DESIGN AND DEVELOPMEMT OF UNDER-ACTUATED MYO-ELECTRIC PROSTHESIS HAND USING RAPID PROTOTYPING TECHNOLOGY

LOH KOK YONG

This Report Is Submitted In Partial Fulfillment of Requirements for the Bachelor Degree of Electronic Engineering (Computer Engineering)

Fakulti Kejuruteraan Elecktronik Dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka

June 2016

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Thank you for my beloved family, my supervisor and all the lecturers who guided me, and to all my friends for giving me mentally and moral support during the process of this project.

ACKNOWLEGDEMENT

First of all, I would like to express my special thanks of gratitude to all those who helped me to complete my Final Year Project. Especially my parents and family for supporting me and provide me resources to complete this project.

Secondly, a special thank I give to my supervisor, Dr. Soo Yew Guan who has been provided material and component of this project to me. Besides, Dr. Soo gave me the fully support and clear guidance in term of knowledge and experience to help me finish the project in time.

Furthermore, I would like to acknowledge with much appreciation to my friends, Ali Mohammad and Liao Shing Wen. They shared the ideas and knowledge about EMG signal processing and motor driver design to guide me in completing the project. Both of them had given me a lot of encouragement and tips to improve my project.

Lastly, thank to anyone who helped me in this project especially who helped me a lot in finalizing this project within the limited time frame.

ABSTRACT

This project illustrated a rapid prototyping prosthetic hand that have been modified from two joint of fingers to become three joints with the purpose to increase its flexibility. With the use of Solidwork software, the prosthetic hand is modified and designed. A modular, low-cost and light-weight prosthetic hand in this project is built and printed by using 3D printing technology. Originally the prototype was being operated by using strain pressure sensor from skin. However, in order to increase its efficiency, the prosthetic hand of this project is being replaced by electromyography signal captured from forearm muscle rather than using pressure sensor. The method used to process the electromyography signal is root mean square and there is only two gestures been classified in this project. Therefore, a threshold value have been calculated from the summation of RMS by measuring the value when opening and closing the hand, then divide by two. This method has a rapid and precise response on controlling the movement of the prosthetic hand. The hand is the very important to us especially in daily activity. Therefore, this project is aimed to be affordable to all level of consumers and can be applicable to limbs amputees as well.

ABSTRAK

Projek ini adalah menggambarkan tentang prototaip pantas tangan palsu telah diubah suai daripada dua sendi kepada tiga sendi dengan tujuan untuk meningkatkan fleksibiliti. Perisian yang digunakan untuk mengubah suai dan reka bentuk jari yang buru adalah Solidwork. Tangan palsu yang modular, kos rendah dan ringan dalam projek ini adalah dibina dan dicetak dengan menggunakan teknologi percetakan 3D. Prototaip asal adalah beroperasi dengan menggunakan penderia tekanan daripada kulit, manakala tangan palsu dalam projek ini adalah beroperasi dengan pelaksanaan menangkap isyarat Electromyography daripada otot lengan untuk meningkatkan kecekapan tangan palsu. Kaedah yang digunakan untuk memproseskan isyarat Electromyography adalah root mean square teknik dan terdapat hanya dua gerak isyarat telah dikelaskan dalam projek ini. Oleh itu, nilai ambang telah dikirakan dari penjumlahan RMS tangan dibuka dan ditutup, kemudian dibahagikan dengan dua. Kaedah ini mempunyai tindak balas yang cepat dan tepat pada pergerakan tangan palsu. Tangan adalah sangat penting kepada kita, terutamanya dalam aktiviti harian, oleh itu, projek ini adalah berpatutan untuk semua peringkat pengguna dan lebih sesuai dipakai untuk orang cacat sebagai tangan palsu.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The number of amputees are increasing yearly due to war, accidents, diseases and etc. Hand is the very important to us especially in daily activity, for example hand is used for grabbing objects, lifting, writing and a lot of things we do in life. However, with the loss of limb will cause a lot of troubles when carrying on daily activity. Thus, prosthesis hand is a tool to help limbs amputees to recover a part of self- confident and making them believed that there is still hope to regain back a partial life of a normal healthy individual. The prosthesis hand acts as a tool to replace the lost limbs physical appearance. As a matter of fact, it works as an aid to help in providing some of the functions that is lost due to accident, war or congenital condition. Moreover, the prosthesis hand is an interchangeable device that can be used only when needed. Much effort in the field of upper-extremity prosthesis research is directed towards the development of prostheses as limb replacements.

Currently, three types of prosthesis hand are commercialized in the market: cosmetic, body powered and myoelectric [1]. Cosmetic prosthesis hand is non-function but light weight. This cosmetic design is outstanding on the outlook design which has the exact appearance as human hand. However it is costly when the design is considered with non-functionality. Body powered prosthesis hand has limitation on only capable of holding certain things. Normally this type of prosthesis hand is built by two or three oppose fingers. Besides, body powered prosthesis hand is using minimum number of actuator to achieve certain functionality. Even though the prosthesis hand is light weight and low cost but it has the limitations on its distinctive outlook and less flexibility of the palm-finger part. However, currently the myoelectric hand that existed in the market is very expensive due to its multi-functional, complex hand design and the quality of inner component of the prosthesis hand. All of this strong point bring out a costly prosthesis hand and unaffordable by most of the consumer.

Most of the amputees are not capable of purchasing a highly functional prosthesis hand even if those who managed to purchase it, they also fear of damaging the prosthesis because it is the maintenance fees are costly and they are forced to avoid using it for daily basic activity [2]. Therefore, a good prosthesis hand is a tool that can help in recovering the health and life of limb amputees with the prices that can be afforded by all amputees. Hence, a light weight, low cost with its outlook that is similar to human's hand with five fingers is designed in this project.

1.2 Objectives

In this project, there are two objectives that needed to be achieved. The first objective of this project is, to design and build a modular, low-cost and light-weight prosthetic hand. The second objective is to ensure the 3D designed prosthetic hand can be operated by using electromyography signal.

1.3 Scope of Project

The scope of this project consists four parts, which are mechanical finger design part, controlling actuator, signal analysing or processing part and control system part. The mechanical hand design is obtained from open sources website which called "HackBerry". This prosthesis hand is designed with one joint of thumb and remaining fingers with 2 joints. Besides, this hand design can be printed out by using 3D printing technology. However, there is a limitation on its finger flexibility when holding an object with round surface. Fig 1.1 shows the 3 forces generated by one finger with 3 joints that proved to be easier to hold a round surface object compare to fingers with 2 joints. Therefore, this project is aimed to modify all fingers with originally two joints to three joints by using "Solidworks" software as well as using 3D printer to print out the designed finger parts. The fingers designed is then being assembled to become a prosthesis hand by using nuts, shaft and spring.

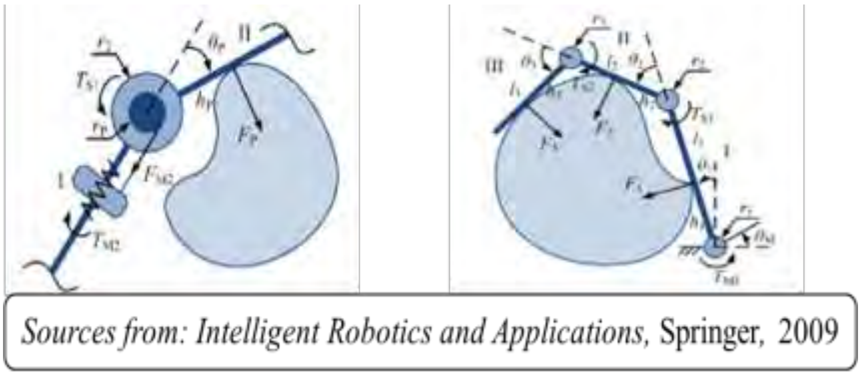

Figure 1.1: Force analyse to holding a round surface.

Olimex board is open source hardware electrocardiography electromyography shield and it can be suited for Arduino board. It can attach on top of the Arduino Uno microcontroller board. In order to capture raw Electromyography (EMG) signal from muscle, Olimex board is required to connect with three lead Differential Muscle /EMG sensors and Snap connector with gel ECG electrodes. The EMG sensor will attach to the forearm muscle of the user to detect signal captured from muscle when there is different movement performed by fingers. Arduino UNO board is used to read the analogue signal and process the signal with the use of root mean square equation.

This project uses Arduino IDE software (fully open source software) to receive the raw signal from Arduino Board that connects to the Olimex board. This software is a tool to analyse the signal of fingers motion. This project will only aimed on two type of gestures/fingers motion which are grabbing and opening the hand. In this project, three servo motors will be implemented to control the movement of the finger. Besides, the servo motor is driven by using angle (degree) method. Arduino Uno will be implemented in this prosthesis hand which acts as a small brain of controlling the prosthesis hand. The programming of the Arduino board is divided into three part, where the first part is to detect/read the input EMG signal from muscle of user, second part is to analyse the signal of the hand on whether it is opened or in grabbing motion and then through the analysis to determine the threshold value for activating specific gestures and the last part is upon finishing the analysis of the hand gesture, Arduino Uno will be programmed to drive the servo motor that controls the finger movement. In conclusion, there is only two hand gestures designed in this project that includes grabbing and opening of the hand and there will be only two outputs for this project.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses about all the researches that have been done in the past which is related to the title of the project. All researches done is being compared and discussed critically.

2.1 Comparison between 3D Design Software

There are few research [10-16] had discuss to the feature between several 3D design software. This section will summarise the basic feature of AutoCAD, Solidworks and Inventor 3D design software. Table 1 is shown the target user of the 3D design software. Table 2 is the comparison the specification strength between these software.

Table 2.1: Invented user of 3D softwares.

AutoCad	Solidworks	Inventor
• Architects • Engineers • Industrial Designers • Students / Casual Users	• Engineers • Industrial Designers • Students / Casual Users	• Architects • Engineers • Industrial Designers • Students / Casual Users

In short, 3 types of these three3D design software are consist of a roughly similar feature and the Inventor software is the one which most easy to use and the interface is simpler compare to Solidworks and AutoCAD. Inventor software is the much better software in term of performance and productivity in drawing and more stable compare to solidworks and AutoCad. However, this software required a high random access memory and disk space to perform well this software, there will be a problem if the platform is not achieve the minimum requirement. Therefore, Solidworks software is a step of behind Inventor. The Solidworks is consists the mostly feature of Inventor but just lack feature on 3D printing and the performance speed will a bit slow compare to inventor. For AutoCad software, it functionality and feature is roughly similar to two others and it is also suitable to design 3D object. But Solidworks software had been chosen in this project is because Solidworks software enables analysis and simulation as Inventor software, also obtain a good feature and performance speed rather than AutoCad.

Table 2.2: Basic data of three 3d design software.

<table>
<tr><th colspan="2"></th><th>AutoCad</th><th>Solidworks</th><th>Inventor</th></tr>
<tr><td colspan="2" rowspan="2">Software function</td><td colspan="3">Part/Assembly Modeling
Simulation & Analysis
Animations & Rendering
Documentation</td></tr>
<tr><td colspan="2">Cost Estimation</td><td>-</td></tr>
<tr><td colspan="2">Feature</td><td colspan="3">2D Drawing
3D Modeling
Parametric Modeling
Photorealistic Rendering</td></tr>
<tr><td colspan="2" rowspan="2">Collaboration Features</td><td colspan="3">3D Viewing Tools</td></tr>
<tr><td>2D to 3D CAD Conversion
3D Printing</td><td>Multiple user reviews</td><td>2D to 3D CAD Conversion
3D Printing</td></tr>
<tr><td colspan="2">Other feature</td><td>-</td><td colspan="2">Electrical design
Sheet Metal Design</td></tr>
<tr><td rowspan="2">No. of Support file</td><td>Writable</td><td>8</td><td>21</td><td>8</td></tr>
<tr><td>Readable</td><td>8</td><td>22</td><td>8</td></tr>
<tr><td colspan="2">Platforms</td><td>Window
Mac</td><td>Window</td><td>Window</td></tr>
<tr><td colspan="2">RAM</td><td>4GB</td><td>2GB</td><td>8GB</td></tr>
<tr><td colspan="2">Disk space</td><td>6GB</td><td>5GB</td><td>100GB</td></tr>
</table>

2.2 Signal Graph Plotting Software

Matlab software is a strongest software in data processing field, this section is to discuss about the weather Processing software able to plotting a real time graph. Processing has promoted software literacy, particularly within the visual arts, and visual literacy within technology. Initially created to serve as a software sketchbook and to teach programming fundamentals within a visual context, Processing has also evolved into a development tool for professionals. The Processing software is free and open source, and runs on the Mac, Windows, and GNU/Linux platforms. Its open source status encourages the community participation and collaboration that is vital to Processing's growth. Contributors share programs, contribute code, and build libraries, tools, and modes to extend the possibilities of the software. The Processing community has written more than a hundred libraries to facilitate computer vision, data visualization, music composition, networking, 3D file exporting and programming electronics. There are some example plotting graph sources to enable user to modify and develop own code to draw the graph line. This processing software is using programming code to generate the user interface window, so, concept and source code of Processing software is similar to Arduino IDE code. However, Matlab is the more powerful software compare to processing and there are a lot of specific method and feature to process the data signal inside of library Matlab and this software require a high random access memory and disk space to run the program.

In summary in this section, the purpose to choose a quick solution and software that is suitable to plotting a real time graph, therefore, Matlab software is suitable to plotting graph but not a necessary need to use it because the Processing software able to plotting graph with using a low memory in window platform.

