml water bottle without any damages. To determine the system model, two experiments were carried out. The first one is to determine the relationship between the voltage of electromyography and the handgrip force. The second one is to determine the relationship between the current of the DC motor and the water bottle grip force.

Mohammadi et al. [12] proposed the design and fabrication of a monolithic design and 3D printing of soft/compliant materials anthropomorphic hand prosthesis for children at their mid-childhood. The fabrication process of the proposed hand resulted in a light-weight, low-cost, and customizable hand prosthesis for children. To address the current limitations of hand prostheses for children, they designed a hand that has the capability to grasp objects of various shapes and sizes.

Aizat et al. [13] proposed a robot hand structure with a four-bar linkage mechanism to overcome the cable-driven actuated mechanism that leads to less structure durability and inaccurate motion range. Their proposed hand is the size of an average human hand, five-fingers with completed joints where each finger is moved by motor individually, joint protection using a mechanical stopper, detachable finger structure from the palm frame, a structure that has sufficient durability for everyday use and an easy to fabricate structure using 3D printing technology.

III. Design of a 3D Printed Hand

A. Selection of Material

The chosen material for 3D printing is Polylactic Acid (PLA) plastic for low cost and arability in the local market. PLA is made from organic resources like corn starch or sugarcane, it is renewable. As PLA is environmentally friendly, easy to work with, it is great for 3D printing. It is also available in a variety of colors. The model is made of PLA plastic due to the following reasons:

1) Made from organic resources, so environment friendly
2) Renewable materials
3) Easy to manufacture
4) Economical compared with other materials
5) Good tensile strength
6) Rigid, fragile behavior
7) Good UV resistance
8) Withstanding operating temperatures up to 50 °C.

The technical data of PLA plastic used are shown in Table I.

B. Selection of Mechanism

We have developed a 3D printed myoelectric prosthetic hand, so we have to print the 3D designed models on a 3D printer. We use the Fab lab from Dhaka University for 3D printing purposes. Fab lab is the most updated lab. It has three 3D printers, one laser cutter, some updated machines, Computers, and also other machinery. It is non-profitable and funded by the Bangladeshi Government to support the students for research purposes. Fab lab has three 3D printers, one of which is ZEUS. ZEUS is the most updated 3d printer from a Bangladeshi perspective. It has some attractive features. We use ZEUS for 3D printing purposes.

TABLE I
Characteristics of PLA plastic

Characteristics	Typical value
Melt mass flow rate (MFR) 210 °C/2,16 kg	9,56 gr/10 min
Tensile strength at yield	70 Mpa
Strain at yield	5%
Strain at break	20%
Melting temp.	115 ± 35 °C
Minimum layer height	0.05 mm

Fig. 1 Images of printing parts of Zeus 3D printer we have used

Usually, sEMG sensors are used by myoelectric prosthetics to convert bioelectrical signals into mechanical work. To control the desired movement of a battery-powered electrical motor is often used. The servo motors are used as leading movers of a prosthetic hand. Servo motors send electrical pulses through the connecting wire/string to curl or control the mechanism of fingers. The string is connected to one end with the finger and another end to the servo motors.

The servo motor can recognize the pulses every 20 milliseconds (ms) and how far the motor turns will be determined by the length of the pulse. For example, if we need to turn the motor to the 90° position we need to give a pulse of a 1.5 ms. If the pulse is less than 1.5 ms the motors move in the counter-clockwise direction toward the 0° position, and any pulse longer than 1.5 ms will turn the servo in a clockwise direction toward the 180° position.

Fig. 2 Images of 3D Fingers parts

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(a) (b)

Fig. 3 Assembled Hand (a) plates with the finger, (b) fully assembled hand

C. Cost Analysis of the Hand

In this modern world, there are many functional supportive hands. But these hands and their maintenance costs are very expensive. That's why; the people of Bangladesh are not able to bear the cost. We always try to keep the cost very low so that all kinds of people of Bangladesh can bear the cost. We are using some local equipment; these are available in our local market and are very cheap. In this way, we can make it available at a lower cost.

TABLE II
COST ANALYSIS OF PROPOSED PROSTHESIS HAND

Sl	Item	Cost per unit (US$)	Quantity	Cost (USS)
1	Metal Gear Servo Motor	$6	6 pieces	$36
2	EMG Sensor	$48	1 piece	$48
3	3D Printing Cost	$0.6	600 g	$36
4	Arduino Uno	$4.8	1 piece	$4.8
5	Electrode	$6	1 pack	$6
6	18650 Battery	$4.8	1 piece	$4.8
7	Voltage Booster	$7.2	1 piece	$7.2
8	Connecting Wire	-	-	$2.4
			Total	**145.2**

IV. SYSTEM OVERVIEW

Our goal for the design of prosthesis hand is to meet the need of the users in a developing country like Bangladesh. So our device needs to be affordable and maintain the quality of current commercial myoelectric prostheses. In designing our prosthetic device we evaluated the tradeoffs among efficiency, performance, cost, durability, and manufacturability.

