A Low-Cost Multichannel Prosthetic Hand: Design and Development

Md Enamul Hoque, Sumona Azad, Mansura Ahmed, Sk S M Tareq Aziz Shovon,

Md. Tareq Aziz, Sharjis Ibne Wadud

***Abstract*—**This study focuses on design and development of multichannel prosthetic hand at an affordable cost for the low-income people (e.g. in Bangladesh). There are many conventional prosthetic arms available in the country but their performance is less than ideal for the hand amputees to go back to their normal life. So, in our research we developed an EMG (Electromyogram) controlled Prosthetic hand providing most of the functionality of a normal hand. People losing their arms due to accidents, trauma or injury still have the capability to produce the action potential responsible for hand movement. So, an EMG sensor was used to acquire that muscle potential from the amputee site of the patient's arm. EMG is basically an analogue signal. So, in order to utilize that signal into an electronic circuit it needs to be digitalized. Arduino, a micro controlling device built in an ADC (Analogue to Digital Converter) was used to digitalize the analogue EMG signal acquired from the patient's arm. By fixing an algorithm after recording patient's different threshold voltage level the digital signal was used to rotate servo motors attached to the prosthetic arm. The prosthetic arm was designed part by part using 'Solidworks'. Then the parts were 3D printed (i.e. built layer by layer) using the FDM (Fluid Deposition Modeling) system. 3D printed parts were then assembled along with the servo motors which were placed inside the forearm. These servo motors are responsible for the functionality of the prosthetic hand following the EMG threshold voltage acquired from the patient's arm.

Keywords*—Prosthetic hand, Amputee, EMG Signal, 3D Printing, Microcontroller, FDM*

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Md Enamul Hoque Department of Biomedical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh enamul1973@gmail.com, enamul1973@bme.mist.ac.bd

Sumona Azad Department of Biomedical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh sumonaazadmist@gmail.com

Mansura Ahmed Department of Biomedical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh roshni22ahmed@gmail.com

Sk S M Tareq Aziz Shovon Department of Biomedical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh tareqaziza@gmail.com

Md. Tareq Aziz Department of Biomedical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh tareqazizmist@gmail.com

Sharjis Ibne Wadud Department of Biomedical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh sharjisibnewadud@gmail.com

I. Introduction

The 3D printed bionic hand controlled with sensing human body signal is a new invention of the Biomedical Engineering world. The goal of this research is to find out what modern world is doing in the advancement of bionic prosthetic hands as well as the research on myoware prosthetic hand. At the start of this research, complete lower arm prosthetics as a whole were strongly considered. Different medical companies provide solutions for those who have unfortunately gone through amputation surgery including different kinds of prosthetics but their performance is not good enough. It was clear that conventional prosthetics were functional and readily available, but body powered prosthetics that essentially not advanced (Mounica et al,2017). Bangladesh is a very road accidents prone country. Everyday people face road accidents, trauma, injury and undergo different medical complications. Sometimes they need to undergo surgery of limbs amputation. As Bangladesh is a lower middle-income country, most of the people here are very low wage earner. So, when a person undergoes limb amputation, he/she becomes jobless and ultimately becomes burden for the family and ultimately for the society. So, keeping that thought in mind, in order to help those people, this research aims to design, fabricate and develop a multichannel prosthetic hand. The purpose is not only just designed and developed but also emphasized on keeping the cost of that prosthetic hand as low as possible to make it affordable for the people the country, like Bangladesh. Different medical organizations in Bangladesh that make conventional artificial limbs. Among them Combined Military Hospital (CMH), National Institute of Traumatology and Orthopedic Rehabilitation (NITOR) and Dhaka Trauma Center are the most active organization that work relentlessly in making conventional artificial limbs. Limbs amputation data collected from some hospitals are presented in Figs. 1 and 2.