2.3 The Prosthetic Hand

Prosthesis is an artificial device that design to replace the missing or loss part of human body. Therefore, a prosthesis design must fulfil the functional needs and appearance requirements of the user. 500 years ago, human start to upgrade their prosthetic limb which more function than old version. Therefore there several types of prosthetic hand in pass 500 hundred years ago. In 1500s, there is a right arm made by iron material (Ohry, 2014) and different appearance compare to previous version shown in Figure 2.1.

Figure 2.1: The Von Berlichingen, made of iron, 1500s
(Image sources from: http://commons.wikimedia.org/wiki/Category:Eiserne_Hand)

This design is mimic to real hand and this design idea is still been use until now. This prosthesis hand built up by iron material, causing the weight of this hand is heavy than old version which prosthesis is only attach with a hook (Figure 2.2) on the front end of the hand. Besides, at mid-19th century the prosthetic hand are made of leather, wood, and iron. The material of prosthesis hand is not only using iron and this innovation are multi attachment prosthetic hand. This design idea is also still been until nowadays. Control algorithms for upper limb myoelectric prostheses have been in development since the mid-1940s [2].

Figure 2.2: Multi attachment of prosthetic hand.

Based on Ahmed M. El Kady, Ahmed E. Mahfouz and Mona F. Taher (2010), the mechanical design is one of the main components of an upper limb prosthesis [3], therefore, this paper is aimed to build an Anthropomorphic Prosthetic Hand for Shape Memory Alloy Actuation presents and the objective of the mechanical design is to have an anthropomorphic hand (similar in size and structure to the human hand) and kinematic accurate movement to fulfil normal grip requirements. In this paper, there are implement two prototype. Both prototypes mechanical structure are consist of 3 phalanges; the joints between them, PIP, DIP and MCP, are interconnected with single DOF hinge joints, each joint is using torsion spring to force the finger extent and cause hand open. First prototypes is using Ertalon hollow tube material, a polymer which features high mechanical strength and good electric insulator properties. Each joint have 2 interlocking hinge with using steel pin to lock down all hole which linking interface of two different part. Plexiglas material is use for palm part and each actuation cable is fixed at end or fingertip of all fingers. Second prototype is four fingers are consist three segments with interlock and two segments inter locking for thumb. By using SMA wires and provide a small strain to generate an optimum joint rotation (flexion), therefore, this wire attach closely to the DIP joint (at the middle). After testing and evaluation, the second prototype is more suitable as prosthesis compare to first prototype because SMA actuator in second prototype is just need a small force to execute grasp motion and clasped an object. Therefore, when the length and segment of thumb also is a main criterial when design a prosthesis hand. Figure 2.3 and Figure 2.4 is showing the different contact area and the gap between two fingers when grasping a same object.

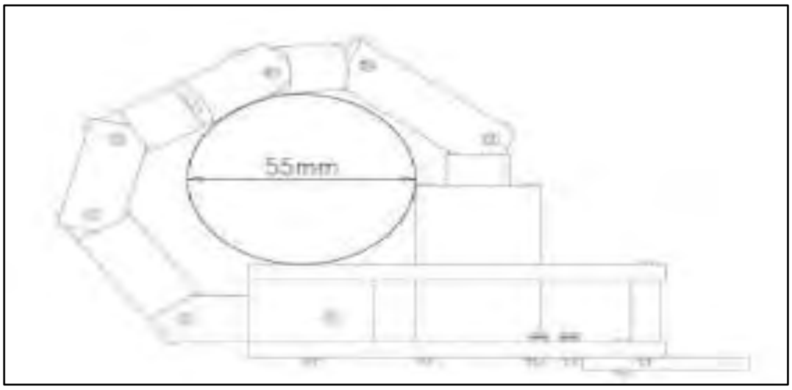

Figure 2.3: CAD drawing of the first prototype grasping cylinder with 3-segment of thumb [3]

Figure 2.4: Model of second prototype grasping a cylinder with 2-segment of thumb [3]

In review on this paper, advantage of this mechanical design is light weight (printed by 3D printer) and no sound produce when it operate. Besides, this paper had clearly show that the longer length and three segment of thumb the higher forces needed to grasp an object to prevent slip, however, shorter length and two segment of thumb will require a small force and easy to grasp an object.

According to Weir, R.; Clark, S.; Mitchell, M.; Puchhammer, G.; Kelley, K.; Haslinger, M.; Kumar, N.; Hofbauer, R.; Kuschnigg, P.; Cornelius, V.; Eder, M.; Grausenburger, R (2007), a research aimed to build prosthetic hand which suitable for 50% of women limb amputee and possess 50% strength of man capability shown in Figure 2.5. First is the hand mechanical and actuator design part, this prosthesis hand consists 5 fingers, each finger has 3 phalanxes and driven by 2 motor. By using differential drive mechanism coupled one motor in distal and middle part of finger then another one motor is coupled for proximal phalange. Thumb part has 4 Degrees-Of-Freedom (DOF) and one motor in each DOF. Besides, another 3 motor are stick at the wrist part to perform a rotation force. Therefore, this prosthesis hand consists a total 15 motor actuator and 18 DOFs. In order to hold up a certain load of an object, DC motor drive train architecture had been choose for actuator design. The second part is to control the motor operation, a force or position sensor are implement into the all finger and joint axis.

Figure 2.5: Image of multifunctional prosthesis hand [4]

For sensing input signal part, this paper are using myoelectric sensors and real time pattern recognition. In review on this paper, although this prosthesis design and concept of hand system were very powerful on functionality but there is some defective part which is the greater number of motor, the heavy the weight of hand and the second regret is this journal has target to use myoelectric sensor as input of control system but without discuss about the method being use for processing and analysing of signal part.

Based on Niola, V.; Rossi, C.; Savino, S.; Troncone, S. (2014), a prototype aim to study about the possibility of realization of a mechanical hand of five fingers, the movement which is realized by use of only one actuator. The mechanical design of prosthesis hand is consists five fingers and one forearm. Each finger have three segments with one interlocking hinge in between joining part of all segment. All finger are attach to the palm and inside the palm consists four pulleys. This prosthesis hand is only using one tendon actuator to control the motion of all phalanges of the fingers which is an inelastic tie rod passing through a set of pulley system. Therefore, the moment of pulling the tie rod, the all fingers will start to bend and complete a hand close motion. But in order to validate the phalanges can do an open hand motion, hence, elastic spring are need to fix at the opposite direction of inelastic tie rod. This installation method is to generate another pulling force on phalanges but in oppose direction of tie rod.

Figure 2.6: Mechanical hand design with one actuator [5].

In fact, if the pulling force generate from tie rod is greater than force from spring, the hand will close, if lower than, it will be open. The outstanding of this design is all fingers is move independently even using one actuator in the system. This incident is due to the great functional of pulley system which the tie pass through routine. The testing result shown that this design is able to grasp several surface object. In review on this paper, found out that this design is modular, light weight and low cost which printed by 3D printer using polyactide (PLA) material and it also able to grasp even more complex surface area of an object. However, the finger is move independently but there are a fix function which is grasping. There are limited gesture can be carry on this design.

Base on Chwan-Hsen Chen (2012), the research is aimed to design a robot hand for a mid-sized service robot with a height of 1.5 meters. Before start to mechanism design, a concept that all component of control system, finger mechanism must be strict together to minimize the size of the prosthesis hand [6]. This paper separate into three part, first is mechanical hand design, second is control system architecture and the last is virtual hand simulation. This paper clearly state out the useful method for this project. At the mechanical part, in order to reduce the size, this prosthesis hand consists 4 fingers, each fingers are build up by 3 phalanges and 2 lower joints is control by a miniature linear actuator. Besides, the thumb and little finger have an additional actuator for palm which make some bending or expand outward to hold a different size of an object. There are two portion in the control system design part, one is servo actuator design second is grasping forces control. For the control system, it involve one master node, nine slave nodes and one Microchip dsPIC33FJ128MC controller with frequency 8MHz. In overall control system design an linear actuator act as a feedback tool for sensing position of finger and also the master node is same as slave node, the only different is slave nodes have extra EEPROM memory which to store sequence of finger position. In servo control design, applying continuous-time model formula:

$$G(s) = \frac{2.2}{s(\,0.07s + 1\,)}$$

This formula consists two polynomial approach which is forward transfer function and feedback transfer function. However, the grasping force control is setup a threshold value to trigger the finger of prosthesis hand to grasp or open. All the control algorithm is created in block diagram by using Simulink platform in MATLAB software. Besides, the CAD 3D design of robotic hand is also extracted to the block diagram by using SimMechanics Toolbox, meanwhile, user can do simulation on control system and the 3D CAD design is use to animate the output respond even there are no ready robotic hand can apply. This can prevent the ready prosthesis hand from damage or overload when testing of control system process. For the virtual model simulator part, user of prosthesis hand can control the movement of fingers through graphical user interface (GUI) which is a platform of MATLAB software to giving command and program the microchip to execute several movement of prosthesis hand. The testing is run at both way, execute the program on ready prosthesis hand through serial port which enable communication between personal computer and the microchip, at the same time, execute program and simulate on virtual hand in software. The result show that the movement of real hand is same as the animate movement in virtual hand in software, therefore, MATLAB software is a strong enough and powerful tools to program by only using block diagrams and this is clearly and easy to modify rather than writing code line by line. In review on this paper, the technique of control system design is very useful and MATLAB software especially Simulink and GUI tools also can create multiple variations of the control system and the block diagrams design are depend on user creative.

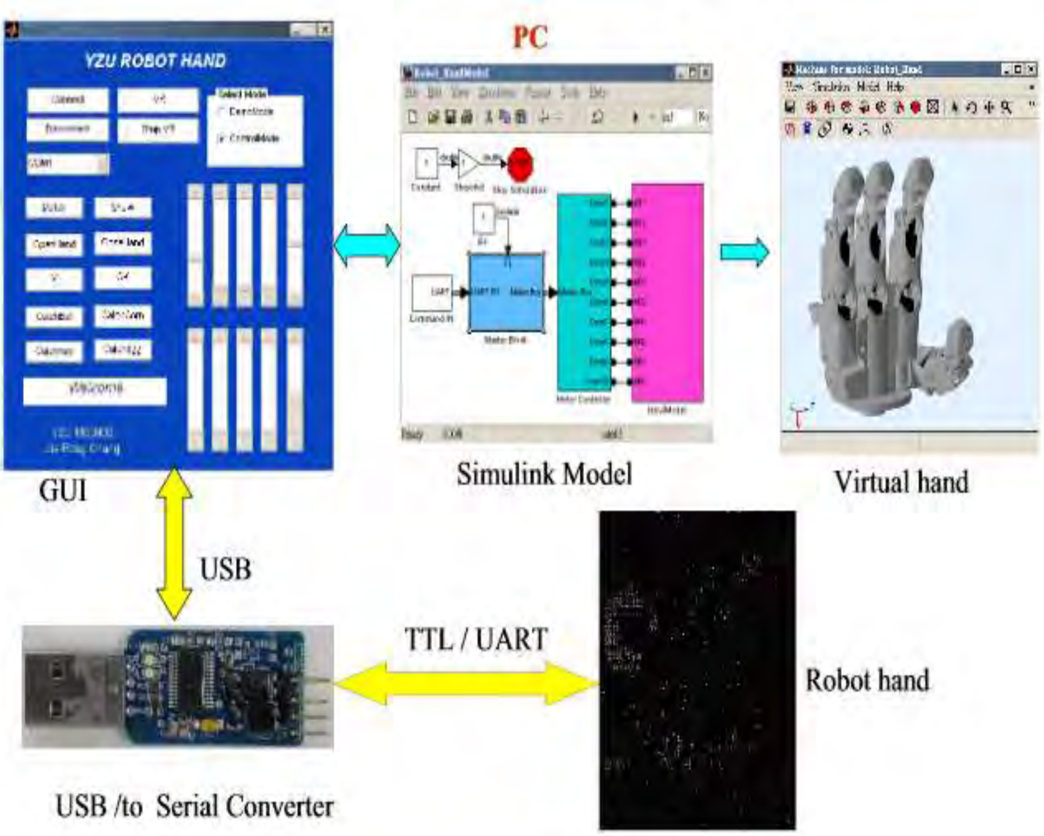

Figure 2.7: The control system create by MATLAB [6].

The research paper of Gamez, B.; Cabrera, M.; Serpa, L.; Cabrera, J. (2015) is purpose to design a prosthesis hand which suitable for a 10-year old child. In this paper had propose a prosthesis hand design with five fingers (thumb, index, middle, little and ring), each fingers consists two section. In order to carry out the grasp motion importantly tips grasp, the thumb and others finger must be in opposite direction. The hand design on the finger which the mechanism structure technique apply for movement of the fingers consists 5 joints: 2 attach to palm, 2 attach to middle phalanx and one of common joint shown in Figure 2.8. By using three linear actuator to control the hand motion which covered inside the palm.