A. Mechanical Design

The mechanical design process will be discussed in this section. We have developed sEMG controlled 3d printed myoelectric prosthetic hand. The mechanical design objective of the 3D hand is to make it low cost and bust-up efficiency and durability. The system consists of

1) Arduino Uno.
2) MG996r Metal Gear Servo Motors.
3) 16 Channel PWM.
4) 18650 3.7 v Battery.
5) Voltage booster.
6) EMG sensor
7) Fishing wires and elastic nylon threads.

We use equipment which is available in our local market and also the price is very cheap. Arduino Uno is a microcontroller board based on the ATmega328P. Uno contains everything required to assist microcontroller; a USB cable is needed to connect it with the computer and to power it we required an AC-to-DC adapter or battery to get started. We used a 12 bit 16 channel PWM servo motor controller. There are lots of servo motors available in the market but we used MG996r metal gear servo motors because the motor can pull a weight of 2.5 kg when it is suspended at a distance of 1cm. It needs 5 V to operate.

B. Electronic Design

The requirements analysis and system consideration for the electronic design of our prosthesis are described below. A small and sensitive EMG sensor and soft-surface electrodes are used in this work along with the Arduino Nano microcontroller unit which is fast and has enough ports for communicating with other electronic components. A servo motor is also used which consumed less power and offers good torque. Finally, the power system should be safe for all the electronic systems.

At first, we need to place the sensor in the correct positions of hand or any necessary muscular part of the human body. The sensor senses the signals with the electrode which is placed on the muscle. The flow chart of the internal circuitry is shown in Fig. 4.

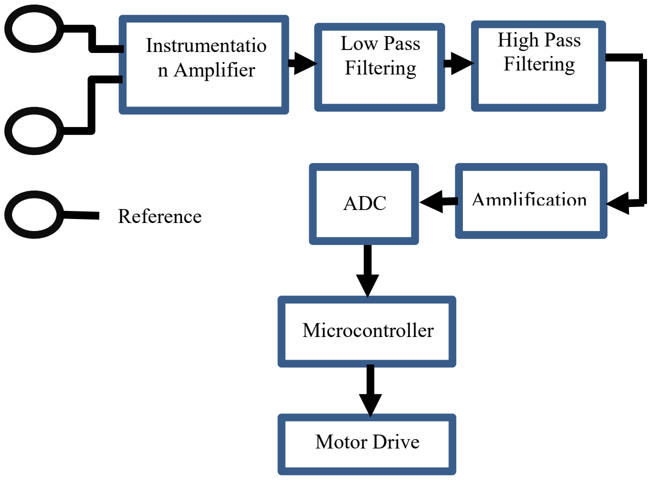


Fig. 4 Block diagram of internal circuitry

When we try to grip any object with our hand then our muscles also move and produce some EMG signals. The sMEG sensor senses the signals with the electrode which is placed on the muscle. Then the signal passes through a low pass filter and high pass filter and removes the noises from it. To boost up the signal, some amplification is done. The signal we get from mussel is analog; it needs to be converted to a digital signal. An ADC is used to obtain the digital signal. After that, the signal is fed to the microcontroller of the Arduino. The incoming input signal comes from the sensors read by the Arduino and sends suitable output data to the servomotors. The microcontroller is programed by a threshold value. When the EMS value is greater than the threshold, then the microcontroller controls the actuator for the specific situation.