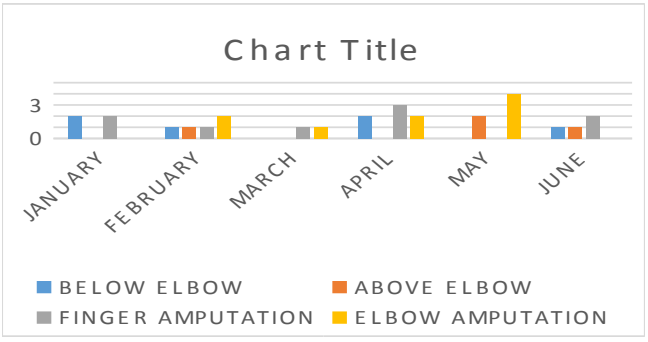


Fig. 1. Statistical data of below elbow amputation performed in CMH, Dhaka (during 1999-2018)

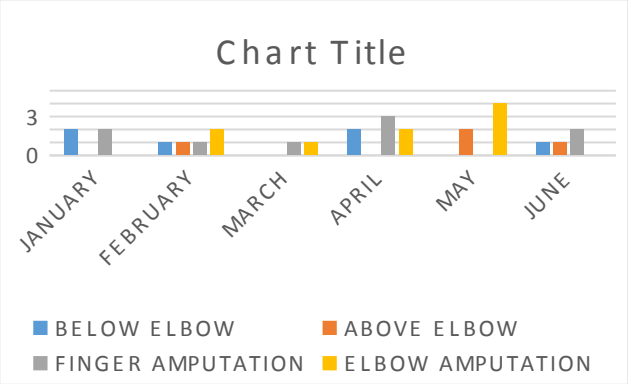


Fig. 2. Statistical data of below elbow, above elbow, finger amputation, elbow amputation performed in NITOR, Dhaka (During January - June, 2018)

The overall objective of this research is to design and develop a multichannel prosthetic hand at an affordable cost for the low-income people (e.g. in Bangladesh). The specific aims of this research are:

- To design the prosthetic hand using Solidworks software.
- To fabricate the prosthetic hand model using Fused Deposition Modeling (FDM) system.
- To design and construct an EMG circuit to acquire the EMG signal from the patient.

II. Materials and Methods

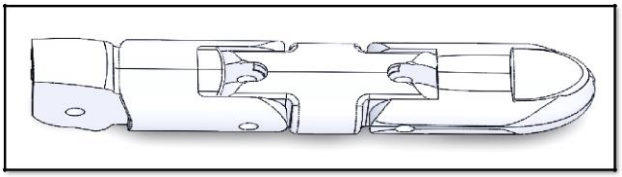
A. Computational Design of Prosthetic Hand

The overall design of this prosthetic hand is treated as continuous development of current prosthetic hand design. After performing necessary background research and studying the available products on the market, this project is decided to construct by the aid of Solidworks software. All the prosthetic hand parts are design and develop with Solidworks and the dimension is mainly targeted for adult user. The prosthetic hand that is design in this project comprises of palm and five finger that are index, middle, ring, thumb and pinky. As the main focus of this project is to increase functionality in humans who suffer from various diseases requiring amputation or by born defect. Therefore, the design of prosthetic hand was made very carefully, considering all aspects as presented in Table 1 (Joshi et al, 2009).

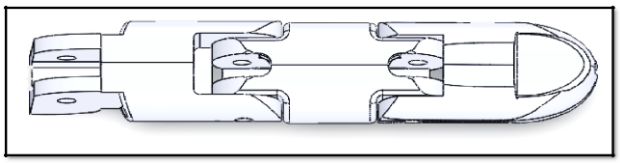
Table 1: Reference Parameters

Finger	Length (mm)	Wide(mm)	Length(mm)	Wide(mm)	Length(mm)	Wide(mm)
Thumb	70	30	45	30	40	30
Index	55	30	40	25	30	25
Middle	55	30	50	25	40	25
Ring	55	30	40	25	30	25
Pinky	30	30	40	25	30	25
Palm	130	120				

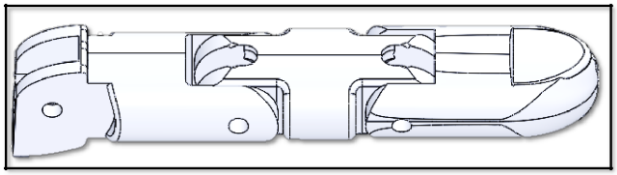
The prosthetic hand that is designed in this project comprises of palm, fingers, forearm and wrist as shown in Figures 3 and 4. Originally, thumb is different from all other parts of the fingers and it's a crucial part in prosthetic hand from shape. Each of the finger has three segments, where thumb has just two segments. As the research purpose is to enhance the functionality so grasping mechanism also depend upon the thumb.