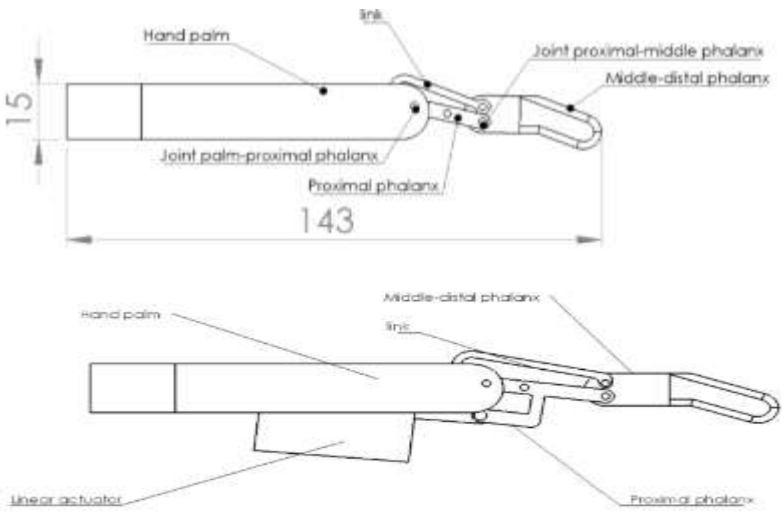

Figure 2.8: The mechanical structure of fingers [7].

Therefore, the overall of mechanical design consist of 20 joint and the movement of finger is driven by four links which connect to the three actuator (one for index finger, one for thumb and last for the left 3 fingers).

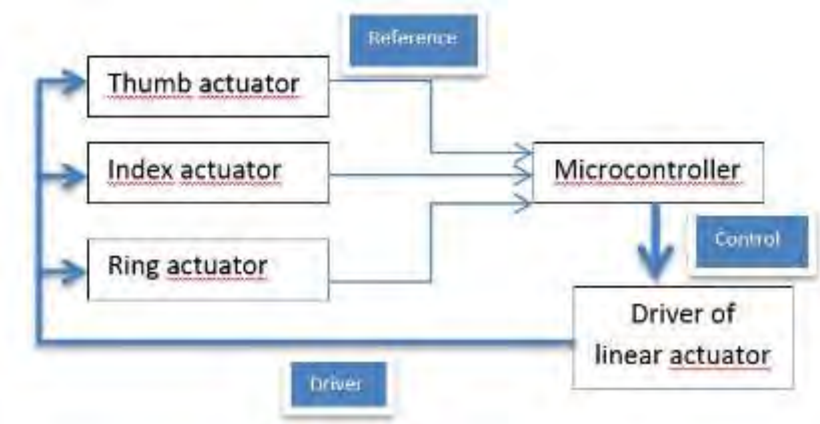

Figure 2.9: control system diagram [7].

For the control system part (Figure 2.9), indication Arduino microcontroller to program the motor driver, three linear actuator are connected to the motor driver. Each actuator have a reference potentiometer or a feedback of their position which send back analogue input signal to the Arduino microcontroller. For the prosthesis hand operating design for open hand gesture, all actuator will stretched; for close hand gesture, all actuator will retracted; for only open index finger gesture, index actuator will stretched and the other actuators will retracted. However, for precision grasp, only the actuator of index finger and thumb will retracted. Finally, this design is allow 4 types of function and built by using 3D printer. Light weight (apply less actuator) and low cost (under $1,000) is the outstanding for this design.

2.4 Conclusion

Literature review is aid to figure out the procedure and method is going used in the project. Therefore, on mechanism hand design and actuator design, there are some useful method can implement in this project. For example, on mechanical hand design the method of mechanism used and the hand grasping result. This result show out different design will lead out different forces and power being used by actuator. Second, the selection of actuator is also important which to trigger the movement of finger, more actuator implement in the hand will increase the weight and the cost, thus, in order to decrease cost and weight required a hand design technique which using minimum actuators and all the fingers can move independently. Next is about control system design, in literature review had a paper is using a platform which interact between the input/output device with microcontroller. This platform is had provided a powerful electronic block library, mathematic base library, and digital signal processing base library. Hence, this platform can built a strong enough control system with simple method.

CHAPTER 3

METHODOLOGY

This chapter discusses about the methods used in conducting this project. In the beginning of this chapter, it explained the concept of the project by using flow chart. Then, the technique and software used or applied in this project will be illustrated as well. This chapter is divided into few sections including project flow, project methodology, workflow and procedures applied in this project. Figure 3.1 shows the basic concept on how the hand prosthesis operates.

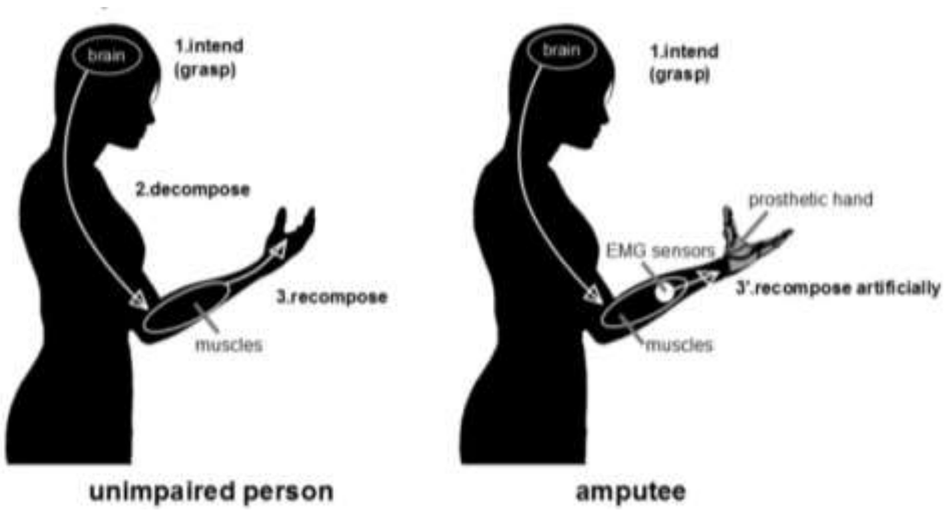

Figure 3.1: Operation of myoelectric prosthetic hand [10].

3.1 Project Flow

Figure 3.2 shows the flow chart of the project. This flow chart shows the overall steps used in this project. Flow chart is used to ensure that the project can run in a more systematically and effectively way. First of all, problem statement, objectives, and scope of work are clearly being identified in the project proposal. After identifying the project's aims and scope, the study on related topic is done to understand the theory and method used in past researches' work. Before the start of designing and implementation of the system, methodology of the project is being done beforehand that acted as a guideline. The prosthetic hand is designed using “SolidWork” and developed by using 3D printing technology. The prosthetic hand is being controlled by using electromyography. The process of testing and troubleshooting is carried out to solve the problem when result obtained is not as expected. Lastly, measuring and analysing the system performance is done and then followed by report writing.

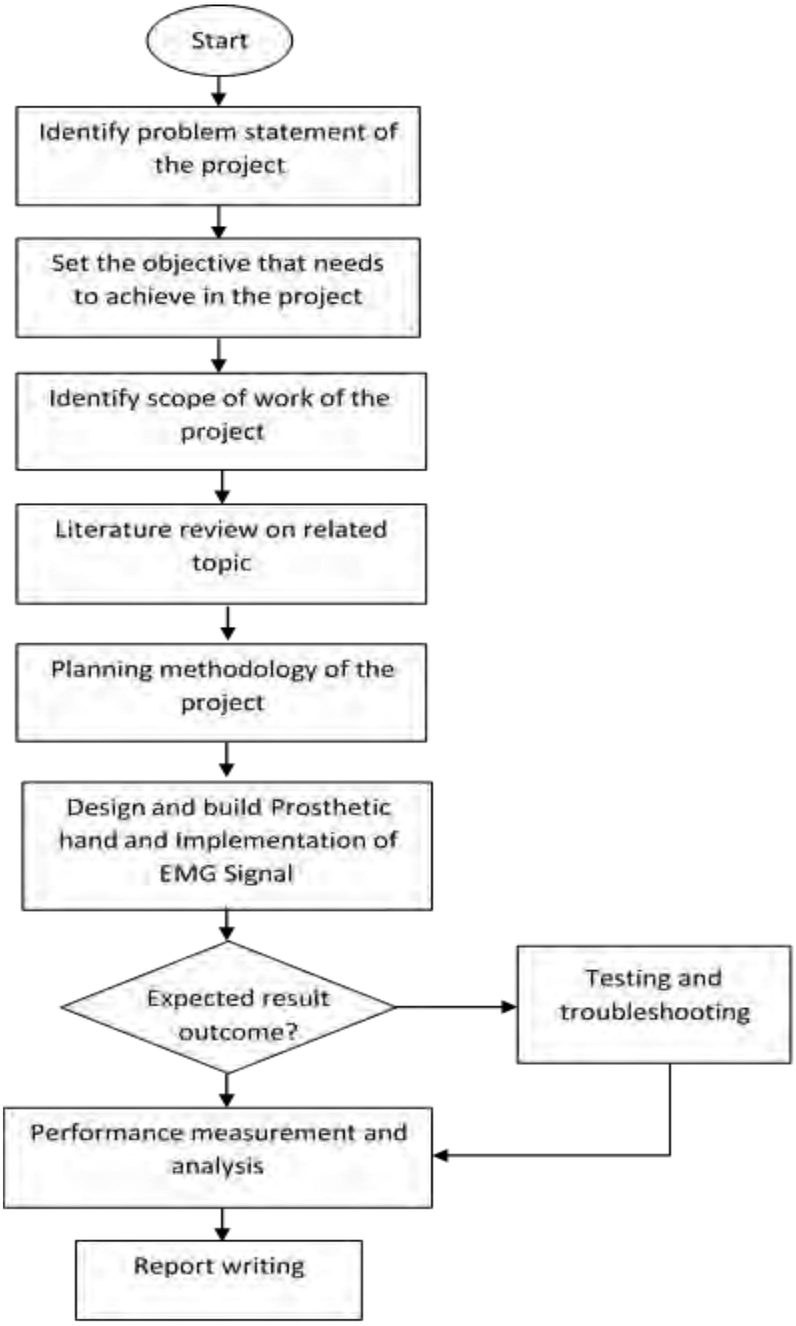

Figure 3.2: Flow chart of this project

3.2 Project Methodology

This project is distributed in three parts, including mechanical fingers design, external power motor driver part and EMG signal analysis and processing as shown in figure below.

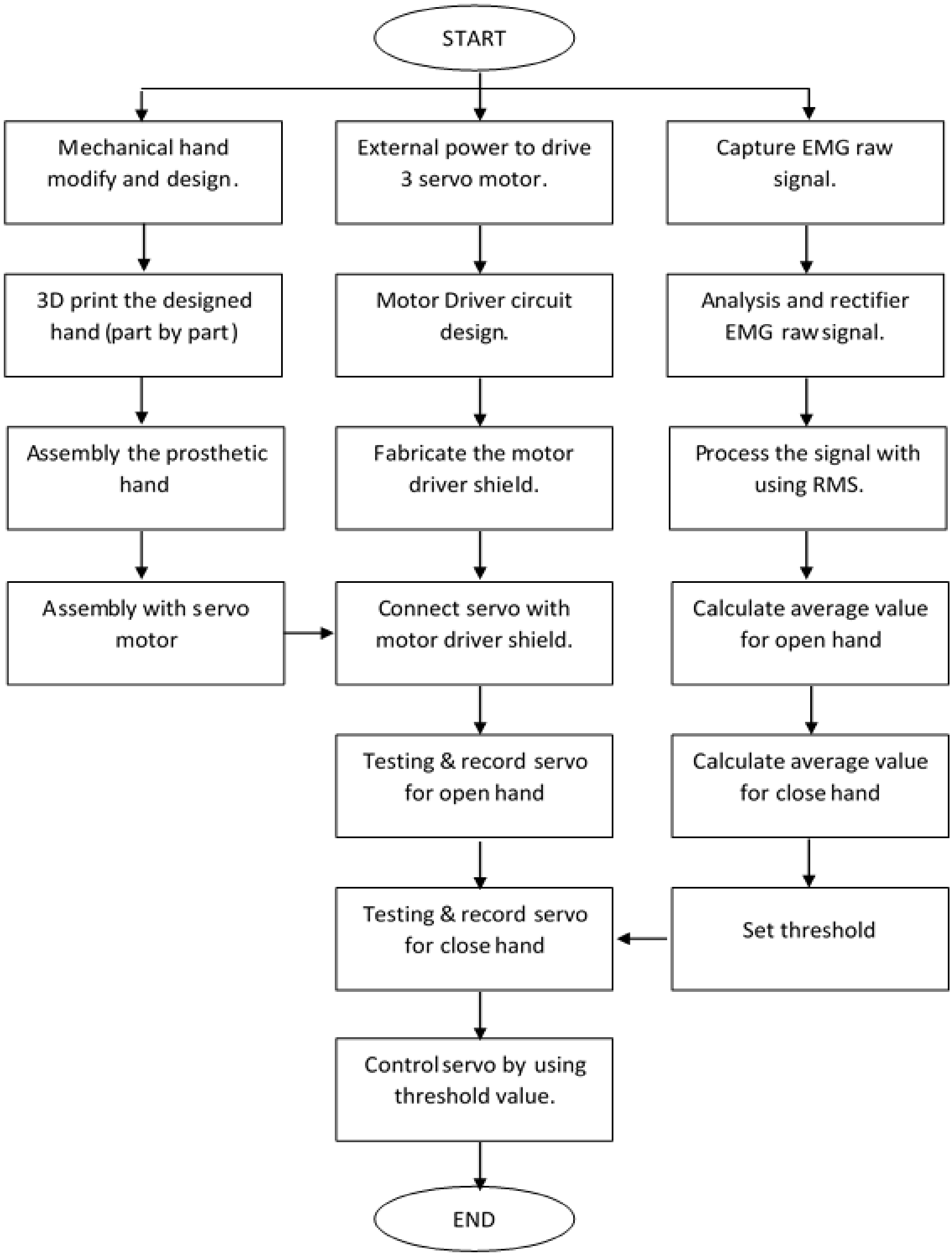

Figure 3.3: flow chart of project methodology.