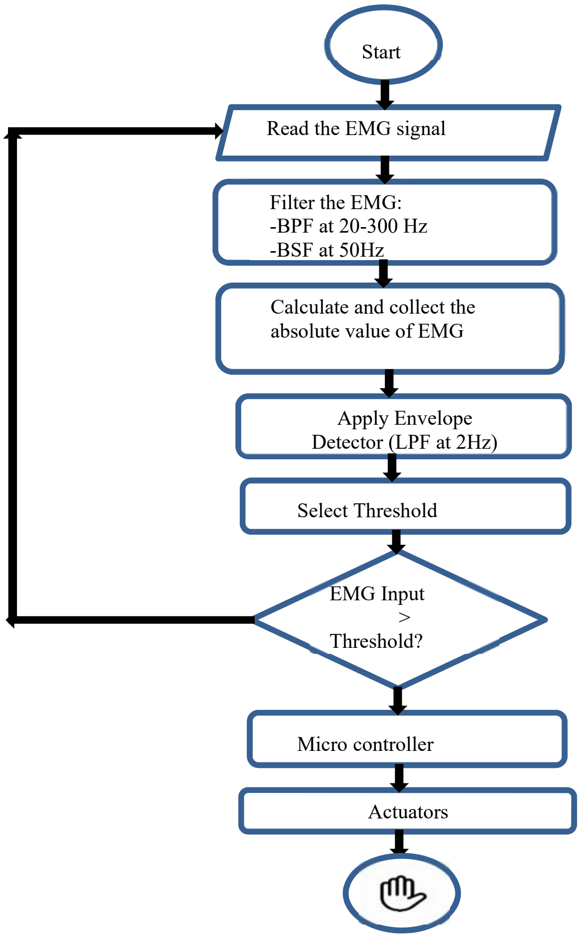
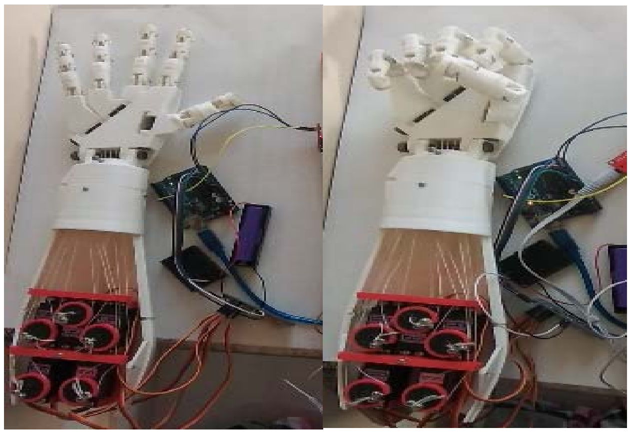


Fig. 5 Flow chart of the system

Servomotors are controlled by pulse width modulation (PWM) sent by the Arduino through the control wires [14]. The duration of the pulse and position of the shaft are determined by the PWM sent to the motor, and the control wire will turn the motor to the desired position [15]. If the motor rotates from 0° position to 180° position it will pull the attached string then the fingers are closed. As shown in Fig. 6 (b). On the other hand, rotation of the motor from 180° position to 0° position will release the thread and bring the finger back to its original location, namely the flexion movement as shown in Fig. 6 (a). The flow chart of the full system is shown in Fig. 5.

C. Assembling

Manufacturing consists of three phases design, assembling, and testing. The design process is described in the previous section. Now we will concentrate upon assembling. The part of the 3D prosthesis hand is printed by using the ZEUS 3D printer. Then the parts are joined together. Fig. 7 shows some parts of the finger and the resultant fingers.



(a) (b)

Fig. 6 Hand gesture (a) finger in the closed position, (b) Finger in the original position

Fig. 7 Different parts of fingers and the assembled finger

We also print different other parts like the elbow parts shown in Fig. 9. Other parts, such as the Servo pulley hand plate are also printed. Then we assembled all parts. The resultant hand is shown in Fig. 10. Sensors, Arduino, servo motors, battery, and other parts also added to the hand. The full system is shown in Fig. 11.

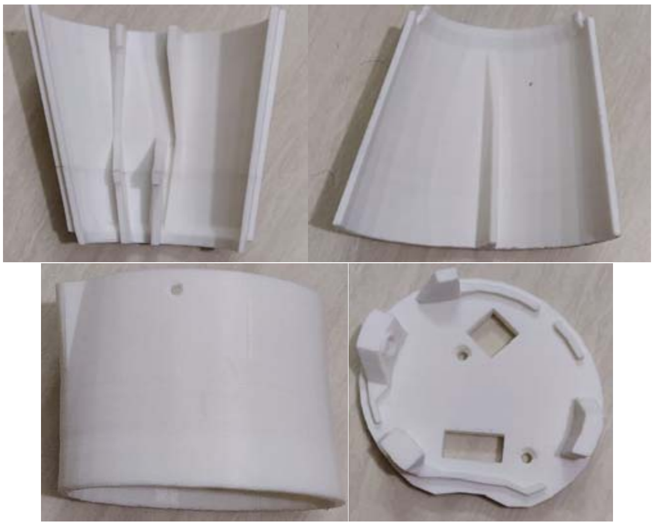
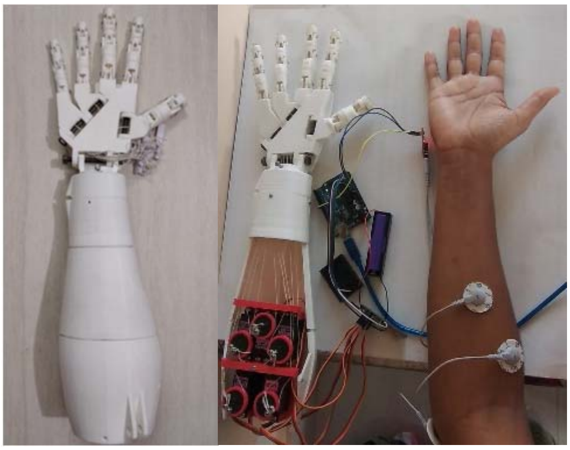