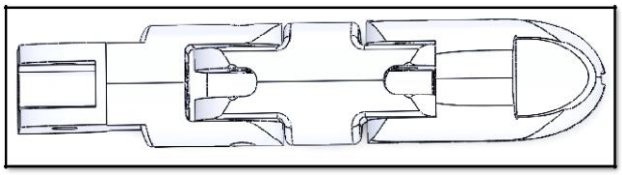
(A) Index finger



(B) Middle finger



(C) Ring finger



(D) Pinky Finger

Fig. 3. 3D Design of Fingers (A-D)

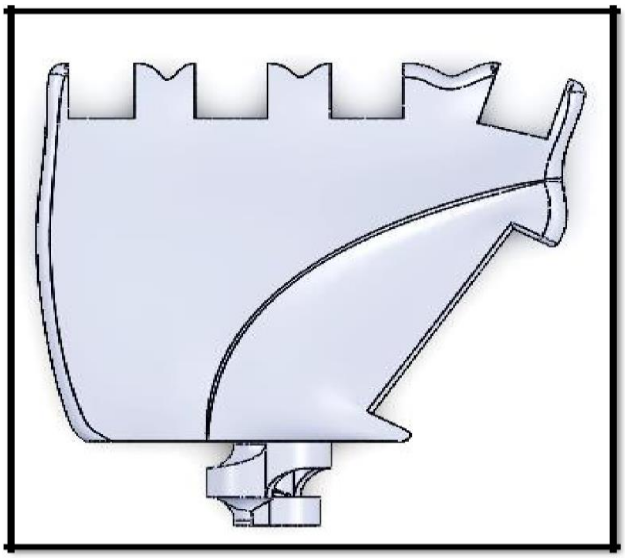


Fig. 4. 3D Design of Palm

B. Materials

A variety of metals are used for prosthetics limbs; Aluminum, Titanium, Magnesium, Copper, Steel and many more. Major material properties to compare and analyze include but are not limited to the following; compressive, torsional, tensile, and shear strength, specific density, energy storage characteristics, stiffness, shock absorption (damping), fatigue resistance, fracture toughness, creep, yield stress, and biocompatibility (Mota, 2017).

In this research work, PLA filament and ABS filament are used in fabricating the part by using 3D printer. There are few factors that contribute to the material selection for this project. ABS defined as Acrylonitrile Butadiene Styrene made out of oil-based resources. It is an opaque thermoplastic that possesses a diverse combination of properties such as

- High resistance to chemicals,
- Heat and impact.
- ABS materials are hard, tough and rigid.
- ABS also have high melting point.
- Its sturdy and hard quality can maintain its shape for a long time and
- It cannot be deformed due to external heat.
- It is also very economical and has a long lifespan.

On the other hand, PLA which defined as poly-lactic acid is a type of bio- degradable plastic that has its own special characteristics.

- PLA is made up of plant-based resources such as corn starch or sugar cane.
- It gives good surface finish with shinier and smoother surface.
- PLA material is an eco-friendly material with zero harmful fumes during printing.
- PLA is a biodegradable thermoplastic which is derived from renewable resources
- It is used in medical suturing as well as surgical implants, as it possesses the ability to degrade into inoffensive lactic acid in the body.
- It is chemically harmlessness or potential toxicity.

C. Control Circuit Design

The 3D printed prosthetic hand, printed by using FDM method has to be assembled with the use of some medical grade threads. After assembling all parts of the hand, it is now ready to be controlled with EMG signal of the patient. Necessary equipment for circuit design is discussed further:

EMG Sensor: EMG or electromyography basically records the movements of the muscles. When a person tends to contract his muscle there is a burst of electric energy generated and it burst through the muscle. Electromyography grabs that energy from the neighboring tissue surface and that signal can be utilizing for controlling the prosthetic. Muscle activation is triggered by the activation of motor nerve that propagates a very small amplitude voltage. EMG transforms these electrical signals into numerical values and enables them to use in varied kinds of application.