3.3 Work Flow

3.3.1 Mechanical Fingers Design

Firstly, the prosthesis hand design used in this project is a set of open source design. It consists nine joints which driven by three independent actuators. This design also is a 3D printable design. This design fulfils the objectives of the project which is modular, low cost and light weight. But due to the limitation of the design, all fingers needed to be modified by adding one extra joint without changing the length of the fingers or the original design of other parts.

Solidwork software is being use to redesign the fingertip part. The method of redesigning is by cutting the original fingertips to become three parts, whereby the first part is to vertically cut it to become one middle part and one new fingertip. Second part is to cut the middle part horizontally to make it separated into upper and lower part. Lastly, the designing process proceed to the joint connection part which call hinge point of finger including front, back, up or down of the finger joint.

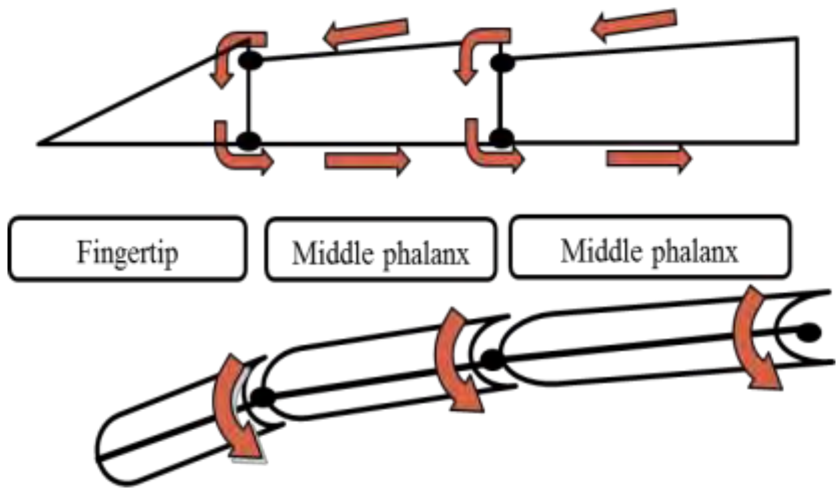

Figure 3.4: the mechanical structure of finger design.

By using Solidwork software, the sketching of the design on one plane is being shown in Figure 3.5, 3.6 and 3.7. Next will be the step of extruding the sketch on becoming a 3D design.

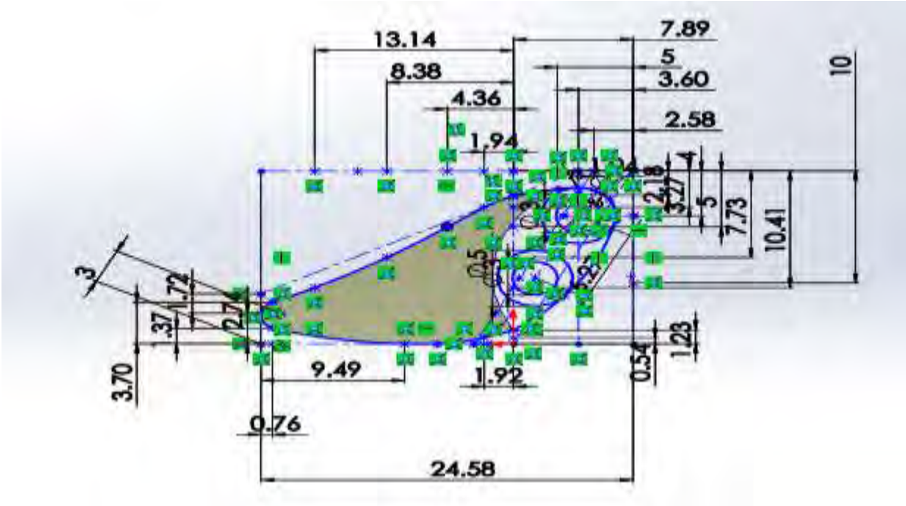

Figure 3.5: The dimension structure of finger design part 1.

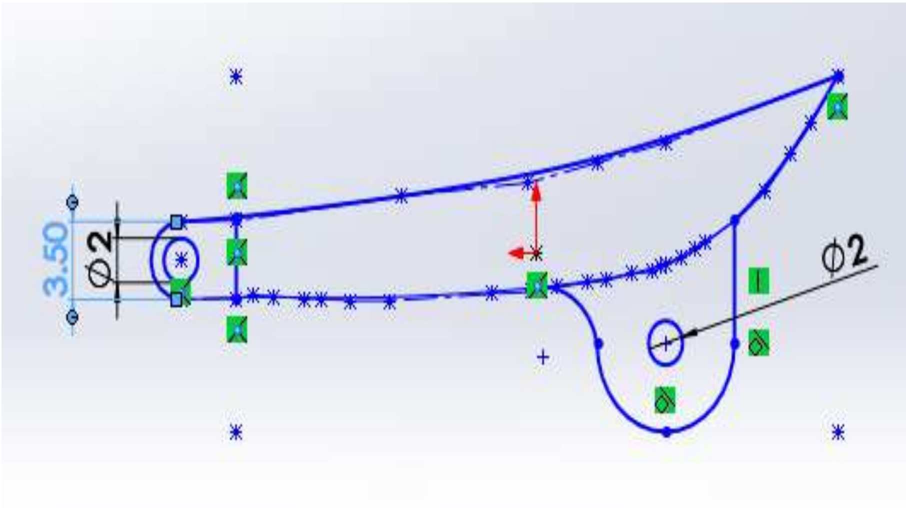

Figure 3.6: The dimension structure of finger design part 2.

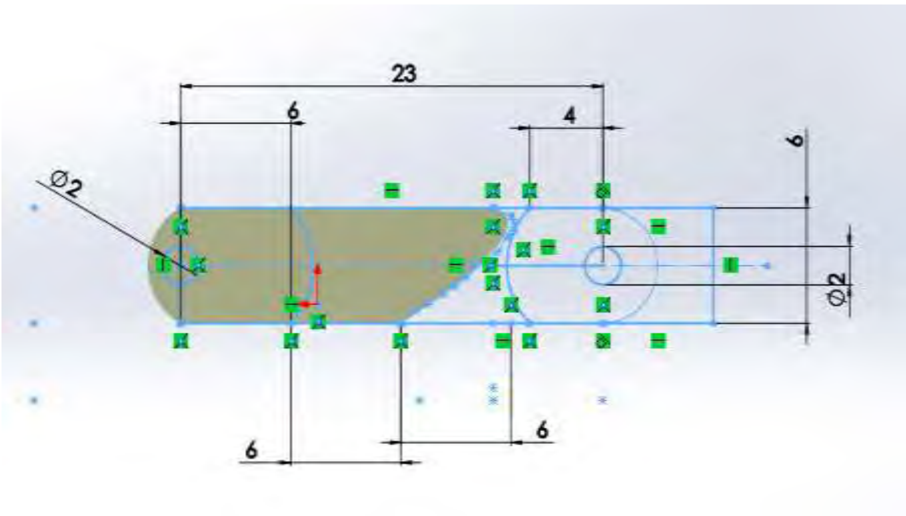

Figure 3.7: The dimension structure of finger design part 3.

3.3.2 Motor Driver Circuit Design

This section illustrates about servo motor controlling. In this project three servo motor will be used in controlling the movements of the finger. Sufficient power is needed to ensure three servo motor can be driven at the same time with strong force/torque.

There are a lot of microcontrollers that are capable to control the basic functions of the fingers for grabbing and opening. ATMEGA328 microcontroller that can be operated together with ARDUINO UNO has been chosen as the main controlling unit of the prosthesis hand as it is low cost and easy to be programmed. ARDUINO is an open-source electronics prototyping platform that is flexible and easy-to-use for programming hardware and software. ARDUINO can be used to connect and program sensors as well. The function of ARDUINO can be referred to the data sheet which has been attached in the Appendix of the report. The current of the ARDUINO I/O port is only 50mA and it is not enough to power all three servo motors. Thus, an external power source is needed to increase the current to trigger the servo motor. Four pieces of 1.5V battery have been used as the external power source for this project. Besides, L293M motor driver has been chosen to build a motor driver shield that is being attached on top of the ARDUINO UNO board. This method is done to make sure the hardware of the project is more tidy and organize. In Figure 3.8 shows the block diagram of motor driver shield. The left hand side of motor driver shown in Figure 3.8 is used to obtain inputs and the other side is used for the activation of the servo motors.

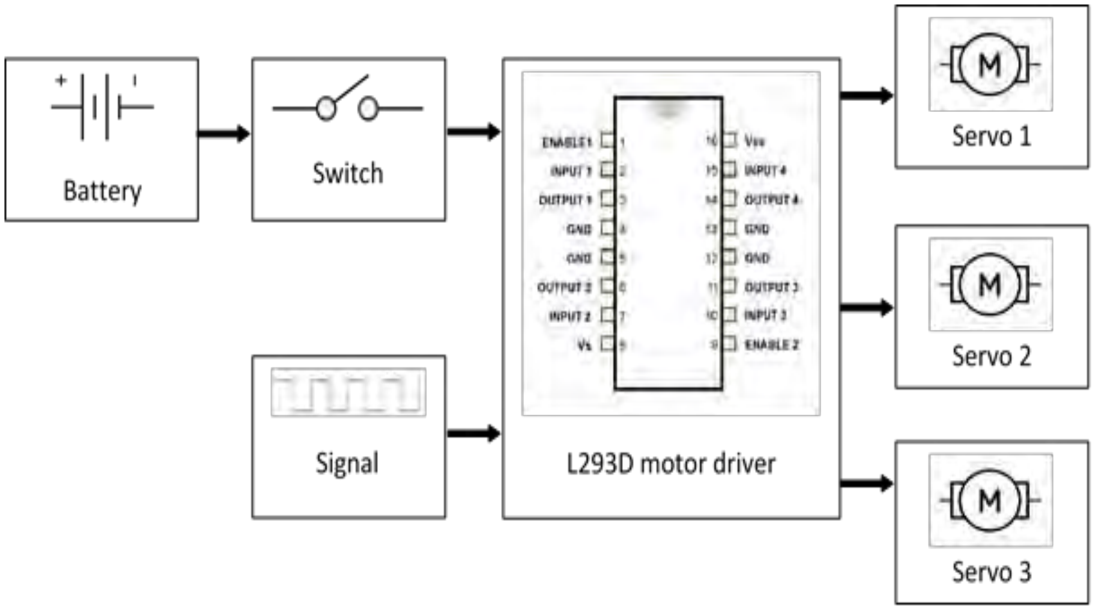

Figure 3.8: the block diagram of circuit design

3.3.3 EMG Signal Processing

The raw EMG signal is the input of the control system for this project. The first part is by establishing communication between computer (PC) and ARDUINO. PC needs to receive the raw signal to collect all the sampling data. The method of establishment of communication between PC and ARDUINO is done by using serial port communication. MATLAB software provides an electronic base platform called "Simulink" for programming ARDUINO. Simulink can use to create serial port by using component block inside the Simulink library.

Then, the second part is collecting the data. By using tools inside MATLAB software, it enables user to setup the sensor connection. The first step is to collect the sensor value when performing grabbing gesture. Then, MATLAB will start to collect EMG signal and calculate the Root Mean Square value from the data. Upon finishing the data collection for grabbing gesture, hand opening gesture is done to obtain EMG signal data for analysing. The last step of EMG signal processing is to calculate threshold value to identify whether the user is performing grabbing or opening hand gesture.

3.3.4 Arduino Program Flow

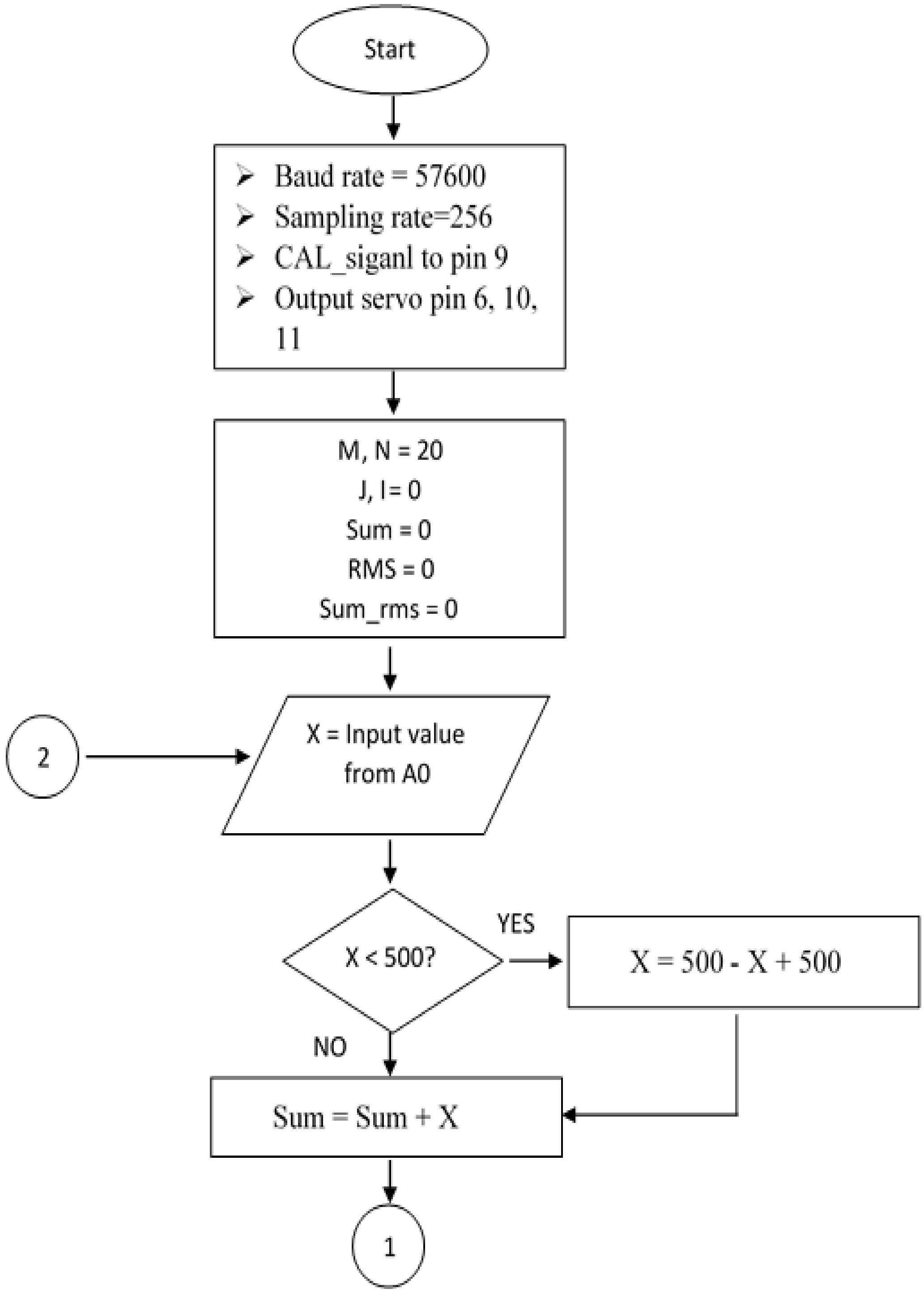

Figure 3.9: Flow chart of program code part 1.