Fig. 8 Other parts of the elbow of the hand



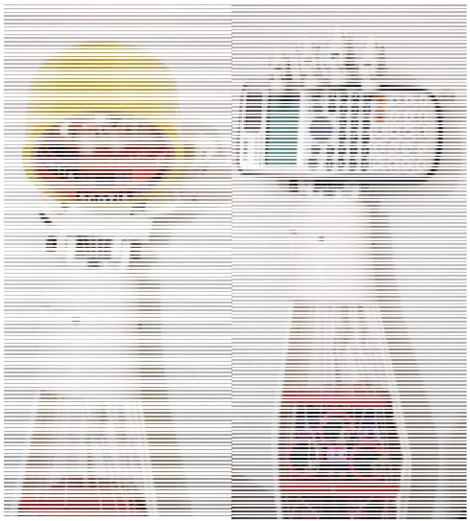
(a) (b)

Fig. 9 (a) Fully assembled hand (b) The full system

V. Testing and Discussions

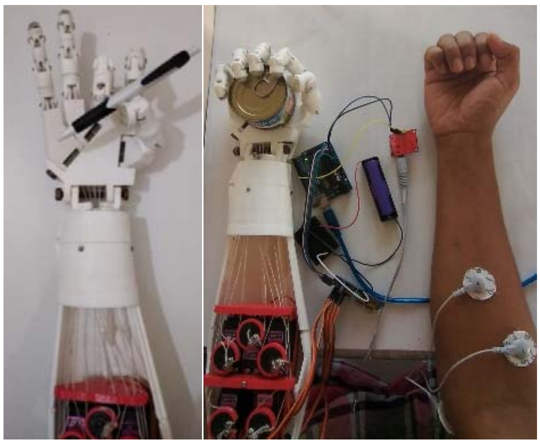
The prosthesis hand test is discussed in this part. The fundamental purpose of a prosthesis hand is to grasp an object. And the most critical part is to test it. Testing consists of electrical connection troubleshooting and check the ability to grasp an object. Different activities and noted and different objects are tried and the activities and noted with compare to the human hand. Fig. 10 shows the various mimicking posture of the prosthesis hand.

The prosthetic hand was tested using known weights up to 2 kg in mass and objects of different shapes, sizes, hard materials test to check the performance of the design. While testing we found that reducing the friction between the joints of the hand is very important. Another very important feature of the design is very cost-effective and this prosthetic hand is affordable for most people. The manufacturing cost will be approximately $145 US dollars. It is scalable for every age of people.



(a) Gripping Tape (b) Gripping Calculator

(c) Gripping Exercise book (d) Gripping 500 ml water bottle



(e) Gripping pen (f) Gripping can

Fig. 10 Various hand grasps

Fig. 11 Some hand gestures

Fig. 11 shows some images of the representation of some hand gestures. 3D printed hand is capable of some types of human gestures. Hand gestures are controlled by the surface electromyogram signal.

VI. Conclusions

Acceptance of 3D printed prosthetic hand is rising day by day. In Bangladesh, up to thousands of people are injured by accident every year and many children were born with autosome problems. In those cases, 3D printed prosthetic hands are getting popular in Bangladesh. CRP- Centre for the Rehabilitation of the Paralyzed is the only place where they provide 3D printed prosthetic hands.

This paper represented the design and development of a 3D printed myoelectric-controlled prosthesis hand using a sEMG sensor. The hand can achieve 5 DoF in fingers. It can open close and grasp some objects of different shapes and sizes. The wrist of the hand has 1 DoF, it can move in left and right. EMG signal is used to control and coordinate all the fingers and wrist. In this paper, we proposed to design and fabrication of a prosthetic hand which is low-cost, customizable, and light-weight. We designed and implemented this prosthetic hand considering the needs of the Bangladeshi people so that it can be bought by all kinds of people of Bangladesh and also by the people of the other lower-income countries. In the future, we hope to develop hand for the loss of upper libs.

Acknowledgment

We want to thank the authority of Fab Lab of Dhaka University. We used the lab for 3D printing purposes. Fab lab is the most updated lab in Bangladesh. It is non-profitable and funded by the Bangladesh Government to support the students for research purposes.

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