Arduino (Nano): Arduino is a type of micro-controller designed with various microprocessor and controllers. It is equipped with some analog and digital pins, I/O pins and power up pins. Normally it works with 5volts power supply. EMG is an analogue signal. If we want to control that signal according to the user interest it needs to be digitalized. So, Arduino as a microcontroller is used to digitalize the signal with its built in ADC (Analogue to Digital Converter). First the Arduino board needs to be power up with 5v power supply. The output of the EMG sensor is directly put into the analogue pins of the Arduino. Arduino takes the analogue EMG signal as input and convert that signal into digital. Different threshold voltage levels for different movement of the hand is recorded via 'Arduino serial monitor'. Then using those threshold voltages an algorithm is set to program the Arduino. The main challenge of working with Arduino circuit is to make such efficient algorithm which will provide the best interface with the EMG signal generation to rotation of the servo motors.

Servo Motors: Servo motor is a rotary or linear actuator that precisely control the linear and angular positions. It's a motor controlled with feedback sensor. The main characteristic of servo motor that makes it different from other motors is, it can be rotated at any angle, for any number of times according to the user interest. So, in order to control the prosthetic hand servo motors are used. The programmed digital output of EMG sensor is used to control the servo motors. It is also used to give the highest degree of freedom to the prosthetic hand.

Batteries (Rechargeable): The battery selected must provide enough power to the arduino board as well as to the motors. They must be rechargeable so that it can be reused again and again. As myoware prosthesis is mainly a portable device, there is a requirement of power supply for each circuit components from batteries.

Surface EMG Electrode: Surface EMG electrodes are used to measure the EMG signal non-invasively. They form a chemical equilibrium between the contacting surface and the detecting surface through electrolytic conduction. Due to that conduction current can flow through the electrodes. The other types of electrodes require strict surgical supervision, but surface electrodes don't require that (Jamal, 2012). In this research amongst all those electrodes the surface electrode has been used because of its availability and low cost.

Fabrication of Prototyping Prosthetic Hand**:** Prosthetic hand design is fabricated by using XYZ 3D printer. XYZ ware is a brand-new application introduced by XYZ printing for designing, customizing and printing digital 3D Models. It can import objects in "*.stl" file format and create realistic

simulated objects. X Y Z ware is also used to quickly print out real products. (Ramlee et al,2015).

Fused Deposition Modeling: Rapid prototyping (RP) is a process by which an object is produced using layer-by-layer deposition of material. Rapid Prototyping (RP)s provide the ability to fabricate prototypes from various model. Fused Deposition Modeling (FDM) is one of the most used RP process that can fabricate prototypes out of ABS plastic and PLA (Polylactic Acid) as in this research used ABS plastic and PLA. In his research FDM method is used to fabricate the prosthetic hand as shown in Fig. 6.

Fig. 5. Fabricated Prosthetic Hand

III. Results and Discussions

To construct the multichannel prosthetic hand, it is focused into two parts. One is passive part used as the purpose of cosmetic and another one is active part for functional. The cosmetic part will offer the patient with a visual replacement. This work is concentrated on the structure parameters and activity of artificial human finger for maximum possible number of grips. Structure is designed into most friendly tool for designer, Solidworks. Active part is added with the passive section for enhancing the functionality of the prosthesis.

3.1 Development of EMG Sensor:

To make the prosthetic hand less expensive and affordable for the low-income people it is important to design/make a cheap EMG sensor. Firstly, a suitable EMG acquiring circuit was designed (Fig. 6). The circuit consists of an instrumentation amplifier, a high pass filter, notch filter, a low pass filter and a non-inverting amplifier. EMG voltage varies from 1mV to 10mV and its frequency is around 1-500Hz. In this design a frequency band of 2Hz to 5KHz is taken hence the cut off frequency of High pass filter is 2Hz and cut off frequency of low pass filter is 5KHz. Instrumentation amplifier gain is 500. The final output voltage is amplified to 1500 times.

3.2 Control Circuit

The control circuit (as shown in Fig. 7) is designed by using ZXBM5210 H bridge IC and the integrated full bridge driver output stage that helps to reduce audible switching noise and electromagnetic interference.