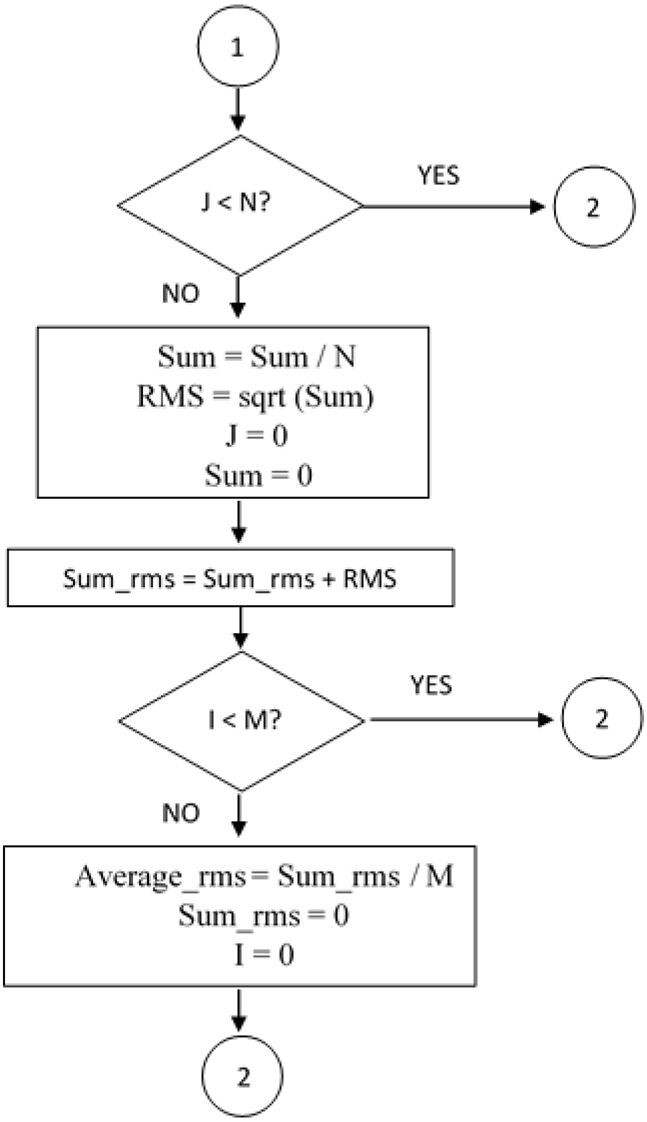

Figure 3.10: The flow chart of program code part 2.

The Figure 3.9 and 3.10 show the complete flow of the programming part of this project. The programming of the project is being done using Arduino IDE software. The programming is started by declaring the variables for the configuration on EMG shield. Then next step is to setup the analogue input pin and perform setting to generate a compulsory pulse width modulation signal to the digital output pin. Another setting is done to capture EMG signal for processing. The EMG signal captured is done by reading or obtaining the analogue value from pin A0. With the use of ADC convertor that is built in ALU will help to convert the analogue value to digital value. Next, digital reference value of the EMG raw signal is checked and rectified. After rectifying the signal, the summation of the digital value is obtained by performing looping for twenty times to get the digital value. When N is equal to 20, the program will execute the calculation of RMS value and then the value of N is reset to zero.

In order to obtain the threshold value, a second check condition with count M is used to take the RMS value through looping until twenty times. The total value of RMS value will be divided by M to obtain the average value, then M is reset to 0 again. This looping conditions are continuous and it will repeat the previous step which started from reading EMG value as input until the average RMS value has been obtained.

3.3.5 Control System

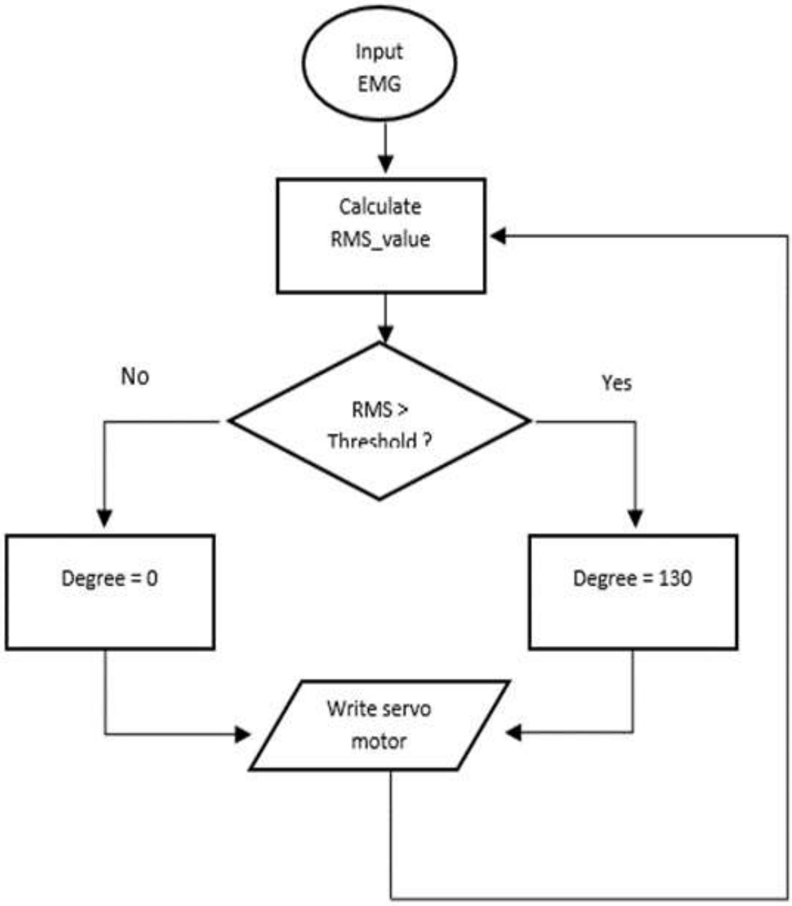

Figure 3.11: The basic flow chart diagram of control system.

Figure above shows the concept of control system in this project. EMG signal from user muscle and the reference point of muscle is read then being analysed accordingly. In Figure 3.12 shows the corresponding muscle position on the forearm to control each of the finger movements.

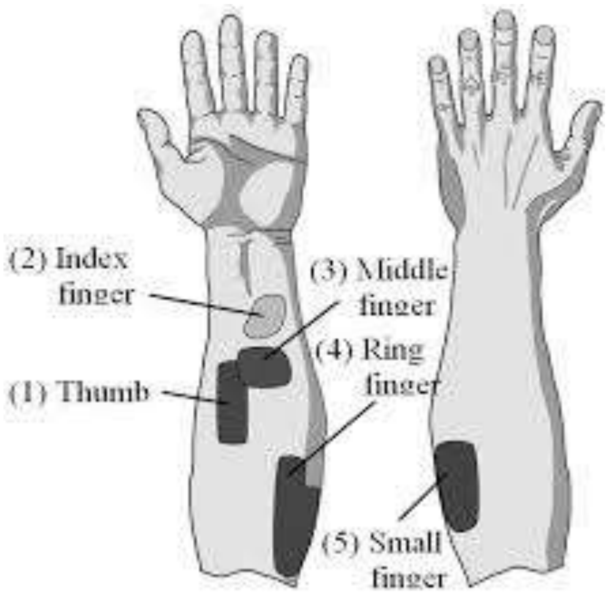

Figure 3.12: Corresponding muscle position to control each fingers.

After obtaining the raw EMG signal, the data signal is being calculated using root mean square (RMS) formula to obtain an average RMS values for hand grabbing and opening gesture. The calculation of threshold value is being shown in section 3.3.3. This threshold value is used as a reference to trigger the different movement of the fingers. If the value RMS greater than threshold, the prosthetic hand will perform hand grabbing gesture while RMS value is lesser than threshold, the prosthetic hand will perform opening hand gesture. Another program is needed for the setting of the motor's angle and to drive the motor corresponded to the angle set. Then, the program will loop back to read the input EMG signal.

3.4 Conclusion

At the end of this section, the whole content illustrated the project's concept and the procedures to carry out this project. In short, the first step is to design the finger using SOLIDWORK software, second step is to capture the EMG signal, obtaining and setting the threshold value through the calculation done on the EMG signal. The last step is controlling the system by using the RMS value. If the average RMS value is greater than threshold value, the gesture is being classified as hand grabbing and servo motors is triggered to close all fingers of prosthetic hand and vice versa.

CHAPTER 4

RESULT AND DISCUSSION

This chapter discusses about the result obtained from this project. The result is presented by using figures and table including explanations. The issues or problems faced throughout the project will be discussed in this chapter as well.

4.1 Result of Design Prosthetic Finger

This section discusses about finger design and development. The project is designed to be a 3 joints prosthetic finger that allows the actuation mechanism to increase the number of active DOF and provide a better functionality compare to 2 joints fingers. In addition, the 3 joints prosthetic fingers is designed to mimic hand movements such as opening and grabbing. This section covers only the mechanical design of the finger, such as the size, shape, joint and degrees of freedom.

A prosthetic hand design is very complex, it requires a lot of time to do research, calculation and testing. Therefore, modify an open source 3D prosthetic hand design of originally two joints finger design to three joints finger design can reduce the complexity of designing the prototype . The end product of the hand design and its control system is similar to the original design of two joints prosthetic finger.

4.1.1 Finger Design

The prototype of the design in Figure 4.1 is based on the original dimension design as shown in Figure. 4.2.

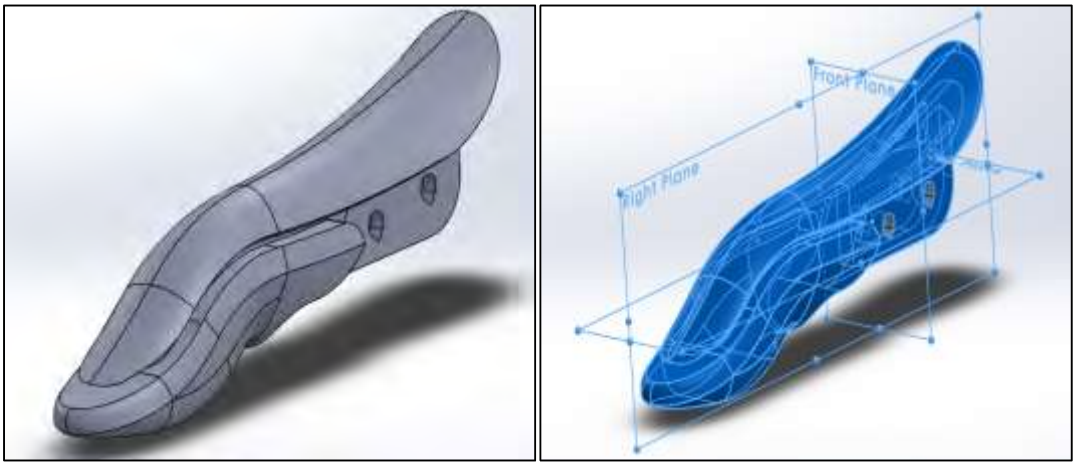

Figure 4.1: The original finger of prosthetic hand.

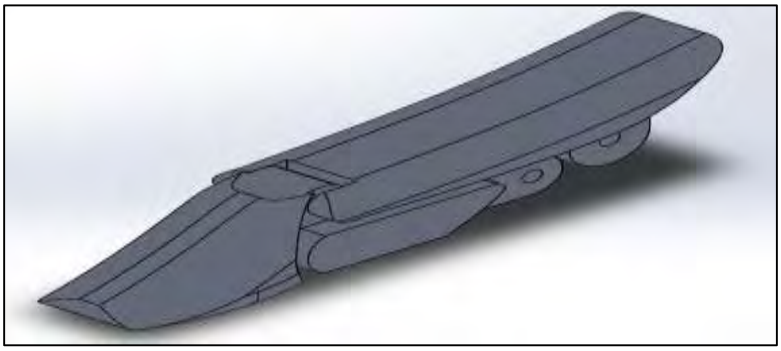

Figure 4.2: The prototype design of finger design.

In this design, a total of three finger joints are used, connected in each joint or each DOF, as shown in Figure 4.2. The original design has middle phalanx and tip being sticked together. SolidWork software is used to separate it into two parts. In order to make it to have a rotation axis, the middle phalanx needed to be cut into two pieces and with each part of phalanx consisting one head and one tail. This head and tail has the function to join all the part of the phalanx together. The prototype and design dimension of the finger is shown in Figure 4.3 to Figure 4.5.

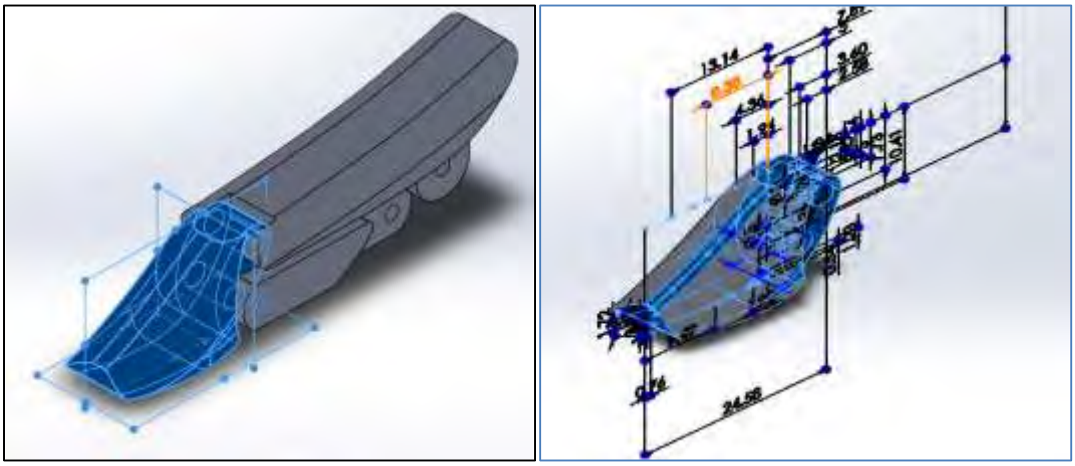

Figure 4.3: The prototype dimension of fingertips.

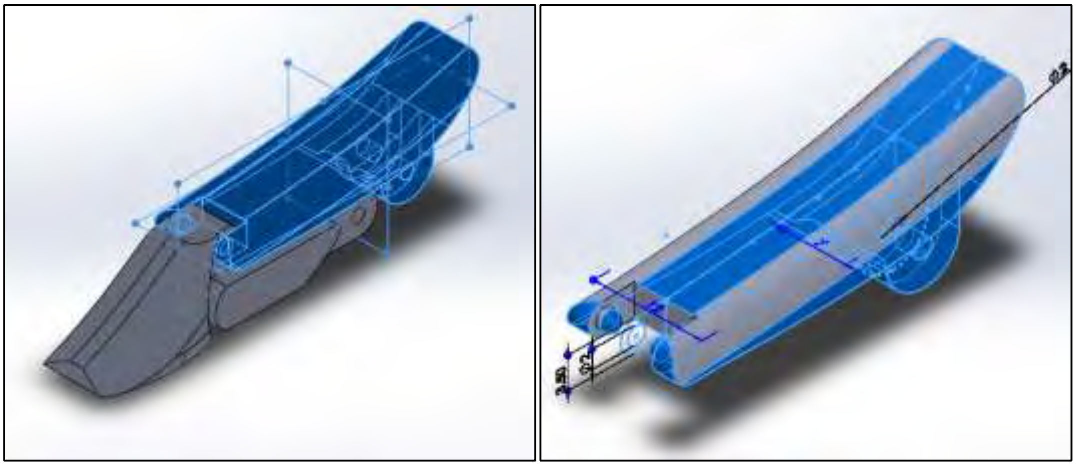

Figure 4.4: The prototype dimension of upper middle phalanx.

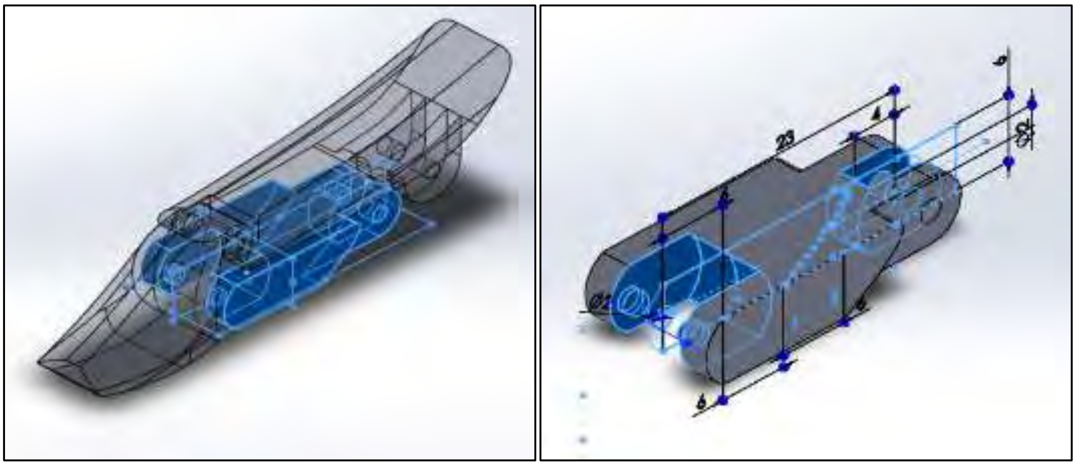

Figure 4.5: The prototype dimension of lower middle phalanx.

Figure 4.6 shows the finger design in plane facing to the right to provide a good view of three separate parts that have combined together. The fingers designed were assembled together with the whole hand design inside SolidWork for simulation of the hand shown in Figure 4.7 whereby the hand can be seen moving accordingly to the setting done. For example, the finger can be set to move according to specific angle of 10 degree once being set inside SolidWork.

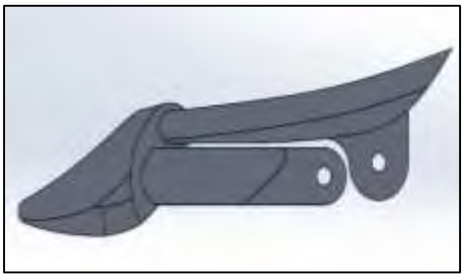

Figure 4.6: The prototype of finger design.

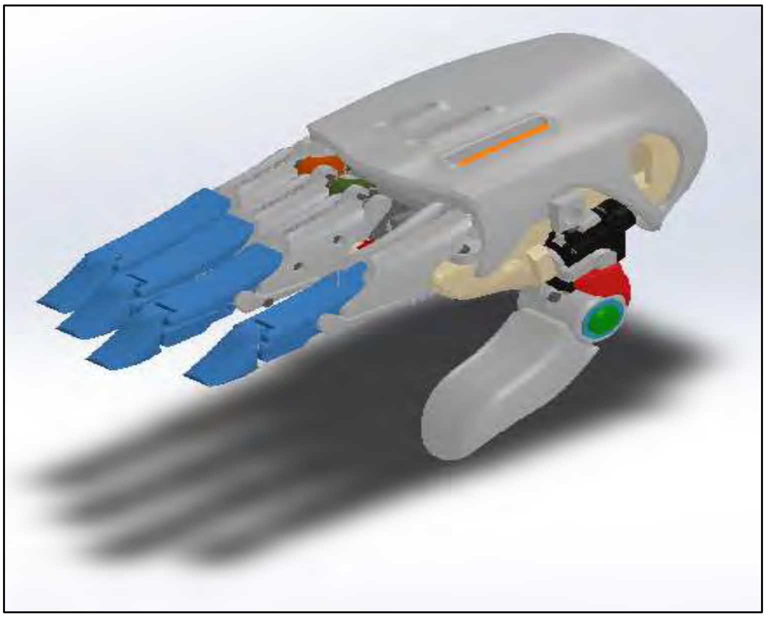

Figure 4.7: The prototype of finger design and assembly the whole hand design.

4.1.2 Build the Prosthetic Hand by using 3D Printing Technology

In this project, “Ultimaker2” the 3D printer is used to print out the hand and fingers design in 3D. This printer melts plastic to print the design developed in layers. There are 3 types of material that can be used in for 3D printing: PLA (polylactic acid or polyclactide), ABS (acrylonitrile butadiene styrene) and CPE (Copolyester).

Figure 4.1.7(a) and (b) show the object design being converted into G-code using Cura software. Cura software is a software that ensures all the object arranged accordingly on the plate in 3D. In addition, this software can assist on directly importing multiple object files into a plane for printing. As compare to Axon software, the software is unable to support multiple objects inside a plane for printing. It only manage to print the design one by one which is very inconvenience. There are few settings that needed to be configured in Cura including the adjustment of the quality of end product and support part that to hold the printing object which can easily collapse during printing. Figure 4.8 and 4.9 show the G-code of after the configuration of the quality and all the support lines of end product which is being pre-observed using Cura software.

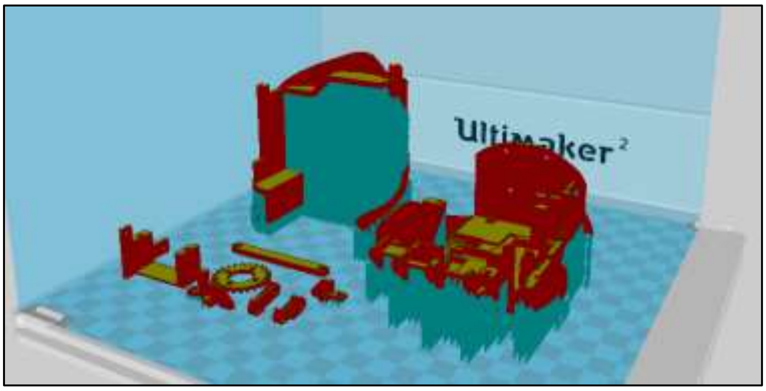

Figure 4.8: Using Cura software to display the G-code of plam and plam cover.

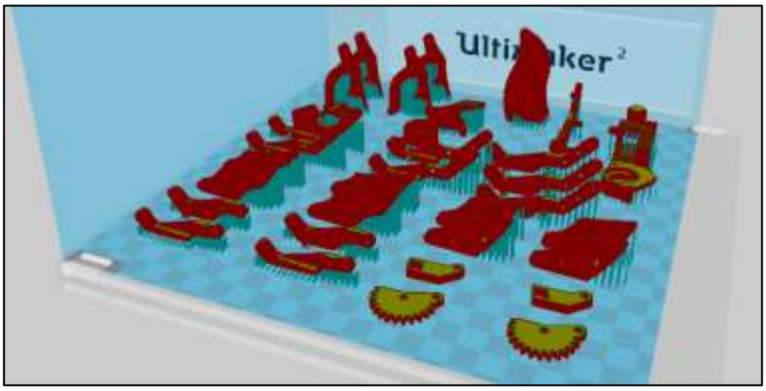

Figure 4.9: Using Cura software to display the G-code of all finger parts.

Figure 4.10 and 4.11 show the printing process. Initially, 3D printer printed the bottom layer with several lines of brim that functioned as a base to increase the bottom area attach on the heater plate for better stability during the printing of the object. After the end product had been printed out completely, the product was removed from the heater plate when it was cooled down to prevent the product from deforming as it was not solid yet. The product printed was then being cleaned and polished using sand paper.

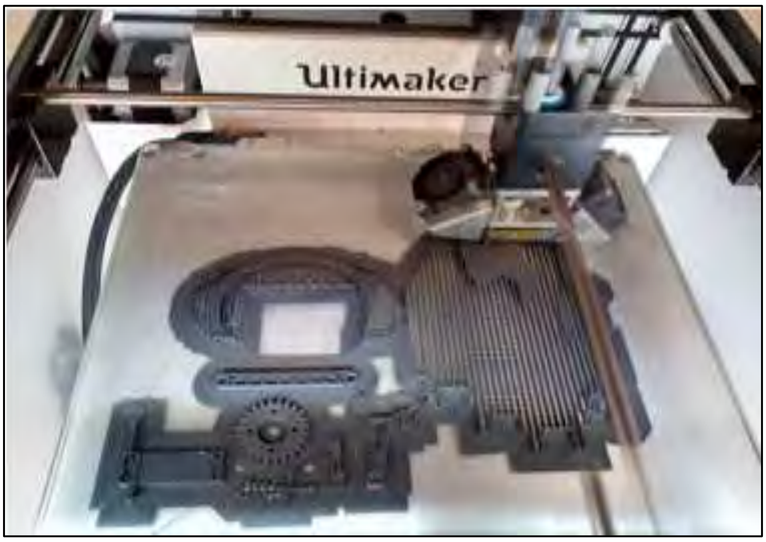

Figure 4.10: Beginning state of 3D printing.

Figure 4.11: Complete state of 3D printing.