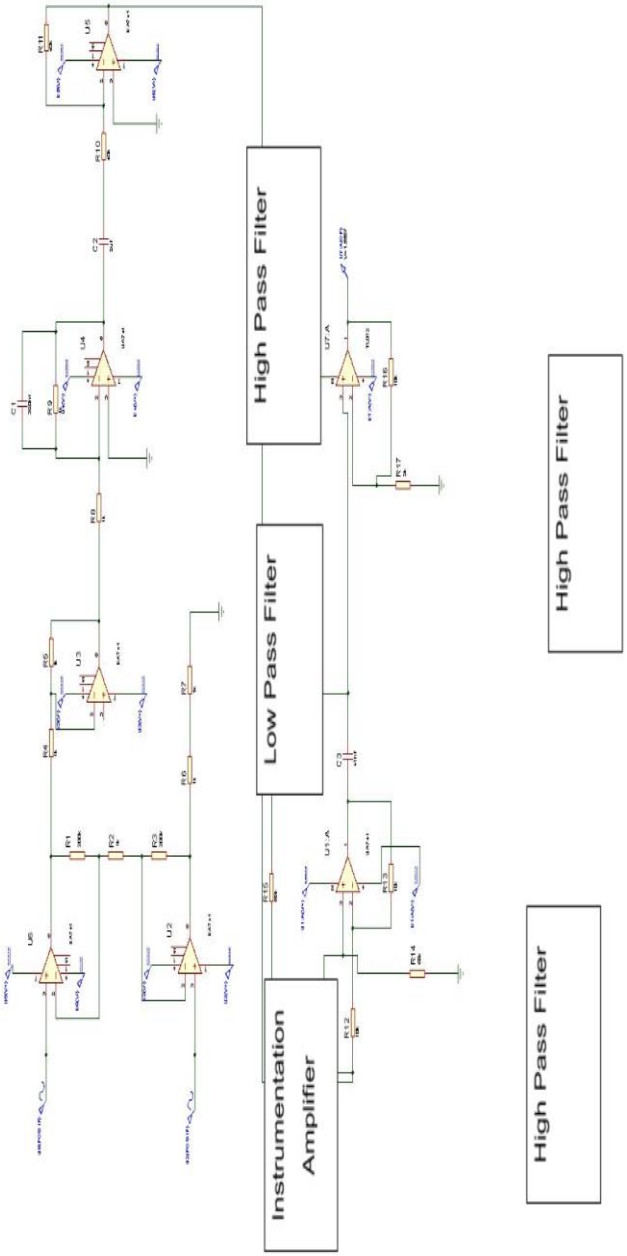


Fig. 6. Overall Diagram of EMG Acquiring Circuit

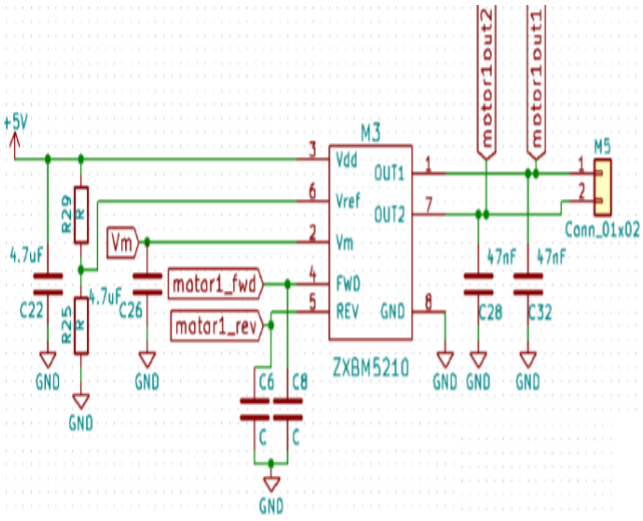


Fig. 7. Finger actuator motor control circuit

IV. Conclusions

The overall design of the fingers was found to be workable that gave flexible movements. The finger attachment to the palm was also functional that can hold the objects during traction generated by motors. The materials chosen were also be technically viable and comfortable to the patient. The EMG sensor output was good that could amplify the small input voltage to 1500 times. The interface between human body signal and motors was suitable to provide the fastest response. The individual circuit outputs of the EMG sensor e.g. all the filters and amplifiers were workable. The prosthetic hand could acquire EMG signal from the body and able to grasp the objects. This preliminary result demonstrates high potential for further in-depth work on technical and commercial evaluations of this developed prosthetic hand.

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