The material used for this design is Polylactic acid (PLA) that has been shown in Figure 4.1. In order to make a low cost prosthetic hand, 3D technology is the most optimal choice to develop the prototype of prosthetic design. PLA is a type of plastic that is being used in building models and prototypes of solid objects and components. It is a thermoplastic that serves as the raw material in 3D printing or additive manufacturing processes and applications. PLA is primarily being created using renewable or green sources such as sugar cane, starch and corn. As a result, it can easily being renewable. It is used in most of the manufacturing processes that design 3D models and prototypes of plastic-based. In fused deposition modelling (FDM) technology, the molten polymer filament, which is extruded from the controller nozzle, is polylactic acid. PLA is a popular and commonly used raw plastic material in 3D printing, after acrylonitrile butadiene styrene (ABS), which comes in both hard and soft forms. Both are suitable for a variety of applications. Polylactic acid is also known as polylactide acid.

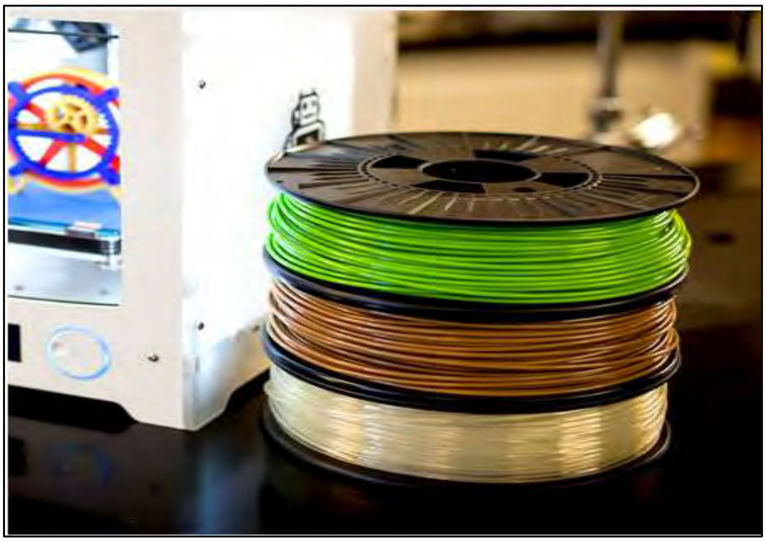

Figure 4.12: PLA material for 3D printing.

PLA material has advantages of fast printing speed, reliable and the colour can be altered, for example yellow, black grey, blue, and even a transparent. It will produce a good quality surface on the product and it is easy to use. The disadvantage of the PLA material is that the material cannot withstand the temperature of over 50˚C (sources from Ultimaker official website). The main concern when choosing the material for prosthetic hand is that the material will easily bend while in condition of high temperature and it will cause the lost in accuracy of the dimension of the design that will eventually effect the functionality of the prosthetic hand. The second concern is when the prosthetic hand cool down from exposing to high temperature or sunlight, the strength material will become weak and fragile. The ABS is a stronger and durable material compare to PLA. In addition, ABS material is impact resistance. It can operates in high temperature but below than 85˚C (sources from Ultimaker official website). However, there are disadvantages of using ABS material. The material will release toxic gas when being heated up. This is the reason ABS material has been rejected for material selection because it is not a user friendly material and it has the potential to harm human health. On the other hand, CPE material has been rejected is because of the cost of CPE material is higher than PLA and ABS material.

Figure 4.13: PLA material for 3D printing.

Figure 4.13 is the end product of 3D printing which had been completely assembled. This end product marks the achievement of objective which is building a modular, light weight and low cost prosthetic hand. Besides, 3 servo motors are assembled inside this prosthetic hand. Thumb is activated by using one small size servo motor, index finger is controlled by one regular size of servo motor and the other fingers shared another one small size of servo motor for operation.

4.2 Result of Controlling Actuator

The development of a prosthetic hand normally is to aim to copy the grabbing gesture of the human hand provided with obvious improvements in the hand functionality and also to rebuild the confidence of amputees. Therefore, there are two main gestures that serves as important functions of a prosthetic hand which includes opening and closing of all fingers. Hence, an effective prosthetic hand/fingers built must allow users to hold or grab an objects with sufficient force/torque. The motor driver shield and controlling actuator by using Arduino UNO processing board was presented in this section.

4.2.1 Motor Driver Circuit Design

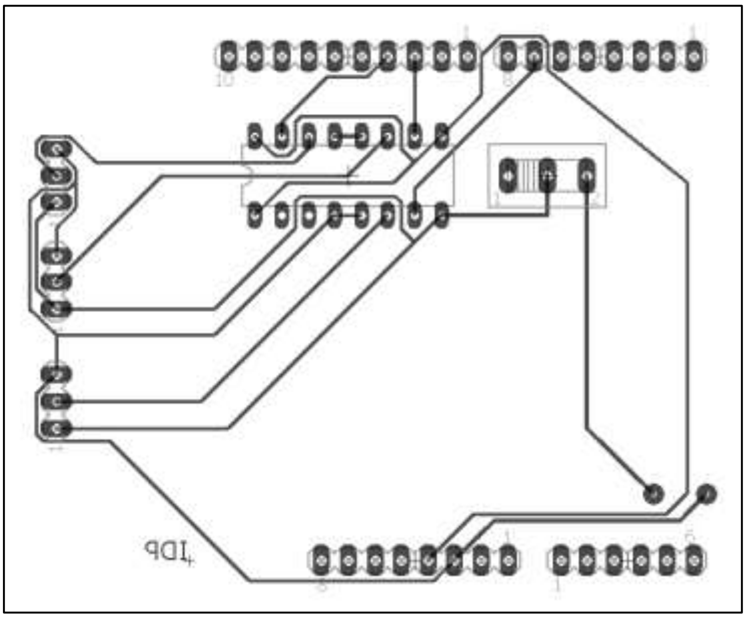

Figure 4.14: The circuit board diagram of motor driver shield.

The rapid prototyping design was implemented for two different size of servo motor. In the total 3 servo motors had been used the trigger the motion of fingers. The processing board of this project is Arduino UNO but the current delivery by Arduino is only 50mA not enough to trigger up 3 servo motors operate at the same time. Therefore external power is needed to increase the voltage and current when driving three servo motors. L293d motor driver had been chose and built a motor driver shield with using external double battery as external power. By using Eagle software a board diagram had been designed as shown in Figure 4.14. Hence, the board diagram had been printed out and built with using ultra violet PCB board.

The result of the circuit shield is can connect with three servo motor and able attach on top of Arduino board. The Figure 4.15 is shown the battery connected to the motor driver shield and the three servo motors inside 3D printed prosthetic hand are connected to the same motor driver shield.

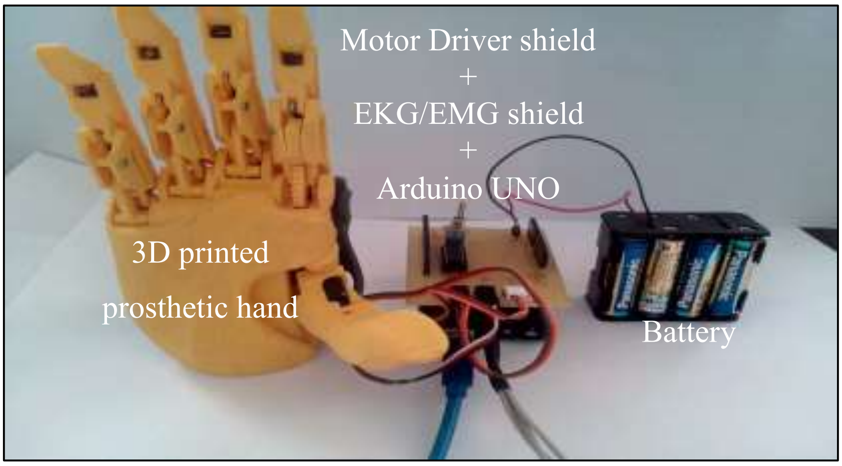

Figure 4.15: Completed of hardware connection.

In Figure 4.15,the left hand side was the 3D printed prosthetic hand, right hand side was the four piece of 1.5V double a battery and the centre part is combination of shield, bottom is the Arduino UNO, middle is the EKG/EMG shield and top is the motor driver shield.

4.2.2 Arduino Code

After motor driver circuit section is the programing to Arduino board section. First, the open sources have servo code library therefore need to include before start to control as code below.

```
#include <Servo.h>
```

Second, is need to declare the variable being use to control the movement of servo motor. In this project, there are consists of three servo motor, therefore, three variable had been declare as shown in Figure 4.16 upper part. Inorder to check the feedback from the servo motor means to detect the current position of the servo motor, three integer variable had been declare shown in Figure 4.16 lower part for record and further checking purpose. The naming of the variable is ensure programmer easy to recoignize the servo motor is belong with which finger and easy to debug when error occur.

```
Servo fingers;
Servo thumb;
Servo index;

volatile unsigned int posthumb;
volatile unsigned int posindex;
volatile unsigned int posfingers;
```

Figure 4.16: Code of declaring servo motor variables.

```
void setup()
{
        thumb.attach(6);
        index.attach(10);
        fingers.attach(11);
```

Figure. 4.17: Assign pins of servo motor variables.

The last on this section is assign the pin of servo motor variable (Figure 4.17) at the same time servo motor in prosthetic hand is connected according to following pin. Then the reason of choosing pin 6, pin 10 and pin 11 is because of PWM I/O, because the servo motor is trigger by pulse width modulation signal and pin 9 is being use by EKG/EMG shield.

4.3 Result of Electromyography (EMG) Signal Processing Technique

4.3.1 Capture EMG Signal

Electromyography is analysis instrument to capture electrical activity in muscle of human and it will had different electricity respond base on different action done by muscle. In this project, the hardware used is Olimex EKG/EMG shield as shown in Figure 4.18, this shield is a fully open sources hardware. It can attach on the top of Arduino Uno board and maximum to six number of Olimex board attach on top. The reason is Arduino Uno only had six number of ADC pins. This shield enable user to capture analogue voltage signal generated by human muscles, attached to its inputs usually is using myo-electrodes sensor, these input will transfer into a single stream of data and process become output. Hence, the output signal is still in analogue form and enable Arduino UNO processor board to read as analogue input through analogue-digital convertor pin.

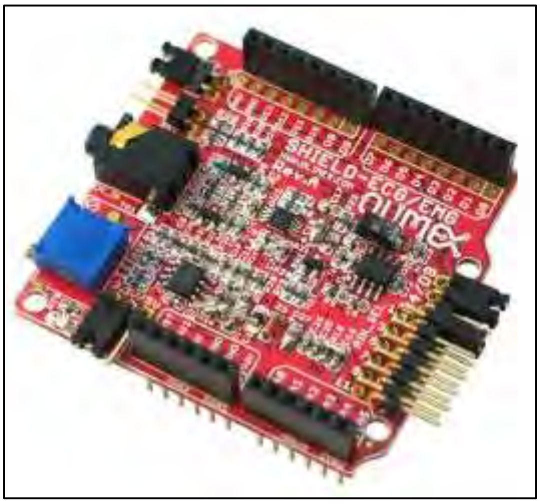

Figure 4.18: Olimex EKG/EMG shield.

Some configuration need to be setup before it can successfully being used as a shield. First is select channel, in this project, only one channel had been use, therefore, analogue pin 0 as the input. A Pulse Width Modulation (PWM) signal need to generate from Arduino UNO on pin 9 to trigger this shield to operate. With using the Arduino IDE software to write the C++ coding and compile to the machine code next will upload into the Arduino UNO board. Below are the code to make a toggle of PWM signal and called the function name as toggle_GAL_SIG and include FlexiTimer2 library to generate the overflow interrupt services routine. The overflow will overflow ever four mille seconds and it will operate the Timer2_Overflow_ISR function. Inside the function had a counter, when counter is equal to twelve, counter will be reset and execute the toggle function and produce the PWM signal to the shield board. In this project, the sampling rate set on 256Hz. Figure are the code of configure to access the shield board.

```
#include <FlexiTimer2.h>
```

```
#define SAMPFREQ 256
#define TIMER2VAL (1024/(SAMPFREQ))
#define CAL_SIG 9
```

```
void toggle_GAL_SIG(void)
{
        if(digitalRead(CAL_SIG) == HIGH)
        {
                digitalWrite(CAL_SIG, LOW);
        }
        else
        {
                digitalWrite(CAL_SIG, HIGH);
        }
}
```

```
void setup()
{

        noInterrupts();  // Disable all interrupts before initialization

        FlexiTimer2::set(TIMER2VAL, Timer2_Overflow_ISR);
        FlexiTimer2::start();
```

Figure. 4.19: Code of EMG Shield configuration.

4.3.2 Signal Processing

Using the root mean square formula into Arduino board to process the input EMG raw signal. In programming, there are no library to collect a group of data and processing with RMS, therefore, using the looping method to collect data signal. From the input signal, there will had a reference value, in my project the reference value is 500 (digital value), therefore the value are located below than 500 need to flip vertically which using simple mathematic equation and sum up all the value for future calculation as shown in Figure 4.20.

```
for (int i = 0 ; i < n ; i++)
    {
  ADC_Value = analogRead(CurrentCh);  //Serial.println(ADC_Value);
  if (ADC_Value < 500)
  {
      ADC_Value1 = ( 500 - ADC_Value) + 500;
      //Serial.println(ADC_Value1);
      ADC_Value1 = ADC_Value1 * ADC_Value1;
      sum = sum + ADC_Value1;
  }
  else
  {
      ADC_Value1 = ADC_Value;
      ADC_Value1 = ADC_Value1 * ADC_Value1;
      sum = sum + ADC_Value1;
  }
```

Figure 4.20: Code of rectifier the EMG raw signal.

```
sum = sum / n;
rms = sqrt (sum);
```

Figure 4.21: Code of RMS value.

After collect a numbers (n) of data, the total of sum need to divide by (n) and call the square root equation in math.h library to calculate the final root mean square value as shown in Figure 4.21, these two line of code need to write at outside of data collection loop.

4.3.3 Plotting Graph

The data capture from the EMG shield was converted to digital by using Arduino UNO through ADC converter and plot the real time graph with using processing software. Processing software also is a fully open sources, therefore the code of processing is similar to Arduino IDE and it can build our own code base on sources codes. Figure.4.22 is a portion code of the processing software for plotting the digital signal graph capture from muscle. First line code was used to read the serial COM port value, then checking whether consists value, the last line code was mapping the received value to the entire window size which to show the real time graph within the range of window size.

```
String inString = myPort.readStringUntil('\n');

if (inString != null) {
  // trim off any whitespace:
  inString = trim(inString);
  // convert to an int and map to the screen height:
  inByte = float (inString);

  println(inByte);
  inByte = map(inByte, 1100 , 500, 0, height);
}
```

Figure 4.22: Processing Code of read serial COM port.

The Figure above is the code for draw a real time graph. In the draw function stroke(R, G, B) is to represent the colour of graph line, strokeWeight(n) is to represent the weight of the line. In order to continue drawing the line, the current x axis and y axis position will set to lastxpos and lastheight purposely use for next calling this draw function.

```
void draw(){
  stroke(127, 34, 255);
  strokeWeight(3);
 line(lastxPos, lastheight, xPos, inByte);

  lastheight= int (inByte);

  if (xPos >= width) {
    lastxPos= 0;
    xPos = 1;
    background(0);
  } else {
    // increment the horizontal position:
    lastxPos= xPos;
    xPos++;
  }
}
```

Figure 4.23: Processing Code of plotting EMG signal graph.

The result of real time graph was divide into three portion. First portion is initial signal graph as shown in Figure 4.23. This graph was shows the original raw signal capture from EMG/EKG shield. This graph had clearly display it had a static reference point which along the middle of the window. This signal was captured from user, and user had done two gestures: open and grasp all the finger. When user have an open finger gesture the graph will had a low peak to peak deviation, however, when user had close all fingers, the graph had shown a big peak to peak deviation. In this experiment user had repeat doing the gestures with this sequence: open, close, open, close and open.

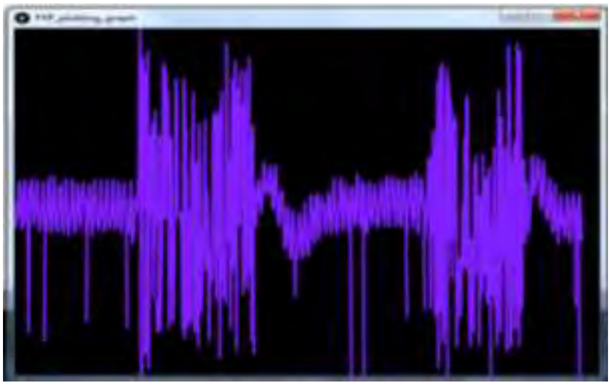

Figure.4.24: Graph of EMG raw signal.

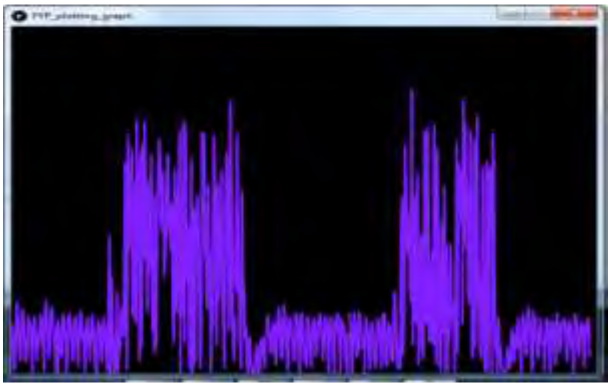

Figure 4.25: Graph of EMG raw signal after rectifier.

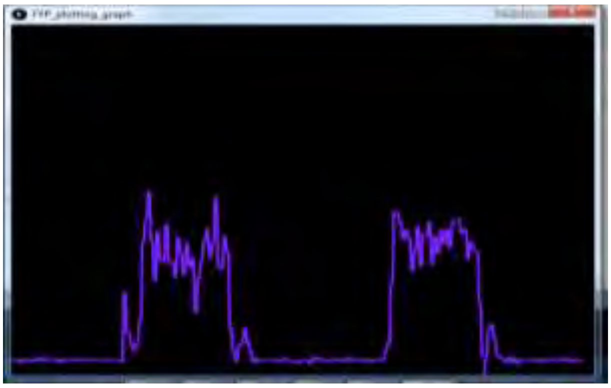

Figure 4.26: Graph of EMG signal after root mean square.

Next, Figure 4.24 shows the graph of raw signal after being rectified. The technique to achieve this is base on the arduino code and it had shown in the Figure 4.25. The Figure 4.26 was the final RMS signal processing value. It had a obvious difference between two gesture and easy to fix a threshold to drive the servo motor.

4.4 Control Movement of Finger by EMG Signal.

4.4.1 Result on Testing Servo Motor Angle

In this section, the movement of the finger was controlled by EMG signal. Before this all the servo motor was tested the corresponding movement angle for each servo and it is related to the mechanism design of prosthetic hand. Table below are the testing result of the angle of prosthetic fingers. The reason of using the servo motor library, the required input is angle, means key in an input angle it will directly generate a proper pulse width modulation signal to the serve motor and the servo motor will rotate to the corresponding position.

Table 4.1: Result of corresponding angle for all fingers.

Fingers	**Angle of open** ($degree^{o}$)	**Angle of close** ($degree^{o}$)
Thumb	124	67
Index	150	0
Other fingers	140	40

4.4.2 Result Code of Open and Close All Fingers

```
void fingermotion(int x){
  posthumb = thumb.read();
  posindex = index.read();
  posfingers = fingers.read();
  if (x <= threshold)   //fingers close
        {
          if (posthumb != 124)  {thumb.write(124);}
          if(posindex != 150)   {index.write(150);}
          if(posfingers != 140) {fingers.write(140);}
        }
        else            //fingers open
        {
          if (posthumb != 67)  {thumb.write(67);}
          if(posindex != 0)    {index.write(0);}
          if(posfingers != 40) {fingers.write(40);}
        }
}
```

Figure 4.27: Code of drive all servo ensuring with a threshold value.

4.5 Discussion

4.5.1 Modular Prosthetic Hand Design

In this project, the prosthetic hand was designed part by part and assembly all together become a robotic hand. This rapid prototype of hand prosthesis called “hackberry” had been choose is because the hand design is fulfil the objective in this project. Besides, this prototypes can be alter depends on the user, user can modify the original design by using CAD software. Therefore, the fingers of the original design had been modify from two joints become to three fingers in this project, the purpose is to increase the flexibility of the finger and increase degree of freedom of the fingers. In the beginning state of this project, the original prototype had been printed by using 3D technology printer. In order to observe the quality and the accuracy of dimension between software dimension and hardware printed dimension, because of lacking experience on 3D printing, the first 3D printed prototyping was successfully built but not perfectly when assembly process and time management on printing process. It spent one month to print out all the part of prototypes and taking around two weeks to clean up all the unused printed support part. After this, the assembly process was facing some problem on screw up all the couple part, such as the 3D printing was printed adding layers process, so, the problem came out when screwing the connection couple part the connection will detach layer by layer. The solution is rotate the 3D design in the software before produce gcode and the connection part will no longer face perpendicular to the plate and avoid the previous problem. In addition, problem of time management of printing process, the main reason is the printer are did not been fully utilize. As a small experience on using 3D printer, ultimaker2 can print multiple of object in one printing and it can save a lot of time when insert multiple objects in the Cura software as long as it can fit all the object. This solution was shorted the period for printing for one month to become two days, but there are also have a risk for this solution which is there are high probability to face fail printing situation and need reprint all the object design. At the end, the time management had been improved but exist a high probability on wasting material when failure printing occur.

4.5.2 Low Cost Prosthetic Hand Design

Table 4.2: The estimation cost for this project.

ITEMS	COST
ARDUINO	Around RM 50 (None warranty) Around RM 140 (with 6 months warranty)
EKG/EMG SHEILD	Around RM 100
ECG-GEL-ELECTRODE	Around RM 5
EKG-EMG cable	Around RM50
Motor Driver circuit	Around RM 30
Servo motor	Around RM 200
Prosthetic hand material	Around RM 50

Table above illustrated the estimation cost of all component been used in this project which in years 2016. The total cost prosthetic hand in this project for sure is below one thousand and lower cost compared to the price smart phone with high specification in the current market. This condition are fulfil the first objective to produce a low cost prosthetic hand.

4.5.3 Light Weight Prosthetic Hand Design

This prototype is printed by using 3D printing technology, therefore, the weight must be lighter than the metal prosthetic hand. The weight of the 3D printed prosthetic hand is affordable by all amputee even a children of primary school. This is condition are fulfil the first objective light weight prosthetic hand.

4.5.4 Under-actuated Myo-electric Prosthetic Hand

This prosthetic hand is using processed EMG signal to control the finger motion. Since, the reference point is the threshold value, the if-else coding is function to check the average value of root mean square is whether lower or higher than threshold. If higher than threshold mean the input is a grasp gesture and the output of the prosthetic hand need to close up all the fingers. When the average root mean square value is below than the threshold value, the input is the open hand gesture and output of the all finger need to open all then finger. All the finger movement is corresponding to angle of the servo and the result of the corresponding angle is shown in table 1 at section 4.4.1. Inside the if-else loop for checking threshold, there consists one more if-else loop to read the current position of servo motor. If current position of servo motor is similar to on-going servo position, it will do nothing, if there are different position value the servo will only drive to the corresponding position. At the end, the prosthetic hand was fully function and it can response in a fast period seem like a real time prosthetic hand but there are exist some mille second of delay and it depend on the length of programming code and this delay is cannot been observe or calculate by human, therefore, user cannot observed the delay by human eye. This project had a limitation which is the servo motor will not stop until achieve to the corresponding position, so, when the prosthesis hand is holding a hard object, the angle of servo will never achieve to the corresponding position and cause the Arduino will keep sending the PWM signal to servo. The effect of this situation is the servo will easily warm and heat up, finally it will lead the servo motor become broken. When this prosthesis hand is holding a soft object, it will not stop when it touching the object and cause the object out of the shape.

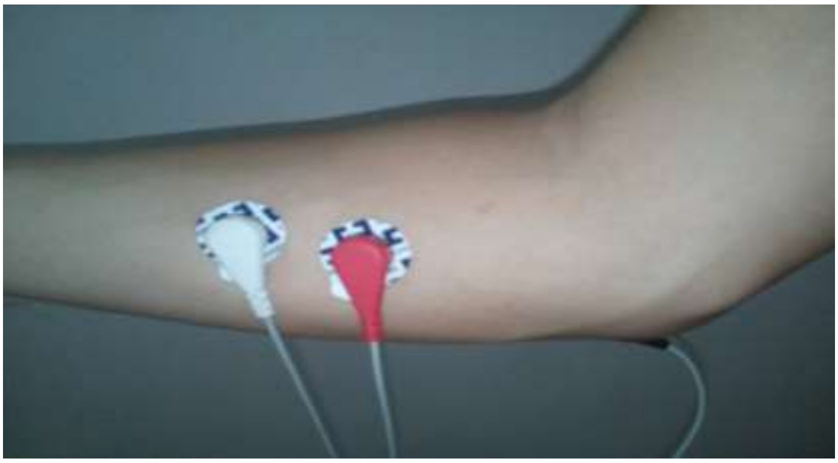

Figure 4.28: The EMG connector attached on muscle skin.

4.6 Conclusion

At the end of this chapter, the designed prosthetic hand had been built out by using 3D printing technology and this prosthetic hand success to do open and grasp finger motion. This finger motion is driven by servo motor with using the electromyography signal as input.

CHAPTER 5

CONCLUSION AND FUTURE RECOMMENDATION

5.1 Conclusion

As conclusion, a modular, low-cost and light-weight hand prosthesis has been successfully built. This design is affordable to all level of consumer and also applicable to lower limbs amputees as a prosthetic hand. Besides, this prosthesis hand is able to control by using the implementation of EMG signal from forearm muscle. This project is beneficial to the amputee who lost their hand and this can help limbs amputees to recover a part of self-confident and making them believe that there is still hope to regain back part of the lifestyle of a normal healthy person. This prosthetic hand design in this project can be applied to the a person as long as he/she still retain his/her forearm muscle.

5.2 Future Recommendation

Although the project is successfully developed, there are few recommendations for improvement. First, during the experiment conducted, the output of the servo motor can be improved on the force/strain feedback. This is because when the finger holding an object with reach a certain force, the servo motor can be stopped moving and avoid servo motor heat up until broken especially holding a hard object. Since, the testing force/torque/strain on the servo motor and designed fingers must be taken into consideration and also testing on strength of the hand for example what is the maximum load can be carried by this prosthetic. Second, some of amputees are dislike to use the prosthetic hand, because of they cannot feel the prosthetic hand is belonging to them. Therefore, create a user friendly feature in prosthetic hand is very helpful to these amputees. For example dancing finger, finger will auto tap according to beat of music. The last but not least, this project can make improvement on wrist controlling part where there are more gestures can be classified and more motion can be done by this prosthetic hand.

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